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ENGINEERING HANDBOOK

Steelmaking: Materials, Attributes, and Manufacturing Processes

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G.L. Huyett, P.O. Box 232, Minneapolis, KS 67467

Engineering Handbook, Second Edition, 2014

INTRODUCTION

This book was created based on years of research and experience of G.L. Huyett staff and is intended to be a consolidated reference source for technical information related specifically to the manufacture and sale of non-threaded industrial fasteners for our customers, vendors, and associates. This handbook is not a design standard, design guide, or otherwise. G.L. Huyett does not engage in designing, developing, or changing the design of products it manufactures or sells.

Invaluable technical information, including statistical data contained in the tables, is from *Machinery's Handbook*, 26th & 28th ed. New York, New York: Industrial Press, Inc., 2000.

Many technical definitions are from Michelle Applebaum, *Everything You Always Wanted to Know About Steel… But Were Afraid to Ask: A Glossary of Terms and Concepts,* New York, New York, Salomon Smith Barney, Inc., 2000.

Other glossary definitions are taken from *Cutting Tool Engineering* (ISSN:0011-4189) Chicago, Illinois, CTE Publications Inc.

Some information regarding differences of steel grades and their properties came from the McMaster-Carr Supply Company website at www.mcmaster.com, McMaster-Carr Supply Company, 2003.

Much of the basic and helpful information about steel properties and usage came from Drake H. Damerau, *Metallurgy FAQ v1.0*, Survivalist Books, 1999.

Other resources were gathered from the Society of Automotive Engineers at www.sae.org.

G.L. Huyett assumes no ownership of the above referenced material nor liability of any kind, implied or expressed, for the accuracy, scope, or completion of the information contained herein.

Suggested Reading

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TABLE OF CONTENTS

1. Steelmaking . . . 2
Smelting Iron: The Blast Furnace . . . 5
Smelting Iron: The Direct Reduction Furnace . . . 6
Smelting Iron: The Basic Oxygen Furnace . . . 7
Smelting Iron: The Electric Arc Furnace . . . 8
Steel Casting: Continuous Casting . . . 9
Hot-working Steel . . . 10
  Advantages of Hot-working: . . . 10
  Disadvantages of Hot-working: . . . 10
Annealing . . . 11
Cold-working Steel . . . 12
  Pickling . . . 12
  Oiling . . . 12
  Cold-working . . . 12
  Cold-rolling . . . 13
  Cold-forging or Cold-heading . . . 13
  Extrusion . . . 13
  Advantages of Cold-working . . . 13
  Disadvantages of Cold-working . . . 13
Storage and Handling of Raw Steel . . . 15

2. Chemical Content . . . 16
Identifying Metals . . . 16
Periodic Table of the Elements . . . 18
Characteristics of Common Alloy Elements . . . 19
Chemical Composition of Steels . . . 20

3. Steel and Steel Alloys . . . 22
Carbon Steels . . . 23
Alloy Steels . . . 24
Common Carbon Steels and Steel Alloys . . . 24
Bright Steels . . . 25
Stainless Steels . . . 26
Tool Steels . . . 27
Common Grades of Steels and Alloys . . . 28
  1018 . . . 28
  1045 . . . 28
  A36 . . . 28
  12L14 . . . 28
  1144 . . . 28
  4140 Alloy . . . 28
  4140 ASTM-A193 Grade B7 Alloy . . . 28
  8630 Alloy . . . 28
Common Grades of Stainless Steels . . . 29
  302 . . . 29
  303 . . . 29
  304 . . . 29
  316 . . . 29
  410 . . . 29
  416 . . . 29
Common Grades of Tool Steels . . . 30
  W1 (Water-Hardened Steel) . . . 30
  O1 (Oil-Hardened Steel) . . . 30
  M2 (High-Speed Steel) . . . 30
  A2 (Air-Hardened Steel) . . . 30
  D2 (High-Chrome Air-Hardened Steel) . . . 30
  S7 (Shock-Resistant Air-Hardened Steel) . . . 30
  A6 (Low-Temperature Air-Hardened Steel) . . . 30
  4142 . . . 30
  P20 . . . 30
Properties of Tool Steels . . . 31
What is That Part Made from? . . . 32
Comparisons of Tool Steels . . . 34
Applications for Common Grades of Steels . . . 35

4. Mechanical Properties . . . 36
Stress . . . 36
  Unit Strain . . . 36
  Proportional limit . . . 37
  Elastic Limit . . . 37
Yield . . . 37
  Yield Point . . . 37
  Yield Strength . . . 37
  Tensile Strength . . . 37
  Shear Properties . . . 37
Fatigue . . . 38

Ductility 38
Modes of Fatigue Failure 38
- Low/High-Cycle Fatigue 38
- Thermal Fatigue 39
- Corrosion Fatigue 39
- Surface or Contact Fatigue 39

Creep Failure 39
- Combined Creep and Fatigue 39

5. Heat Treatment 48

Quenching 49
Thermal Modification of Steel 50
- Annealing 50
- Baking 50
- Stress Relieving 50
- Tempering 50

Direct Hardening Vs. Indirect Hardening 51

6. Manufacturing 54

Band Sawing 54
Cold-drawing 55
Cold-heading 55
Cold-sawing 55
Grinding 56
Lasering 56
Milling 56
Non-Milling Processes that Mimic Milling 58
- Arbor Milling 58
- Broaching 58
- Shaping 58
- Shearing 58

Punching/Stamping 58
Threading 59
Tumbling 59
Turning 60
- Turning and Facing 61
- Parting and Grooving 61
- Boring 61

Wire Forming 61
G.L. Huyett Manufacturing Capabilities and Case Studies 62

7. Hardness Tests 68

Hardness Testing 68
Brinell Hardness Test 68
Rockwell Hardness Test 69
Vickers Hardness Test 70
Microhardness Testing 70
Micro-Vickers Test 70
Knoop Test 71
Relationship Between Hardness and Tensile Strength . . . 71
Durometer Test 71
How a Rockwell Test is Performed 71
Avoiding Faulty Rockwell Tests 72
Comparison of Hardness Scales 74

8. Finishing Processes 78

Anodizing Aluminum Alloys 78
Black Oxide Coatings 78
Brushed Metal 79
Buff Polishing 79
Chromate Conversion Coatings 79
Dip-Spin Coating 80
Dry Film Lubricants 80
Electroless Plating 80
Electroplating 80
Electropolishing 80
Metal Grinding 80
Passivation 81
Phosphate Coatings 81
Vibratory Finishing 81
Powder Coating 81
Zinc Electroplating 81
Steel corrosion 82
Common Forms of Corrosion 82
Military Plating & Coating Specifications 86
- Anodizing (Chromic and Sulfuric), MIL-A-8625F 86
- Black Oxide Coating, MIL-C-13924C 86
- Cadmium Plating, QQ-P-416F 86
- Lubrication, Solid Film, MIL-L-46010D 86
- Nickel Plating, QQ-N-290A 87
- Phosphate Coating – Heavy, DOD-P-16232-F 87
- Zinc Coatings, ASTM-B633 87

Environmental Concerns 88
- REACH – Registration, Evaluation, Authorization, and Restriction of Chemical Substances 88
- IMDS – International Material Data System 88
- RoHS – Restriction of Hazardous Substances 89

9. Conversion Charts 90

Linear Measure Conversions 90
Weight Conversions 90
Metric and English Equivalents – Use of Conversion Tables 91
Units of Force Conversion 95

Glossary 96

Links & Related Sites 132

Index 133

TABLES & ILLUSTRATIONS

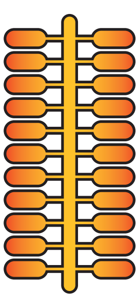
Effects of Chemical Composition 4
How to Read a Material Certification 4
Steel Extrusion Methods 13
Two Easy Ways to Differentiate Carbon Steel from Stainless Steel 17
Composition of AISI/SAE Standard Carbon Steels 20
Composition of Tool Steels 20
Composition of AISI-SAE Standard Alloy Steels 21
Composition of AISI-SAE Standard Stainless Steels 21
Four-digit AISI Alloy Numbering System 23
Chemical Comparison of 4140 Chrome and 8630 Nickel 24
Characteristics of Bright Steels 25
ANSI Keystock Tolerance Specifications 26
Steel Phases 27
Comparative Properties of Tool Steels 34
Types of Stress 37
Testing and Measuring Shear Strength 38
Testing and Measuring Tensile Strength 39
Expected Minimum Mechanical Properties of Cold-drawn Carbon Steel Rounds, Squares, and Hexagons 40
Typical Mechanical Properties of Selected Hot-Rolled, Normalized, and Annealed Carbon and Alloy Steels . . 41
Typical Mechanical Properties of Selected Quenched and Tempered Carbon and Alloy Steels 43
Typical Mechanical Properties of Selected Standard Stainless Steels 47
Case Hardening 51
Typical Heat Treatments for SAE Carbon Steels (Direct Hardening) 52
Typical Heat Treatments for SAE Carbon Steels (Indirect Hardening) 53
Rockwell Hardness Testing Machine 69
Microhardness Testing Machine 70
Rockwell Hardness Scales and Applications 73
Comparative Hardness Scales for Steel 74
Factors Influencing Hardness Testing 76
Tensile Strength Hardness Number Comparisons 77
Mechanical Plating 79
Chromate Conversion 79
Electrochemical Corrosion Process 82
Common Types of Steel Corrosion 83
Common Platings and Finishes 84
Banned RoHS Materials 89
Dodd-Frank Section 1502: Conflict Minerals 89
Metric Conversion Factors 91
U.S. Pound to Kilogram and Kilogram to U.S. Pound Conversion Table 92
Inches to Millimeters and Millimeters to Inches Conversion Table 93
Decimal Equivalents of Fractions of an Inch 94
Fractions of an Inch to Millimeters Conversion Table . . . 94
Pound-Force-Inches to Newton-Meters and Newton-Meters to Pound-Force-Inches Conversion Table 95

CHAPTER 1
STEELMAKING

An introduction to making carbon, alloy, stainless, and tool steels.

Steel is an alloy of iron and carbon containing less than 2% carbon and 1% manganese and small amounts of silicon, phosphorus, sulfur and oxygen. It exists in several phases and is malleable, within a temperature range, immediately after solidification from a molten state.

Did you know that pig iron got its name because it looked like a litter of pigs and a sow when it was poured into its earthen molds?



The principal raw materials used in steelmaking are iron ore, coal, and limestone. These materials are converted in a blast furnace into a product known as "pig iron," which contains considerable amounts of carbon (above 1.5%), manganese, sulfur, phosphorus, and silicon.

Pig iron is hard, brittle, and unsuitable for direct processing into wrought forms. Pig iron was named long ago when molten iron was poured through a trench in the ground to flow into shallow earthen holes. The arrangement looked like newborn pigs suckling. The central channel became known as the "sow," and the molds were "pigs."

Steelmaking is the process of refining pig iron as well as iron and steel scrap by removing undesirable elements from the melt and then adding desirable elements in predetermined amounts. During steelmaking carbon is reduced by blowing oxygen through the molten steel. When oxygen combines with carbon, carbon monoxide or carbon dioxide is produced which must be removed from the molten steel. If this dissolved oxygen is not removed from the melt prior to or while pouring, the gaseous products continue to evolve during solidification. If the steel is strongly deoxidized by the addition of deoxidizing elements, no gas is evolved, and the steel is called "killed" because it lies quietly in the molds. Increasing degrees of gas evolution (decreased deoxidation) characterize steels called "semikilled," "capped," or "rimmed." The degree of deoxidation affects some of the properties of the steel. In addition to oxygen, liquid steel contains measurable amounts of dissolved hydrogen and nitrogen. For some critical steel applications, special degassing practices as well as vacuum treatments may be used to reduce and control dissolved gases.

The carbon content of common steel grades ranges from a few hundredths of a percent to about one percent. All steels also contain varying amounts of other elements, principally manganese, which act as a deoxidizer and facilitates hot-working. Silicon, phosphorus, and sulfur are also always present, if only in trace amounts. Other elements may be present, either as residuals that are not intentionally added through raw materials used in steelmaking practices, or as alloying elements added to effect changes in the properties of the steel. When reviewing a steel chemical certification, it is important to remember that iron is the primary element of steel and is not included in the list of chemical values. *See "How to Read a Material Certification," page 4.*

Steels can be cast to shape, or cast in ingots or strands to be reheated and hot-worked by rolling, forging, extrusion, or other processes into a wrought mill shape. Wrought steels are very versatile and the most widely used of engineering materials, offering a multitude of forms, finishes, strengths, and usable temperature ranges.

In certain instances following hot-working, steel is annealed in preparation for cold-working. Annealing softens the metal making it more ductile. *See "Annealing," page 11.* After annealing it goes through a "pickling" process. Pickling is a chemical process where steel is run through a progressive series of tanks. Chemicals – such as hydrochloric acid – remove oxidation and impurities from the surface of the product.

Finished steel, typical of the grades used in G.L. Huyett's manufacturing, is cold-rolled (or cold-drawn) after being annealed and pickled. Commonly referred to as cold-finishing, the process involves running the product through a series of progressive dies or rollers at room temperature that stretches the steel creating a permanent increase in its hardness and strength, and improves its finish. The effects of cold-finishing can be undone if the steel is reheated to above its recrystallization temperature.

Cold-finished steel is typically ready to be used to manufacture finished goods, but in some cases, additional processes such as bead blasting that creates a "bright steel" free of surface imperfections are performed.

Other grades, such as blue tempered, also known as blue clock or clock spring steel, which is used to manufacture shims, are heat treated and ground for finer tolerances and harder finishes. *See also "Chapter 5: Heat Treating," page 48*.

Steel must be handled carefully after manufacturing so that straightness tolerances are maintained, and surface imperfections are not created. Proper storage from the elements must be used (including when shipping on a truck) to minimize corrosion. Finally, steel must be handled carefully during loading and unloading so that bars are not bent, warped, or "pinged" on the sides. Particularly for keystock, edges must be sharp, straight, and true to ease installation into the keyway. *See "Storage & Handling of Raw Steel," page 15.* ■

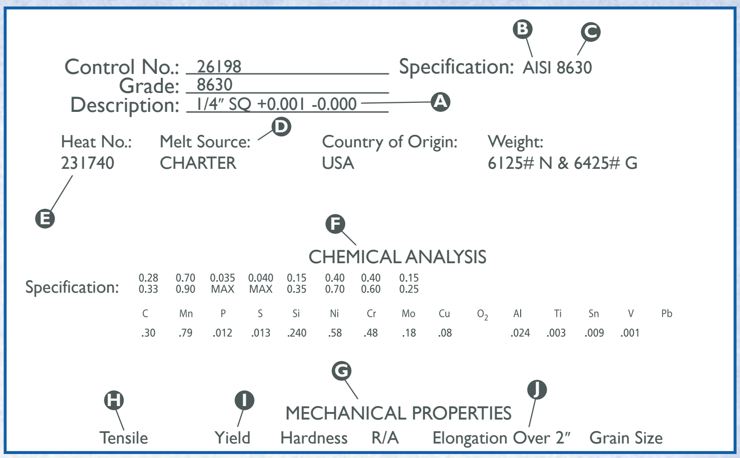
Effects of Chemical Composition*

Element	Source	Effect on Properties	If Too High	If Too Low
Carbon	Coke from smelting process	Hardens steel	Steel is brittle, but hard	Steel is soft, but ductile
Manganese	Added in refining	Controls sulfur in steel	Steel can be brittle	Too much sulfur
Silicon	Raw materials, deoxidizer	Improves hardness	Similar to manganese	Similar to manganese
Sulfur	Iron ore, coke	Lowers ductility through formation of iron pyrite	Steel will “hot short” (crack/tear at high temperature) and will be soft	N/A
Phosphorus	Iron ore, coke	Similar to sulfur	Similar to sulfur	N/A

* *See also “Characteristics of Common Alloy Elements,” page 19.*

How to Read a Material Certification

A material certification is generated by the producer using a sample of molten material taken directly from the ladle. In the case of slabs used for reheating or rolling, a sample is taken from the finished state. In this example, you will notice that the chemical composition does not equal 100%. Since iron is the primary component of steel, its percentage is not included in the analysis.



- **A** **Tolerance** describes the accountable manufacturing tolerance.
- **B** **Specification Authority** describes the organization that created the specification (AISI is the American Iron and Steel Institute).
- **C** **Grade** specifically refers to chemical content and physical properties.
- **D** **Melt Source** denotes actual mill where iron was smelted.
- **E** **Heat Number** is the special lot or “melt” from which the product was produced.
- **F** **Chemical Analysis** lists the content values of various elements expressed as a share of one percent (ex.: 0.30 of carbon = 0.003).
- **G** **Mechanical Properties** represents values determined by physcially testing the product.
- **H** **Tensile Strength**, also called ultimate strength, is the measurement at which steel exhibits strain.
- **I** **Yield Strength**, related to tensile strength, yield strength is the stress level at which steel exhibits strain.
- **J** **Elongation** is the increase in gauge length or “pull” when steel is tensile tested.

SMELTING IRON: THE BLAST FURNACE

Iron is the primary ingredient in steel and is made by chemically and physically altering iron ore in combination with coke and limestone.

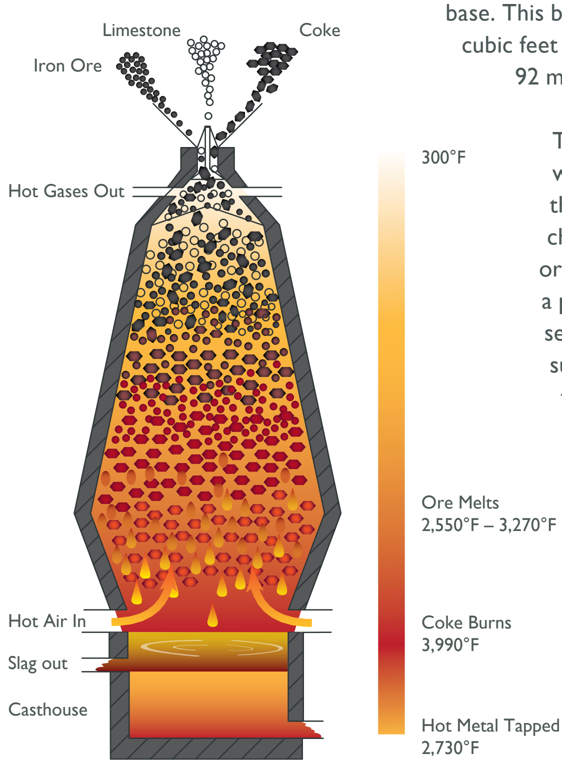
Iron Ore Processing

Iron (Fe) is not a free element on earth, but is trapped in the Earth's crust in its oxide state. Iron ore is a mineral containing enough iron to be a commercially viable source of the element to be used in steelmaking. High iron content ores such as hematite and magnetite only need to be pulverized to 0.5″ – 1.5″ before being sent directly to a blast furnace.

Lower grade ores, such as taconite, require processing before being sent to a blast furnace. In a series of steps, the ore is ground to a powder as fine as facial powder. During the grinding processes impurities are removed until the remaining ore attains a high enough concentration of iron to be used in a blast furnace. The powder is formed into marble sized pellets and then sent to the blast furnace.

Coke Processing

Coke is produced in a process very similar to creating charcoal from burning wood. Coke furnaces are large, narrow chambers arranged side-by-side with common walls. Coal is dumped into the chambers then heated to 2,012°F in an oxygen deprived atmosphere that prevents the carbon in the coal from being consumed. The coal decomposes to form a plastic mass while loosing most of its tars and oils. As the carburizing process continues, the plastic mass solidifies into the final stages of coke and is nearly 93% carbon. The resulting material is extremely strong but highly permeable and capable of providing the high heat and gases required in the blast furnace process.



BLAST FURNACE

The Blast Furnace

The blast furnace is where most iron ore is turned into iron. Blast furnaces run for years in continuous operation once started and are shut down only when it becomes necessary to rebuild them.

Coke, iron ore, and limestone are charged into the furnace from the top. The mass is held in place above the casthouse located at the bottom of the furnace. Air, heated to 2,300°F, is blasted into the furnace at its base. This blast can be as much as 230,000 cubic feet per minute, equivalent to a 92 mph wind in a 36″ pipe.

The blast of air ignites the coke which begins to alter and melt the iron ore. Through a series of chemical reactions the oxygen in the ore is removed, reducing the ore to a purified iron state. The limestone serves as a flux removing unwanted sulfur and other compounds from the iron. As the iron melts, it begins to trickle through the coke to the bottom of the furnace. It can take six to eight hours for the iron ore and coke to work its way to the bottom while it takes only six to eight seconds for the hot blast air to reach the top of the furnace.

Discharged hot gases are used to fuel the ovens creating the hot air, reducing coke consumption and increasing efficiency.

The liquid iron collects in the casthouse chamber underneath the furnace along with the slag. The slag is a remnant product of the flux materials and other compounds and floats on top of the liquid iron. The result is pig iron, which is used in the creation of steel.

Tap-to-tap cycles (the time from one pour to the next) on a blast furnace can range from forty-five minutes to two hours.

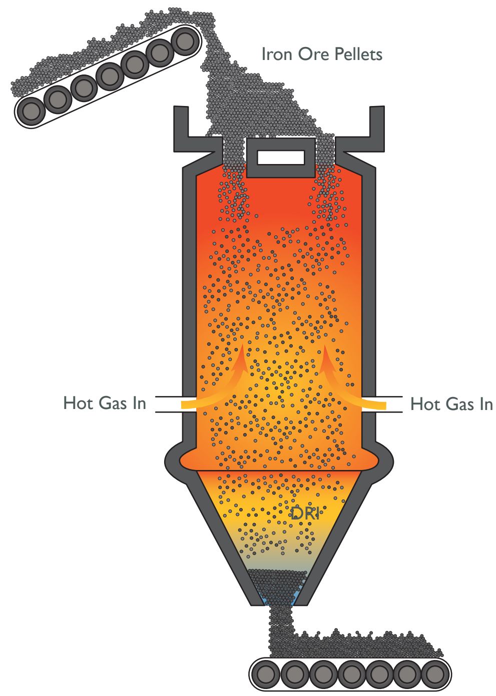
SMELTING IRON: THE DIRECT REDUCTION FURNACE

The direct reduction furnace has a much lower investment cost than a typical blast furnace because its scale is much smaller. Likewise, the raw materials used in them do not need to meet the higher quality requirements of blast furnaces. They can also operate with lower energy requirements. However, they cannot produce the same quantities as a blast furnace. The process was prevalent until the sixteenth century when the modern blast furnace became the standard.

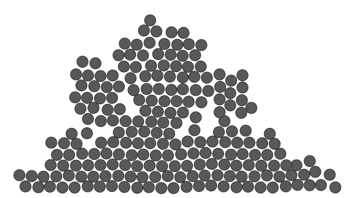
Iron ore – in the form of lumps or pellets and with 65% – 70% iron content – is fed into the top of the shaft furnace. Heated reducing gases, primarily carbon monoxide and hydrogen, are fed in a counter-current against the flow of ore. As the hot gas rushes against the ore, it strips the carbon and oxygen molecules from the ore. While the gas is hot enough to strip out these elements, it is not hot enough to melt the remaining iron, so the iron forms pellets or lumps known as direct reduced iron (DRI) or sponge iron because of its porous nature. Sponge iron is 90% – 97% pure iron making it an excellent source of raw material for electric arc furnaces which can readily melt DRI, but are not hot enough to melt ore.

The resulting sponge iron can be formed into lumps, pellets, or briquettes. It can be left hot – provided it is immediately sent to a furnace, usually no further distance than forty meters – or it can be cooled for transport. Care must be taken during storage and transport as sponge iron is highly prone to oxidation and can even self-combust.

While DRI is much easier to produce, it requires large quantities of natural gas as the major ingredient of the reducing gas. Coal and coal gas can also be used, but it must be processed for use beforehand.

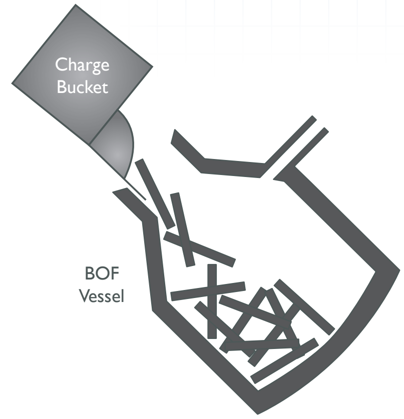


DIRECT REDUCTION FURNACE


DIRECT REDUCED IRON PELLETS

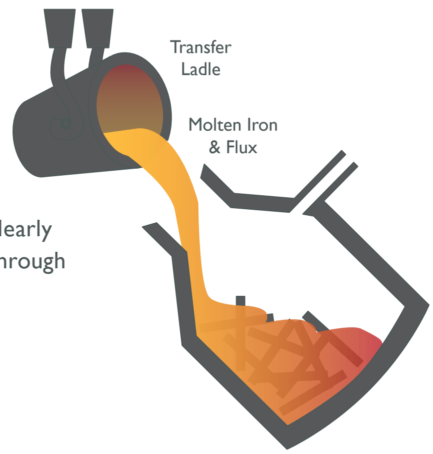
SMELTING IRON: THE BASIC OXYGEN FURNACE

Nearly 54% of the crude steel output in the U.S. is produced by basic oxygen furnaces (BOFs). Usually these furnaces are in proximity to the blast furnace so that liquid iron can be transported directly to the BOF. A BOF is self-sufficient, collecting energy from its own processes.

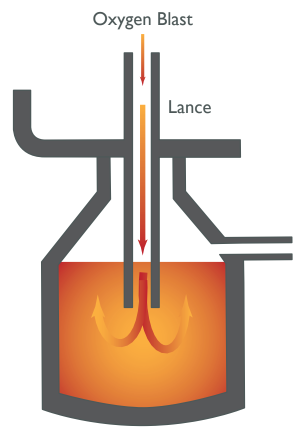


CHARGING SCRAP

The primary ingredients used in a BOF are 70% – 80% molten iron and the remaining balance is steel scrap. The BOF chamber is tilted to the charge bucket where scrap metal is charged into the vessel immediately followed by a pour of molten iron from a transfer ladle. The charging process only takes a couple of minutes then the vessel is righted. Flux, in the form of limestone or dolomite, is added from overhead bins while a lance is lowered to within a few feet of the bottom of the vessel. Nearly pure (99.5%) oxygen is injected into the mass through the lance at near supersonic velocities.



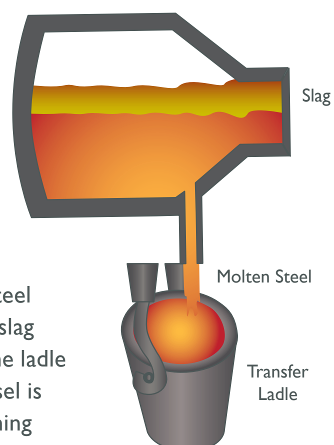
CHARGING HOT METAL



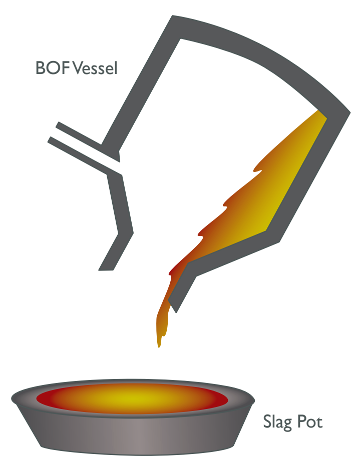
MAIN BLOW

With an ear-piercing shriek, the oxygen begins to oxidize the carbon and silicon in the liquid iron generating enough heat to melt the scrap metal. The shriek is silenced as soon as enough silicon is oxidized to form a gassy molten slag surrounding the lance. The generation of these gases, primarily carbon monoxide (CO^2), causes the entire cauldron to have the appearance of a giant mud pot.

As the melt, referred to as the main blow, continues, the lance is gradually raised in the mixture depending on the specifications and chemistry of the melt. A typical melt can take 15-20 minutes. Once completed, the mass is tested for chemical and temperature accuracies. The BOF vessel is then tilted to pour the molten steel into a waiting preheated ladle without pouring the slag floating on top. At this point, alloys are added to the ladle to produce the required metal. Then, the BOF vessel is turned completely upside down to pour the remaining slag into a "slag pot." The ladle may be sent for further processing or to continuous casting for solidification.



TAPPING

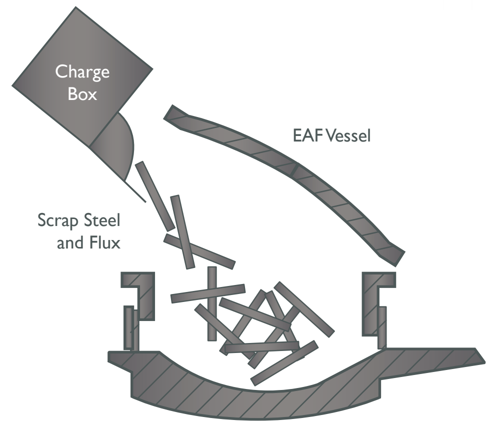


SLAG OFF

Tap-to-tap cycles of a BOF can be as little as forty minutes with half of it being blow time.

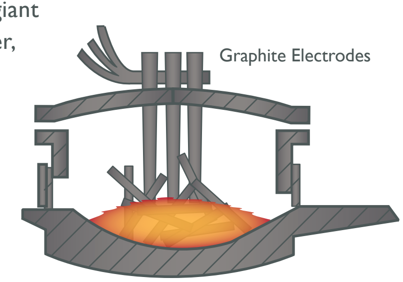
SMELTING IRON: THE ELECTRIC ARC FURNACE

Unlike a blast furnace or a basic oxygen furnace, an electric arc furnace (EAF) uses only scrap steel and direct reduced iron (DRI) for its raw material. Before the heat begins, scrap is carefully selected for its content and size. The scrap is carefully placed in a charge bucket along with lime and carbon to act as a flux. The scrap is placed in layers according to size and density to assure efficient meltdown of the scrap and protect the vessel from scrap "cave-ins" as the material melts. Most melts will take two to three charge buckets for a single melt. Each load of scrap must be melted enough to accommodate the next charge before the subsequent charge can be added, creating inefficient down times when the furnace is off between charges.



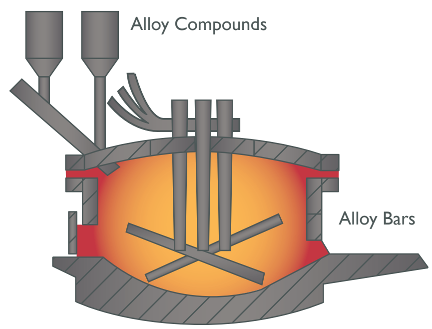
CHARGING SCRAP

The melt begins when the vessel is sealed and giant graphite electrodes, usually 4" – 36" in diameter, are lowered into the scrap. Initially, an intermediate voltage is used as the electrodes "bore in" to the pile. Lighter pieces of scrap are placed on top to help initiate this process. Once the electrodes have "bored in," the voltage is increased to create a long-arc tap which melts the scrap into a pool of liquid steel in the bottom of the vessel. The process is repeated with each charge until the desired volume has been reached.



MELTING

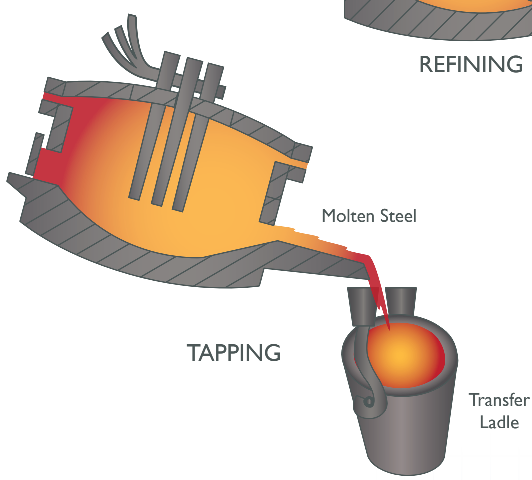
In some cases, the melt may be enhanced with the addition of oxyfuel burners and oxygen lances. Oxyfuel burners burn natural gas using oxygen or a blend of oxygen and air. This will create exothermic (heat generating) reactions with many of the compounds in the metal and supply additional heat to aid in the melting process.



REFINING

Once the metal is fully melted the refining process begins. Oxygen is blown in to lower the carbon content and oxidize unwanted compounds. These oxidized compounds float into the slag leaving behind a purified or refined steel. At this point, alloying elements may be added to achieve the desired melt specifications. The refined metal is then transferred via ladle to a ladle furnace or station.

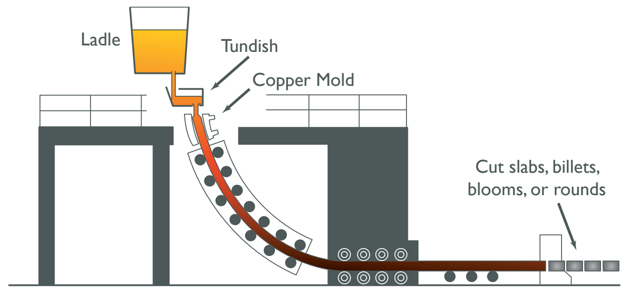
The tap-to-tap cycles of an EAF are usually about sixty minutes.



TAPPING

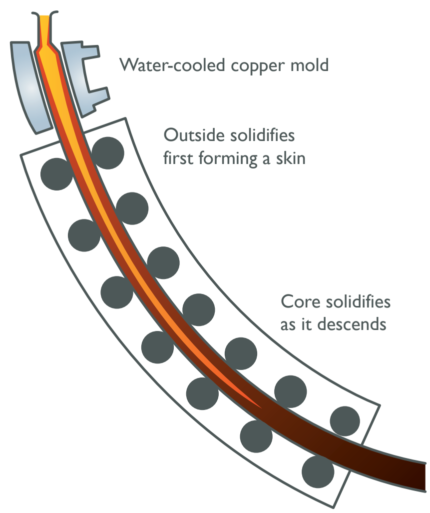
STEEL CASTING: CONTINUOUS CASTING

Once molten steel has been processed to its final stage it is ready to be cooled and solidified. Prior to the 1950's, it was common to let the steel solidify into blocks called ingots. Continuous casting was later developed which allowed for casting to a near-net-shape and reduced the entire process chain time from liquid metal to finished rolling to under two hours. As a result, production yields, product quality, productivity, and cost efficiencies have been greatly improved.



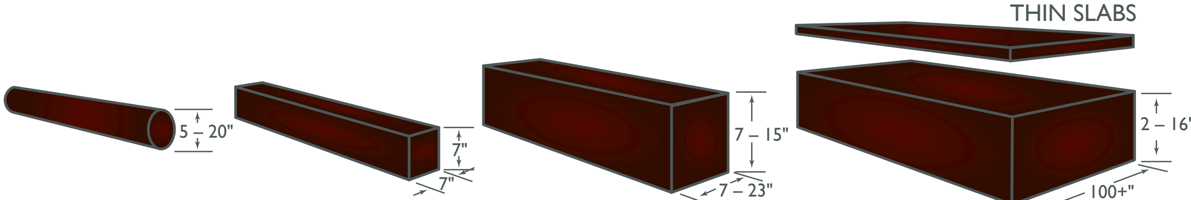
CONTINUOUS CASTING

Essentially, a casting system is a large tower with a large holding tub on top. Molten metal is poured into the tub, called a tundish, which is connected to a water-cooled copper mold. Simply using gravity, the molten metal fills the mold and begins to cool. Once the metal develops a solidified skin 0.4″ – 0.8″ thick, a door is opened on the bottom side of the mold, and the steel begins a controlled exit. Liquid metal replenishes the mold at the same rate the steel exits the mold creating a continuous strand of nearly solidified steel. The strand will take one of three paths: continue straight down where it is sectioned while still vertical, continue straight down then bend to a horizontal plane for sectioning, or follow a gentle curve to a horizontal plane. The withdrawal rate can vary 12″ – 300″ per minute depending on the grade and quality of steel being produced. An entire heat typically takes sixty to ninety minutes avoiding excessive ladle heat loss.



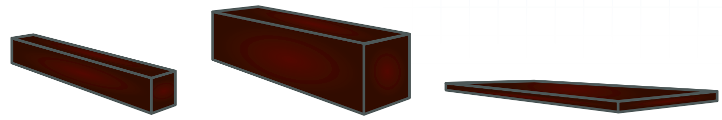
When the strand exits the mold, it enters a roller containment section which preserves the shape integrity and quality of the strand. At the same time, it is also subjected to water spray or water/air combination spray to promote solidification. The strand emerges from the roller/cooling section and is then sectioned into slabs, blooms, billets, rounds, or beam blanks. These can be sold as semi-finished product, put into storage, or moved directly into hot-working lines.

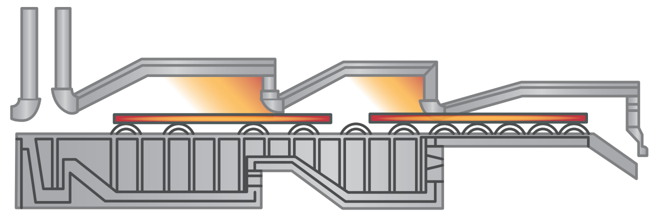
Billets have cast section sizes up to 7″ square. Bloom sections range 7″ square – 15″ x 23″. Slab castings range in thickness 2″ – 16″ and over 100″ wide. Round castings will have diameters 5″ – 20″.



HOT-WORKING STEEL

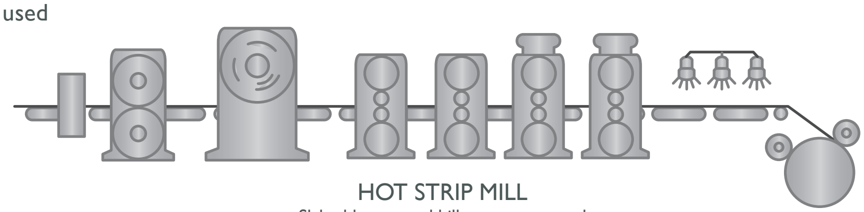
Hot-working steel is the process of rolling, stamping, or hammering near-molten steel that has been heated 1,350°F – 2,000°F into desired shapes. At room temperature steel is considered rigid since the molecular structure of its crystals is tightly packed. Heating steel above its crucial point, or crystallization temperature, increases its plasticity. Hot-worked steel is easier to roll or shape and is less likely to fracture than steel that is worked or forged at room temperature because its ductility is greater. *See "Thermal Modification of Steel," page 50.*



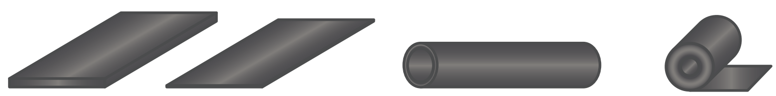


REHEAT FURNACE
Brings the steel product up to a malleable temperature and ensures an even temperature throughout the product.

While ductility is advantageous for many steel formed products, it can be a disadvantage for tool steels and blades that require high impact resistance. Tempering – the rapid cooling of heated steel in water or oil – is used to harden steel after it has been shaped. Once steel is formed and cooled, it can be annealed – reheated and gradually cooled – to recover some of the original strength and toughness of the steel.



HOT STRIP MILL
Slabs, blooms, and billets are squeezed and rolled into coiled sheets and plate products.



Advantages of Hot-working:

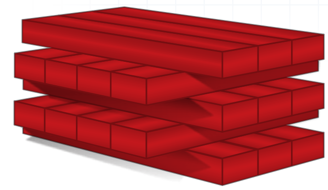
- Decreased yield strength makes steel easier to work with less energy or force
- Increased ductility
- Elevated temperatures increase molecular consistency
- Inconsistencies, flaws, and pores may reduce in size or close completely during hot-working
- When most steel alloys are heated above 1350°F a corrosion resistant solid solution called austenite is formed that can be worked easily and later hardened by cold-working instead of heat treating

Disadvantages of Hot-working:

- Scaling or rapid oxidation may occur due to undesirable reactions between steel and the surrounding atmosphere. This layer can be very hard and dull cutting tools.
- Thermal contraction makes tolerances difficult to maintain
- Uneven cooling may result in warping
- Expensive heating is required and must be maintained by using high-temperature heating circuits to keep tooling between 500°F – 850°F while rolling or stamping parts.

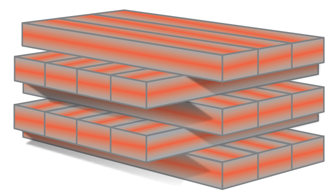
ANNEALING

Steel can exist in several phases, each with distinct characteristics. These phases can be manipulated through heating and cooling processes to produce steel with specific mechanical properties. Annealing is a heating and cooling process which relieves internal stresses caused by hot-working. It also increases ductility making the steel more workable. Annealing is usually done after steel is hot-worked but before it is cold-worked; however, it can also be performed on individual workpieces.



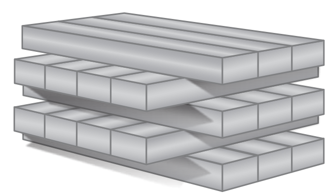
Steel is heated to above its critical temperature forcing it into an austenitic phase.

During hot-rolling, the outside grains of the steel receive more work than the inner grains. This makes the grains on the surface smaller than those in the middle creating a residual stress. Annealing will homogenize the grains, making them all the same size eliminating the stress. *See"Chapter 5: Heat Treatment," page 48 and "Steel Phases" illustration, page 27.*



The steel is then slowly cooled in a controlled atmosphere letting it settle into a stress-free ferrite/pearlite phase.

The steel or workpiece is heated to above its upper critical temperature for a period long enough for the microstructure to fully transform to an austenitic phase. It is then slowly cooled in a controlled atmosphere allowing maximum transformation to the ferrite and pearlite phase. By carefully managing this process, the steel or workpiece is taken through three stages: recovery, recrystallization, and grain growth.



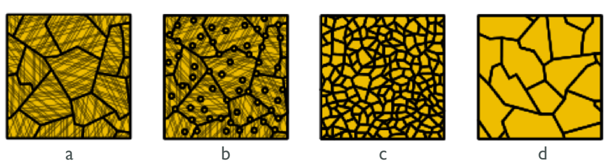
When the steel reaches room temperature it is ready for pickling, oiling, and cold-working.

Recovery

Recovery happens at the lowest temperatures of the heating process and softens the metal by allowing defects known as dislocations to realign into the crystal lattice eliminating the stress associated with them.

Recrystallization

As the steel continues to heat, new strain-free grains begin to nucleate and grow replacing grains deformed by internal stresses. The crystallized grain structure of the steel changes shape and then recrystallizes into longer and thinner strain free grains. This makes the finished, cooled product more ductile and workable while lessening the yield strength and hardness of the material.



a) Cast steel often contains stresses prone to fracturing (light gray lines in grains)
b) Annealing steel reorients the molecular structure of steel properties
c) Stronger, more compact grains are formed as elements realign
d) Longer, strain-free recrystallized steel results that is more ductile and resistant to fracturing

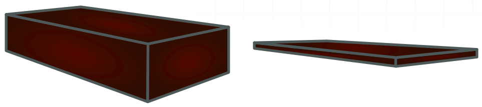
Grain Growth

In the final stage, grain growth occurs making the grains larger and more coarse. The steel loses a substantial part of its original strength, but its ductility is increased dramatically allowing it to be easily worked. Once worked the steel can be quenched to increase its mechanical properties.

COLD-WORKING STEEL

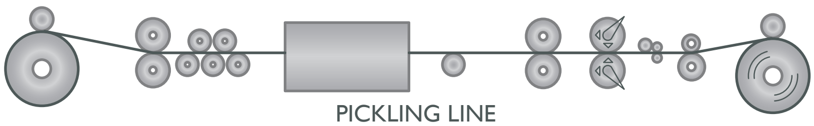
Pickling

Prior to cold-working, hot-worked steel is allowed to cool and is cleaned using an alkaline solution. Since hot-working steel at high temperatures leaves a discolored oxide layer or rust-like scale on the surface, the steel is run at high speeds (up to 800' per minute) through an acidic solution called "pickle liquor." Pickling results in a higher quality steel product as oxidation (rust), contaminants, imperfections, or scale are removed or dissolved in hydrochloric or sulfuric acid. Chemical inhibitors are also added to discourage the acid from attacking the steel beneath the scale. The steel is then rinsed with water and air-dried leaving bare steel with a dull silver luster.



Oiling

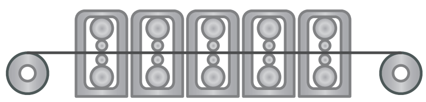
After pickling, the steel is coated with a thin layer of high-quality oil, often containing sulfur additives, to create a barrier to moisture and inhibit rust in moderately humid atmospheric conditions. Oiling steel can protect it for up to six months though the oil must be removed prior to most fabrication, plating, or painting processes.



PICKLING LINE
Cleans steel of rust, dirt, and oil.
Uses hydrochloric acid baths and water cleaning to enhance the steel for further working.

Cold-working

Frequently called work hardening, strain hardening, or forging – cold-working is any process used to reshape steel at temperatures below the recrystallization temperature. In most cases, cold-working is performed at room temperature. *See "Recystallization" illustration, page 11*. Unlike hot-working that relieves stresses and makes the steel easier to work, cold-working introduces mechanical stresses that increase yield strength, tensile strength, and hardness while reducing ductility to produce very strong results.



COLD-ROLLING
Structure of steel changed through rolling, hammering or stretching; enhancing its hardness, strength and finish.

During cold-working, mechanical processes such as rolling, forging, bending, shearing, or drawing are used to manipulate the microstructure of steel. Similar to stretching a rubber band, cold-worked steel under stress initially wants to return to its original form even as its crystalline structure is compacted. As mechanical stress increases steel starts to resist additional efforts to reshape the steel. The evolving crystal structure allows the steel to withstand greater stress, however if too much stress is introduced the steel will break rather than bend or stretch. Once shaped, cold-worked steel may require heat treatment by annealing to reduce surface and internal stresses in the material.

For high-volume production, cold-working is typically less expensive than heat treating finished products. At smaller scales, heat treating may be more cost effective due to the initial capital costs of cold-working. In some instances, both processes are used to produce finished goods. The most significant benefit of cold-working vs. hot-working is that the cold-worked steel can be measured and formed to tight tolerances since it is not subjected to heat that can potentially distort the workpiece during the cooling process used on hot-worked steel.

Squeezing, bending, shearing, and drawing are the most common operations utilized to cold-work steel. Though many processes have been developed for each method, cold-rolling, cold-forging, and extrusion are the most common.

Cold-rolling

Cold-rolled steel is formed by squeezing sheets, rolls, or bars of steel through a series of rotating progressive dies to form products with smooth surfaces and accurate dimensions in just about any desired profile.

Cold-forging or Cold-heading

With cold-forging (or cold-heading), steel is forced into a die with a press or hammer to produce the desired shape. The heads of bolts, nails, and other fasteners are made by cold-heading ends of rod or wire.

Extrusion

Extrusion is typically performed while material is hot to reduce the effort needed to reshape metal, however, cold extrusion is possible and often used to create simpler shapes and smaller parts.

As shown in the examples below, a cylindrical or square billet of steel can be forced through a die to produce any number of profiles. Though less common, cold extrusion features several advantages over hot extrusion: better control over finished dimensions, cleaner surfaces free of scale and oxidation, and higher rates of production.

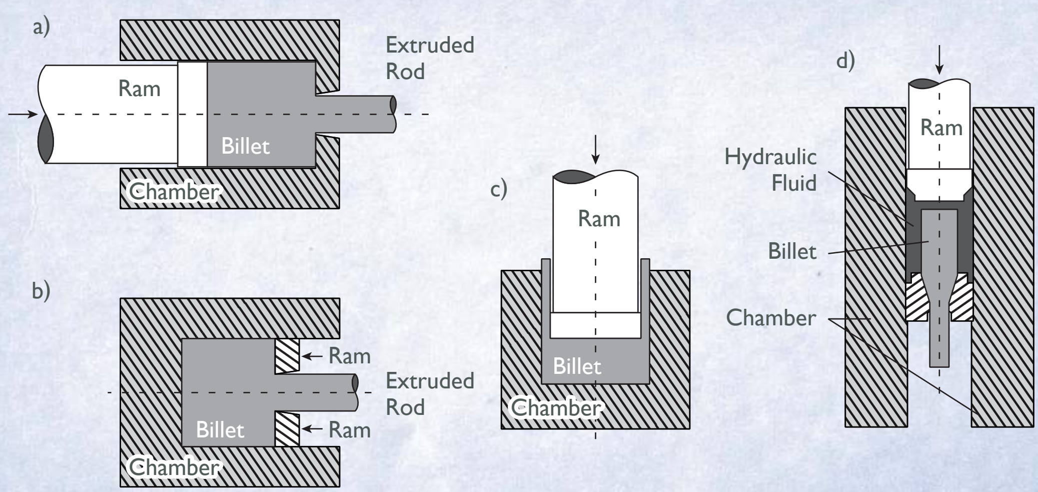
Advantages of Cold-working

- Heating is not required
- Better surface finishes (no oxidation occurs)
- Easier to maintain dimensions and tolerances
- Stronger and harder finished results possible
- Greater consistency of finished parts

Disadvantages of Cold-working

- Decreased ductility
- Requires greater force to shape
- Required equipment must be heavier and more powerful
- Requires clean, scale-free surfaces
- May require annealing to alleviate brittleness
- Greater risk of fracture/failure due to residual stresses

Steel Extrusion Methods



a) Direct or Forward b) Indirect or Reverse c) Impact d) Hydrostatic

STORAGE AND HANDLING OF RAW STEEL

Preserving the straightness of raw steel and protecting it from the elements requires that extreme care and caution be taken in the procurement, production of, and shipment of raw steel and finished parts.

Product handling is an important consideration in product quality. While not addressed in the ANSI standard, numerous references are made in the ASTM A108 specification. From Section 9.3.1, "bars shall be given a surface coating of oil or other rust inhibitors to protect against corrosion during shipment." From section 9.3.2, "The bars bundles shall be identified, packaged, and loaded to preserve the physical appearance [and] product tolerance…" In the notes in Table A1.4, "…straightness is a perishable quality and may be altered by mishandling. The preservation of straightness in cold-finished bars requires the utmost care in subsequent handling."

Above: Finished parts ready for packaging and shipping. Facing Page: Steel bars are tagged and stored by lot in rigid steel cradles.

At G.L. Huyett, significant effort is made to ensure proper handling, storage, and transportation of steel products. Most mill shipments arrive wrapped in oil-soaked paper and crated in wooden protective boxes instead of simple open bundles.

Full bundles of steel are lifted in two places to minimize bending, twisting, and contortion.

Raw materials and finished products are usually shipped on flatbed trucks and unloaded using a crane and cradle system. This system ensures that full bundles are lifted from two points to minimize bending, twisting, or contortion. The bundles are lifted directly from the truck bed to the cradle so that forklift and other less reliable transportation means are avoided. Bundles are placed in rigid steel cradles that interface with the overhead crane. Each bundle is painted with proprietary grade colors to avoid misidentification from mill-specific and inconsistent coloring schemes. Bundles are tagged for lot and heat number control. When production commences, bars are transported from cradles to steel support tables to minimize distortion. Production ready bars are rolled to band saws for operator ease and product protection.

Operators are trained, and equipment is configured to control drop length during production to prevent pinging ends of keystock which can affect dimensions, tolerances, and performance in the field. Following production, parts are cleaned, rust inhibitor applied, and then dried. Finished parts are shipped in extra heavy-duty boxes with a liner. The box and liner provide extra shock and environmental protection.

CHAPTER 2

CHEMICAL CONTENT

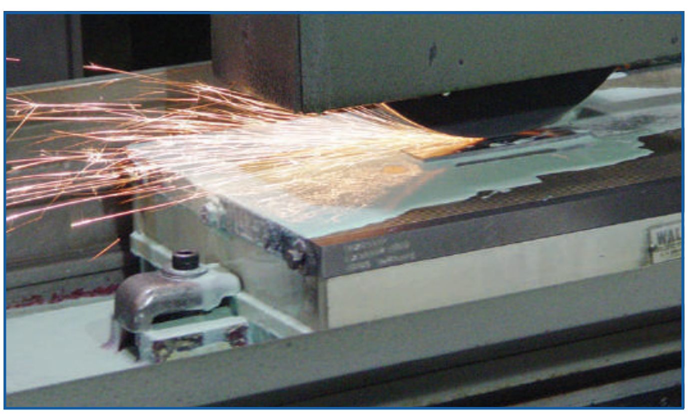
Identification factors and composition standards.

Steel is differentiated by its grades and mechanical properties. The chemical composition of each grade determines its characteristics. A specific recipe of alloying elements is used to create each particular grade and achieve the desired attributes for a given application.

Did you know that each kind of metal creates a unique spark when it is ground?

Identifying Metals

When it is necessary to sort materials, several rough methods may be used without elaborate chemical analysis. The most obvious of these is by using a magnet to pick out those materials that contain magnetic elements.



Grinding creates carrier lines and sprigs caused by the combustion of the constituent elements which can help identify the chemical composition of a particular piece of metal.

To differentiate various levels of carbon and other elements in a steel bar, hold the bar in contact with a grinding wheel and observe the sparks. With high levels of carbon, sparks are produced that appear to split into several bright tracers. Patterns produced by several other elements, such as small amounts of aluminum or titanium, can be identified with the aid of *Heat Treating Data Sheet 13*, issued by the American Society for Metals (ASM), Metals Park, OH.

The idea of this test is simple: the spark stream given off during a grinding operation can be used to approximate the grade or alloy of the steel piece. The equipment used should be a grinder with a no-load speed of 9000 rpm and a 2.5″ wheel. A semi-darkened location is necessary.

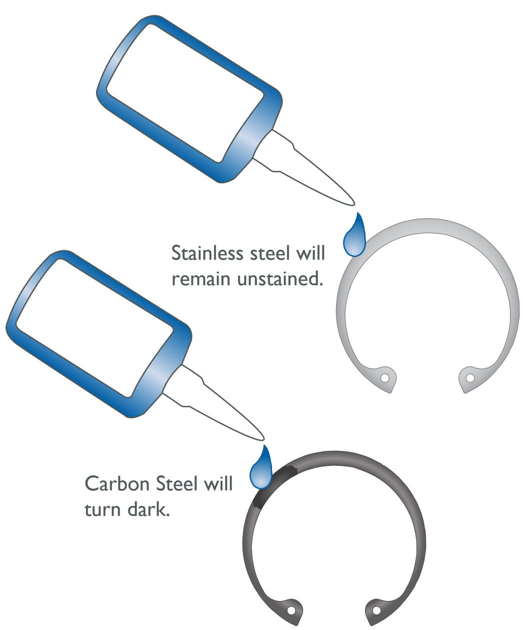
The easiest way to learn the test is to observe the spark streams from various known grades and compare them with this text. As you grind, you will see lines called carrier lines. At the termination of the carrier lines, you will see small bursts called sprigs. Low-carbon (1008) produces a very simple stream with few bright sprigs. The higher the carbon content, the more numerous the carrier lines and sprigs. Some alloying elements change the appearance of the test. Sulfur imparts a flame shaped, orange colored swelling on each carrier line. The higher the sulfur, the more numerous the swellings. A spear-point shape detached from the end of the carrier line identifies phosphorus. The higher the phosphorus content, the more numerous the spear points. Nickel appears as a white rectangular-shaped block of light throughout the spark stream. Chromium appears as tint stars throughout the carrier lines, having a flowering or jacketing effect to the carbon burst. The presence of silicon and aluminum have a tendency to depress the carbon bursts.

There are three primary methods of determining the chemical analysis of steel; Optical Emission Spectrometry (OES), X-ray Fluorescence Spectrometry (XRF), and Coupled Plasma - Atomic Emission Spectrometry (ICP-AES). All three are laboratory-based analyses and yield highly accurate results. Field tests will produce general results and cannot be used to certify steel compositions. ■

Two Easy Ways to Differentiate Carbon Steel from Stainless Steel

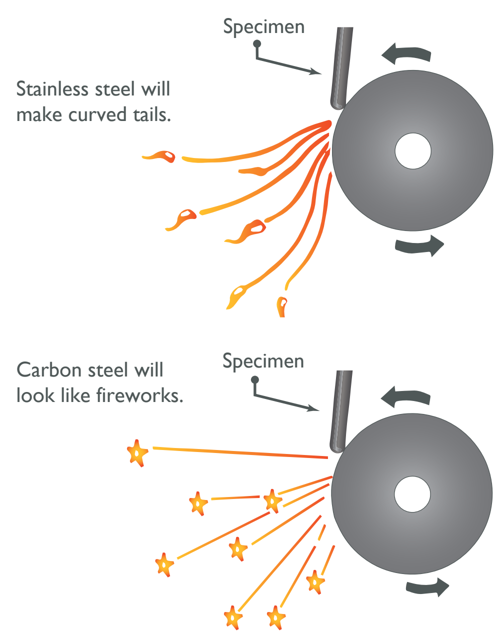
CHEMICAL TESTING

Place a drop of 20% nitric acid solution on a cleaned portion of the specimen

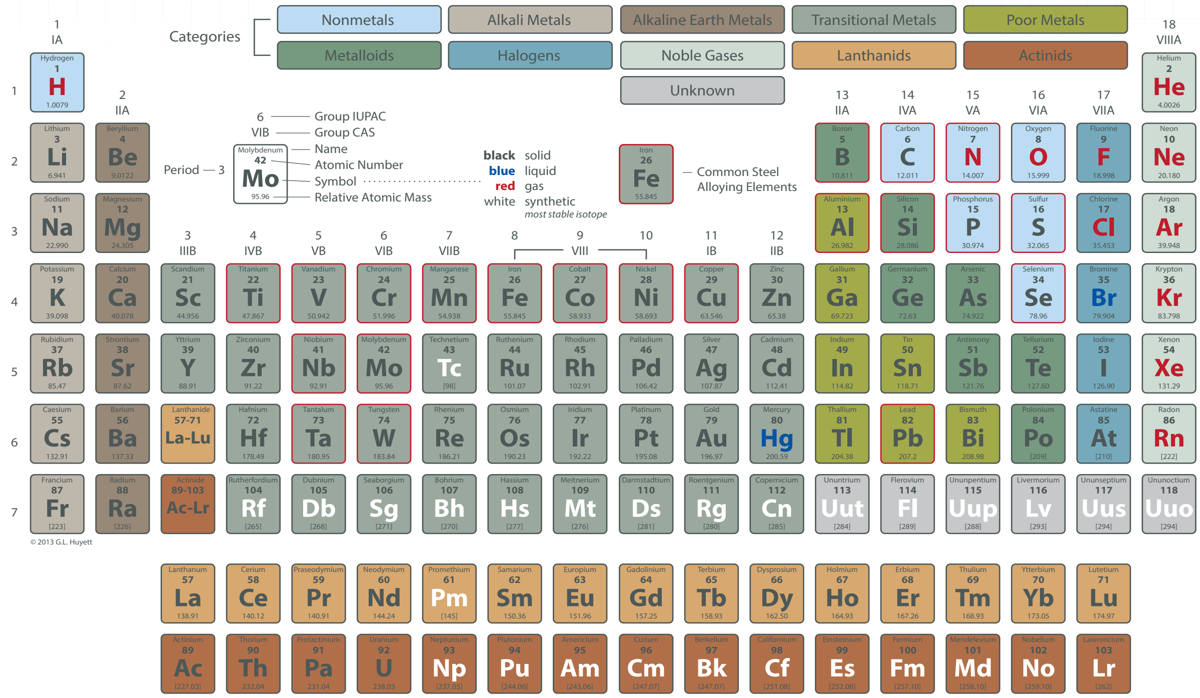


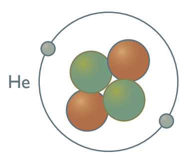
MECHANICAL TESTING

Hold the specimen with pliers and place it against a grinding wheel



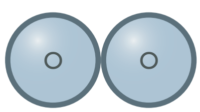
PERIODIC TABLE OF THE ELEMENTS





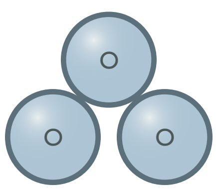
Atom

An **atom** is the basic unit of a chemical element and is described by the number of its protons, neutrons, and electrons.

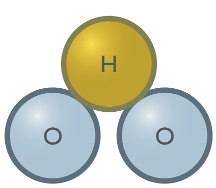


Element

An **element** is a substance made entirely of one type of atom. All known elements are charted in the Periodic Table of Elements.

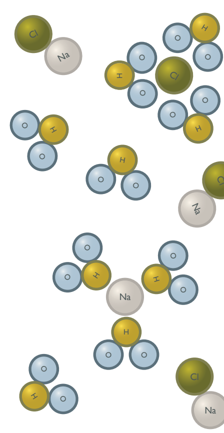


Molecule

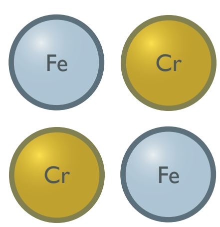


Compound

Molecules are groups of atoms that have been chemically bonded together. A **compound** is a molecule made from different elements. Compounds cannot be easily taken apart. Water is a compound because it is made from hydrogen and oxygen. All compounds are molecules but not all molecules are compounds.


Mixture

Mixtures are combinations of elements that are not bound together by a chemical reaction and can be easily sorted into their constituent elements/compounds. Salt water is an example of a mixture.



Alloy

Alloys are metals made by combining two or more metallic elements. Other elements may also be added to enhance specific characteristics.

CHARACTERISTICS OF COMMON ALLOY ELEMENTS

Boron

Boron 5 B 10.811

Boron increases hardenability.

Carbon

Carbon 6 C 12.011

Carbon is the basic alloying ingredient in steel. It increases the hardness and strength of iron.

Nitrogen

Nitrogen 7 N 14.007

Nitrogen helps in the formation of austenite and increases its stability and strength.

Aluminum

Aluminium 13 Al 26.982

Aluminum deoxidizes steel and restricts grain growth.

Silicon

Silicon 14 Si 28.086

Silicon is used as a deoxidizing or killing agent. It increases hardening of the ferritic phase in steels.

Phosphorus

Phosphorus 15 P 30.974

Phosphorus is added to increase machinability; however, it can contribute to cracking during welding.

Sulfur

Sulfur 16 S 32.065

Sulfer improves machinability but can also damage hot forming characteristics.

Titanium

TItanium 22 Ti 47.867

TItanium is used to keep carbon from combining with chromium so that the piece retains its noncorrosive properties.

Vanadium

Vanadium 23 V 50.942

Vanadium increases hardenability and corrosion resistance.

Chromium

Chromium 24 Cr 51.996

Chromium is the primary alloy ingredient in stainless steel adding corrosion resistance.

Manganese

Manganese 25 Mn 54.938

Manganese increases strength, toughness and hardenability; and counteracts brittleness from sulfur.

Iron

Iron 26 Fe 55.845

Iron is the primary ingredient of all steels. It is the foundation element in the chemical composition of steel.

Cobalt

Cobalt 27 Co 58.933

Cobalt can become highly radioactive and is limited in nuclear applications. Used in medical implants and is corrosion resistant.

Nickel

Nickel 28 Ni 58.693

Nickel is used in the most corrosion and heat resistant stainless steels increasing strength and toughness.

Copper

Copper 29 Cu 63.546

Copper, normally present in stainless steels, can be added to aid in precipitation hardening.

Selenium

Selenium 34 Se 78.96

Selenium is added to improve machinability.

Niobium

Niobium 41 Nb 92.91

Niobium helps stabilize carbon and adds strength to steel intended for high temperature service.

Molybdenum

Molybdenum 42 Mo 95.96

Molybdenum enhances corrosion resistance and increases high temperature strengths.

Tantalum

Tantalum 73 Ta 180.95

Tantalum is very similar to Niobium and has the same effects when alloying to iron.

Tungsten

Tungsten 74 W 183.84

Tungsten increases wear resistance and raises hot strength and hot hardness.

Lead

Lead 82 Pb 207.2

Lead increases machinability characteristics.

CHEMICAL COMPOSITION OF STEELS

Composition of AISI/SAE Standard Carbon Steels

AISI-SAE No.	UNS No.	Composition (%)			
		C	Mn	P (max)	S (max)
Nonresulferized Grades – 1% Mn (max)					
1008	G10080	0.10 max	0.30 – 0.50	0.040	0.050
1010	G10100	0.08 – 0.13	0.30 – 0.60	0.040	0.050
1018	G10180	0.15 – 0.20	0.60 – 0.90	0.040	0.050
1020	G10200	0.18 – 0.23	0.30 – 0.60	0.040	0.050
1026	G10260	0.22 – 0.28	0.60 – 0.90	0.040	0.050
1035	G10350	0.32 – 0.38	0.60 – 0.90	0.040	0.050
1038	G10380	0.35 – 0.42	0.60 – 0.90	0.040	0.050
1043	G10430	0.40 – 0.47	0.70 – 1.00	0.040	0.050
1045	G10450	0.43 – 0.50	0.60 – 0.90	0.040	0.050
1065	G10650	0.60 – 0.70	0.60 – 0.90	0.040	0.050
1070	G10700	0.65 – 0.75	0.60 – 0.90	0.040	0.050
1080	G10800	0.75 – 0.88	0.60 – 0.90	0.040	0.050
1090	G10900	0.85 – 0.98	0.60 – 0.90	0.040	0.050
1095	G10950	0.90 – 1.03	0.30 – 0.50	0.040	0.050
1541	G15410	0.36 – 0.44	1.35 – 1.65	0.040	0.050
Free-Machining Grades – Resulferized					
1117	G11170	0.14 – 0.20	1.00 – 1.30	0.040	0.08 – 0.13
1144	G11440	0.40 – 0.48	1.35 – 1.65	0.040	0.24 – 0.33
Free-Machining Grades – Resulferized and Rephosphorized					
1212	G12120	0.13 max	0.70 – 1.00	0.07 – 0.12	0.16 – 0.23
1213	G12130	0.13 max	0.70 – 1.00	0.07 – 0.12	0.24 – 0.33
1215	G12150	0.09 max	0.75 – 1.05	0.04 – 0.09	0.26 – 0.35
12L14	G12144	0.15 max	0.85 – 1.15	0.04 – 0.09	0.26 – 0.35

Source: Machinery's Handbook, 26 ed.

Composition of Tool Steels

Grade	C (%)	Mn (%)	Si (%)	P (%)	S (%)	Cr (%)	Mo (%)	V (%)	Other* (%)
A36	0.26	1.00	0.40	0.04	0.05	---	---	---	---
W1	0.95 – 1.05	0.30 – 0.40	0.10 – 0.25	0.025	0.025	0.15	0.10	0.10	0.15 Tungsten
O1	0.94	1.00 – 1.40	0.30	0.03	0.03	0.50	---	0.30	0.40 – 0.60 Tungsten
M2	0.85	0.30	0.30	---	---	4.00	5.00	2.00	6.00 Tungsten
A2	0.95 – 1.05	1.00	0.30	0.03	0.03	4.75 – 5.50	0.90 – 1.40	0.25	---
D2	1.40 – 1.60	0.60	0.30	0.03	0.03	11.00 – 13.00	0.75	0.90	---
S7	0.45 – 0.55	0.20 – 0.80	0.20 – 1.00	0.03	0.03	3.00 – 3.50	1.30 – 1.80	0.20 – 0.30	---
A6	0.70	2.00	0.30	---	---	1.00	1.00	---	---
P20	0.33	0.75	0.50	---	---	1.70	0.40	---	---

**Iron makes up the remaining percentage.*

Composition of AISI-SAE Standard Alloy Steels

AISI-SAE No.	UNS No.	Composition[a,b] (%)							
		C	Mn	P (max)	S (max)	Si	Ni	Cr	Mo
4037	G40370	0.35 – 0.40	0.70 – 0.90	0.035	0.040	0.15 – 0.35	---	---	0.20 – 0.30
4130	G41300	0.28 – 0.33	0.40 – 0.60	0.035	0.040	0.15 – 0.35	---	0.80 – 1.10	0.15 – 0.25
4137	G41370	0.35 – 0.40	0.70 – 0.90	0.035	0.040	0.15 – 0.35	---	0.80 – 1.10	0.15 – 0.25
4140	G41400	0.38 – 0.43	0.75 – 1.00	0.035	0.040	0.15 – 0.35	---	0.80 – 1.10	0.15 – 0.25
4142	G41420	0.40 – 0.45	0.75 – 1.00	0.035	0.040	0.15 – 0.35	---	0.80 – 1.10	0.15 – 0.25
4150	G41500	0.48 – 0.53	0.75 – 1.00	0.035	0.040	0.15 – 0.35	---	0.80 – 1.10	0.15 – 0.25
4340	G43400	0.38 – 0.43	0.60 – 0.80	0.035	0.040	0.15 – 0.35	1.65 – 2.00	0.70 – 0.90	0.20 – 0.30
E4340[c]	G43406	0.38 – 0.43	0.65 – 0.85	0.025	0.025	0.15 – 0.35	1.65 – 2.00	0.70 – 0.90	0.20 – 0.30
E52100[c]	G52986	0.98 – 1.10	0.25 – 0.45	0.025	0.025	0.15 – 0.35	---	1.30 – 1.60	---
6150	G61500	0.48 – 0.53	0.70 – 0.90	0.035	0.040	0.15 – 0.35	---	0.80 – 1.10	0.15 V min
8620	G86200	0.18 – 0.23	0.70 – 0.90	0.035	0.040	0.15 – 0.35	0.40 – 0.70	0.40 – 0.60	0.15 – 0.25
8630	G86300	0.28 – 0.33	0.70 – 0.90	0.035	0.040	0.15 – 0.35	0.40 – 0.70	0.40 – 0.60	0.15 – 0.25
8640	G86400	0.38 – 0.43	0.75 – 1.00	0.035	0.040	0.15 – 0.35	0.40 – 0.70	0.40 – 0.60	0.15 – 0.25
8740	G87400	0.38 – 0.43	0.75 – 1.00	0.035	0.040	0.15 – 0.35	0.40 – 0.70	0.40 – 0.60	0.20 – 0.30

Source: Machinery's Handbook, 26 ed..

a) Small quantities of certain elements are present that are not specified or required. These elements may be present to the following maximum amounts: Cu, 0.35%; Ni, 0.25%; Cr, 0.20%; and Mo, 0.06%.

b) Standard alloy steels can also be produced with a lead range of 0.15 – 0.35%. These steels are identified by inserting the letter "L" between the second and third numerals of the AISI or SAE number, e.g., 41L40.

c) Electric furnace steel.

Composition of AISI-SAE Standard Stainless Steels

AISI Type (UNS)[a]	Composition (%)								
	Cr	Ni	C	Mn	Si	P	S	Mo	N
316 (S31600)	16.0 – 18.0	10.0 – 14.0	0.08	2.0	0.75	0.045	0.030	2.0 – 3.0	0.10
302 (S30200)	17.0 – 19.0	8.0 – 10.0	0.15	2.0	0.75	0.045	0.030	---	0.10
316L (S31603)	16.0 – 18.0	10.0 – 14.0	0.03	2.0	0.75	0.045	0.030	2.0 – 3.0	0.10
303 (S30300)	17.0 – 19.0	8.0 – 10.0	0.15	2.0	1.0	0.20	0.015 min	0.60 optional	---
304 (S30400)	18.0 – 20.0	8.0 – 10.5	0.08	2.0	0.75	0.045	0.030	---	0.10
304L (S30403)	18.0 – 20.0	8.0 – 12.0	0.03	2.0	0.75	0.045	0.030	---	0.10
321 (S32100)	17.0 – 19.0	9.0 – 12.0	0.08	2.0	0.75	0.045	0.030[b]	---	0.10 max
430 (S43000)	16.0 – 18.0	0.75 Ni	0.12	1.0	1.0	0.040	0.030	---	---
416 (S41600)	12.0 – 14.0	---	0.15	1.25	1.0	0.060	0.15 min	0.60 optional	---

a) Type 430 is ferritic, type 416 is martensitic, all others are austenitic.

b) Ti, 5(C+N) min, 0.70 max

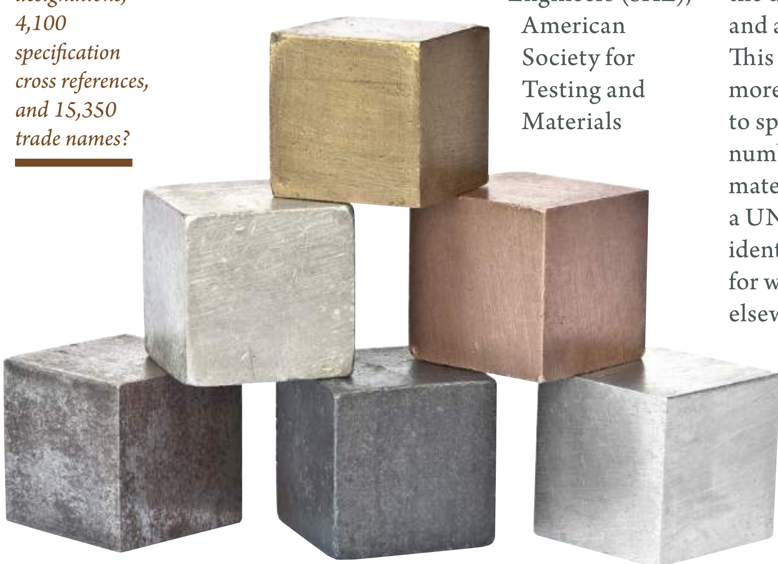
CHAPTER 3

STEEL AND STEEL ALLOYS

Carbon grades, types, and numbering systems.

Several different numbering systems have been developed for metals and alloys by various trade associations, professional engineering societies, standards organizations, and by private industries for their own use. The numerical code used to identify the metal or alloy may or may not be related to a specification, which is a statement of the technical and commercial requirements that the product must meet. Numbering systems in use include those developed by the American Iron and Steel Institute (AISI), Society of Automotive Engineers (SAE), American Society for Testing and Materials (ASTM), American National Standards Institute (ANSI), Steel Founders Society of America (SFSA), American Society of Mechanical Engineers (ASME), American Welding Society (AWS), Aluminum Association, Copper Development Association, U.S. Department of Defense (Military Specifications), and the General Accounting Office (Federal Specifications).

Did you know the 12th edition of the UNS contains over 5,600 designations, 4,100 specification cross references, and 15,350 trade names?



The Unified Numbering System (UNS) was developed through a joint effort of the ASTM and the SAE to provide a means of correlating the different numbering systems for metals and alloys that have a commercial standing. This system avoids the confusion caused when more than one identification number is used to specify the same material, or when the same number is assigned to two entirely different materials. It is important to understand that a UNS number is not a specification; it is an identification number for metals and alloys for which detailed specifications are provided elsewhere. Each number consists of a letter prefix followed by five digits. In some instances, the letter is suggestive of the family of metals identified by the series, such as "A" for aluminum and "C" for copper. Whenever possible, the numbers in the UNS groups contain numbering sequences taken directly from other systems to facilitate identification of the material; e.g., the corresponding UNS number for AISI 1020 steel is G10200.

Carbon Steels

Carbon steel is steel that has properties made up mostly of the element carbon, and relies upon carbon content for its structure. The hardest carbon structure in the world is a diamond, which is 100% carbon. Carbon is present in all steel and is the principal hardening element that determines the level of hardness or strength attainable by quenching. It raises tensile strength, hardness, and resistance to wear and abrasion as the carbon content of steel is increased. However, it can also lower ductility, toughness, and machinability.

Cold-drawn carbon steel is typically numbered with the prefix "10" in the AISI numbering system, followed by two numbers that represent the nominal percentage of carbon in the product (up to 1.00%). For example, 1018 has 0.18% carbon, while 1045 has 0.45%.

Carbon adds hardness to the material improving its wearability. For carbon contents above 0.30%, the product may be direct hardened ("through hardened"). Carbon steel below this level typically requires carburizing when heat treated. During carburization carbon molecules are introduced so that a hardened "skin" develops on the surface, creating a "case." This is where the concept of case hardening is found. *See "Direct Hardening vs. Indirect Hardening, page 51.*

Carbon is maximized under 1.00% of steel because higher levels cause the material to become brittle. The higher the carbon content, the more difficult carbon steel is to machine.

In the same way that salt lowers the temperature at which water changes phases, carbon lowers the temperature at which iron changes phases.

Four-digit AISI Alloy Numbering System

Note: Alloying elements are in weight percent, "xx" denotes carbon content.

10xx	Basic plain carbon steels
11xx	Plain carbon steel with high sulfur & low phosphorous (resulferized)
12xx	Plain carbon steel with high sulfur & high phosphorous
13xx	1.75 manganese
23xx	3.50 nickel (series deleted in 1959)
25xx	5.00 nickel (series deleted in 1959)
31xx	1.25 nickel & 0.60 chromium (series deleted in 1964)
33xx	3.50 nickel & 1.50 chromium (series deleted in 1964)
40xx	0.20 – 0.25 molybdenum
41xx	0.50 – 0.95 chromium & 0.12 – 0.30 molybdenum
43xx	1.83 nickel, 0.50 – 0.80 chromium & 0.25 molybdenum
44xx	0.53 molybdenum
46xx	0.85 or 1.83 nickel & 0.23 molybdenum
47xx	1.05 nickel, 0.45 chromium & 0.20 – 0.35 molybdenum
48xx	3.50 nickel, & 0.25 molybdenum
50xx	0.40 chromium
51xx	0.80 – 1.00 chromium
5xxx	1.04 carbon & 1.03 or 1.45 chromium
61xx	0.60 or 0.95 chromium & 0.13 – 0.15 vanadium
86xx	0.55 nickel, 0.50 chromium & 0.20 molybdenum
87xx	0.55 nickel, 0.50 chromium & 0.25 molybdenum
88xx	0.55 nickel, 0.50 chromium & 0.35 molybdenum
92xx	2.00 silicon

Alloy Steels

Alloy steels are derivatives of carbon steels where elements are added or deleted to yield certain properties. Typically these properties include machinability, wearability, and strength. An iron-based mixture is considered to be an alloy steel when manganese is greater than 0.165%, silicon over 0.5%, copper above 0.6%, or other minimum quantities of alloying elements such as chromium, nickel, molybdenum, or tungsten are present.

Iron alloys are the most common ferrous alloy. Steel is a solid solution of iron and carbon. The carbon is dissolved in the iron – iron is the solvent and carbon is the solute.

Steel, like water, can go through phase changes. With water, the phases are solid, liquid, and gas. With carbon steel the phases are liquid, austenite, and ferrite. If salt is added to water, the transition temperature between phases is shifted. This is why salt is a common ice melt compound. Salt will lower the transition temperature from solid to liquid, but raises the transition temperature from liquid to gas. When carbon is added to iron, the temperatures are altered in the same way. The more carbon that is added (to a point), the lower the temperature at which the phase change will occur. Carbon also creates new phases that don't exist in iron by itself. Pearlite is a mixture of cementite (Fe_3C) plus ferrite. The most carbon that can be dissolved in austenite is 0.80%. This is called "eutectic." Other alloys can be described as being eutectic alloys. These alloys have the maximum amount of the alloying elements that can be dissolved into the parent material. It is important to note that the thermal history of a piece also plays a role in its phase development.

For most low-alloy and carbon steels the more carbon you add (above 0.20%), the more pearlite you get, up to 0.80%. Above 0.80%, you get carbides. If a steel has less than 0.20% carbon, all you can get is ferrite. If a steel has 0.40% carbon, you get pearlite and ferrite. If a steel has 0.90% carbon, you get pearlite and carbides. *See "Steel Phases" illustration, page 27.*

To know the chemistry of a steel by knowing its grade, remember the following rules: plain carbon steels are 10xx grades. 10 is plain carbon, and the next two numbers are the carbon content. All 10 grades also have manganese, phosphorus, and silicon. The last two numbers of ALL grades designate the carbon content. If a grade is 12L14 or 10B21, the L means it contains lead for machinability, and the B means it has boron for increased hardenability. If you know the chemistry of the alloy, you will know its hardness, strengths, and if a thermal treatment will work at all.

Chemical Comparison of 4140 Chrome and 8630 Nickel

	4140 Chrome	8630 Nickel
Carbon – C	0.38% – 0.43%	0.25% – 0.35%
Manganese – Mn	0.75% – 1.00%	0.65% – 0.85%
Silicon – Si	0.035%	0.30%
Phosphorus – P	0.04%	0.04%
Sulfur – S	0.15% – 0.35%	0.04%
Chromium – Cr	0.8% – 1.10%	0.40% – 0.70%
Nickel – Ni	---	0.40% – 0.70%
Molybdenum – Mo	---	0.20% – 0.30%
Other	---	---

Common Carbon Steels and Steel Alloys

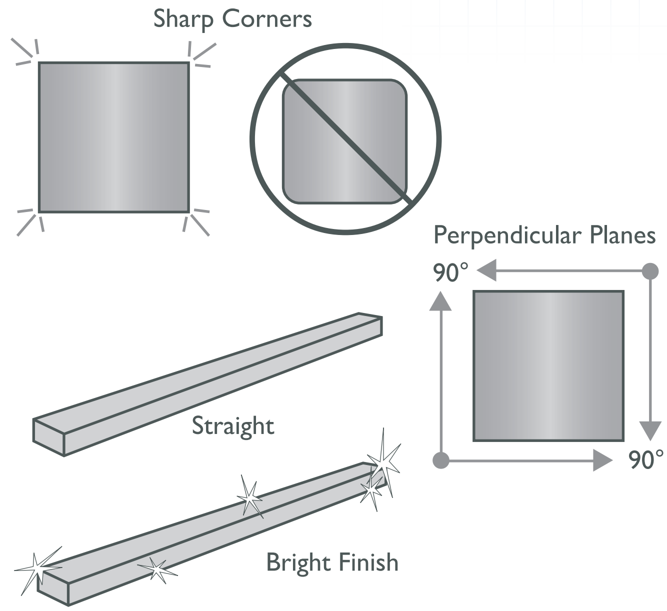
One of the more common alloys is 1144, a carbon steel in which alloying elements enhance machining. StressProof™, a product of LaSalle Steel, is an example of 1144 alloy with good machinability and hardenability features that possesses high strength and can be through hardened.

Chrome alloy steels, such as 4130, 4140, and 4340 are so named because chromium content is high (around 1.00%), and is the primary alloying element. Chrome alloy steels begin with a "40" prefix and end in two numbers that account for the nominal percentage of carbon. For example, 4140 has 0.40% of carbon and 1.00% chromium.

Nickel alloy steels substitute nickel in place of roughly half of the standard chromium content for chrome alloys. For example, whereas 4140 has 0.00% nickel and1.00% chromium, 8630 has 0.60% nickel and 0.50% chromium. These alloys begin with an "80" prefix.

It is difficult to make mechanical comparisons between chrome alloys and nickel alloys as they are similar but unique to a grade. Nickel alloys can be drawn to a more precise finish size and, therefore, are more common in end use steels such as keystock.

CHARACTERISTICS OF BRIGHT STEELS



Bright Steels must have perpendicular planes, sharp corners, and parallel sides. Quite often they have been blasted to a bright finish.

Bright Steels

Bright steels typically refer to a class of cold-finished square and rectangle bars that are drawn to more exacting tolerances; they possess sharp corners, perpendicular and parallel sides, and may be bead blasted to make them "bright." Bright steels are also known as keystock.

The definitions of keystock and barstock have been elusive because no single standard exists. ANSI sets forth two classes of cold-drawn steel. Many users of keystock use these specifications in their own product designs, which has led to two problems. First, because ANSI does not specify a grade, there is confusion. Second, most American mills will not produce to the Class 2 fit because the tolerance is too low compared to other cold-finished forms, and the draw is overly technical. As a result, there is often a difference between what customers want and what is available. Most technicians refer to "barstock" or "key barstock" as cold-finished material drawn from market-ready grades to market-ready tolerances; whereas, "keystock" refers to barstock carefully drawn to ANSI Class 2 fits. *See "ANSI Keystock Tolerance Specifications" table, page 26.*

Keystock squares and rectangles are more difficult to draw than rounds because of the 90° angled corners. Bars must be straight and true, and the width must be in a perpendicular plane with the height. The surface finish of keystock must be free of pits and stresses so that installation is smooth and efficient. Most customers prefer sharp corners for increased keyway contact (and minimal rocking), but edges must be sufficiently deburred for ease of use.

G.L. Huyett has pioneered the development of new cold-drawing technologies. Working in concert with steel mills in both the U.S. and abroad, G.L. Huyett has put together the most comprehensive line of keystock steel anywhere in the world.

ANSI Keystock Tolerance Specifications

ANSI B17.1-1967 (R1998)	Type of Key	Key Width (In.)		Tolerance
		Over	To (incl.)	
Class 1: A clearance or metal-to-metal side fit obtained by using barstock keys and keyseat tolerances.	Square	---	1/2	+0.000 -0.002
		1/2	3/4	+0.000 -0.002
		3/4	1	+0.000 -0.003
		1	1-1/2	+0.000 -0.003
		1-1/2	2-1/2	+0.000 -0.004
		2-1/2	3-1/2	+0.000 -0.006
Class 2: A side fit, with possible interference or clearance, obtained by using keystock and keyseat tolerances.	Parallel Square	---	1-1/4	+0.001 -0.000
		1-1/4	3	+0.002 -0.000
		3	3-1/2	+0.003 -0.000

Stainless Steels

Stainless steel, also referred to as corrosion-resistant steel (CRES), is defined as a steel alloy that has a minimum of 11.5% chromium by mass. Carbon steel rusts when exposed to air and moisture. Iron oxide (the product of rusting) is unsightly and can weaken the structural strength of steel over time. The presence of chromium stimulates the formation of chromium oxide, which prevents surface corrosion.

There are numerous grades of stainless steel which divide into four major groups: austenitic general purpose stainless steel (100 series), austenitic chromium/nickel/manganese alloys (200 series), austenitic chromium/nickel alloys (300 series), and ferritic and martensitic chromium alloys (400 series). (The SAE steel grades system includes the 500 & 600 series also, but these are infrequently used.)

Austenitic, or 300 series, account for roughly three-fourths of stainless steel production. Austenitic stainless steels contain a maximum of 0.15% carbon and a minimum of 0.16% chromium, with added nickel or manganese. The nickel and manganese retain what is known as an austenitic structure which stabilizes iron, and, therefore, inhibits the formation of iron oxide. *See "Chapter 5: Heat Treatment" for additional information on austenite, page 48*.

304 stainless steel, also known as 18/8, a common austenitic stainless steel term, refers to steel containing 18.00% chromium and 8.00% nickel. 304 stainless steel and 316 stainless steel, which has added molybdenum, is used to avoid corrosion problems stimulated by welding. Nickel is an expensive compound, so other major grades of stainless have been created.

Ferritic stainless steels have better engineering properties, but reduced corrosion resistance due to lower chromium and nickel content. They are also less expensive. Martensitic stainless steels are even less corrosion resistant, containing chromium (12.00–14.00%), and higher carbon and manganese. Martensitic stainless steels are harder and can be heat treated, but are also magnetic.

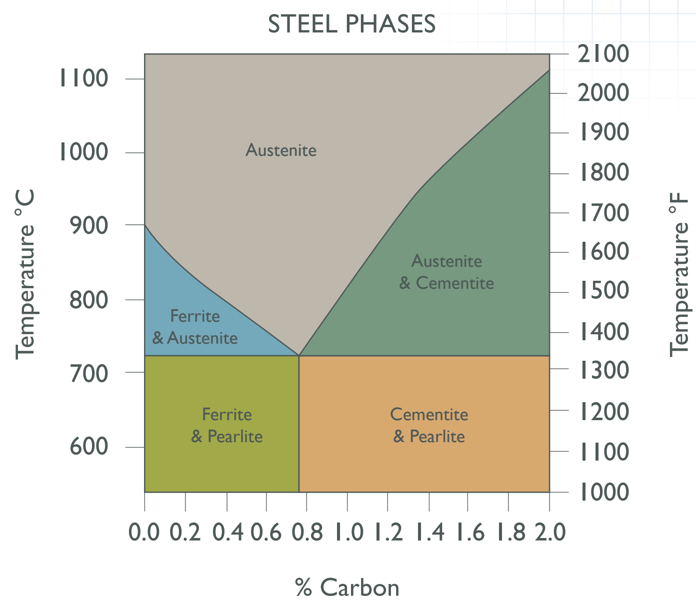
Precipitation-hardened martensitic steels have less corrosion resistance than austenitic steels, but by using precipitation hardening can be made even harder and stronger than standard martensitic varieties. *See "Common Grades of Stainless Steels" on page 29.*

Internationally, stainless steel has two commonly used looser designations that are used in DIN specifications, not only for shaft keys, but also for all fastener categories. A2 refers to 300 series stainless such as AISI 303. A4 is a high nickel content, referencing AISI 316. For example, "DIN 6885A A4" refers to a full radiused machine key (both ends round), made from 316 (A4) stainless steel.

Tool Steels

Tool steels are primarily used to make tools used in manufacturing and in trade professions to work and form metals, wood, plastics, and other industrial materials. Tools must withstand high specific loads – often concentrated at exposed areas. In addition, they may have to operate at elevated or rapidly changing temperatures, be in continual contact with abrasive types of work materials, be subjected to frequent shocks, or perform under other varieties of adverse conditions. Nevertheless, when employed under circumstances that are regarded as normal operating conditions, the tool should not suffer major damage, untimely wear resulting in the dulling of the edges, or be susceptible to detrimental metallurgical changes.

Tools for less demanding uses, such as ordinary hand tools, including hammers, chisels, files, mining bits, etc., are often made of standard



Steel changes phases as it is being heated. The phase is determined by the percent of carbon in the alloy and its current temperature.

AISI steels that are not considered as belonging to any of the tool steel categories. The steel for most types of tools must be used in a heat-treated state, hardened and tempered, to provide the properties needed for a particular application. Tool steels must also be adaptable to heat treatment with a minimum of harmful effects while maintaining beneficial changes in material properties.

To meet such varied requirements, steel types of different chemical composition, often produced by special metallurgical processes, have been developed. Due to the large number of tool steel types produced by steel mills, under their own proprietary designations, it can be difficult for the user to select those types that are most suitable for any specific application, unless the recommendations of a particular steel producer or producers are obtained. ■

COMMON GRADES OF STEELS AND ALLOYS

The following information should be considered only as a basic guideline; the data should not be considered as absolute. For specific applications, proper testing is required. The hardness of a metal is determined by its resistance to deformation, indentation, or scratching. Rockwell hardness is the most common measure of a metal's hardness. Soft steels are usually measured using the Rockwell B scale while harder steels and deep case hardened steels are usually measured on the Rockwell C scale. In some cases, one object may fall within more than one scale. For example, a typical steel spring has a Rockwell hardness of 110 on the B scale and 38 on the C scale. In addition, several factors, including the size of the piece, can affect the hardness rating. *See "Chapter 7: Hardness Tests," page 68.*

Yield strength is the amount of pressure a material will accept before becoming permanently deformed. *See "Chapter 4: Mechanical Properties," page 36.*

1018

Heat treating in contact with carbon (carburizing) hardens the surface of this low-carbon steel. It is easy to cold-form, bend, braze, and weld. Rockwell hardness is B71. Melting point is 2800°F. Yield strength is 53,700 psi. It is commonly used in shafts, spindles, pins, rods, sprockets, and component parts such as clevis pins, straight pins, machine keys, and keystock.

1045

This medium-carbon steel is stronger than 1018 and is slightly more difficult to machine and weld. Rockwell hardness is B84. Melting point is 2800°F. Yield strength is 45,000 psi. It is used in gears, shafts, axles, bolts, studs, clevis pins, machine keys, and keystock.

A36

General purpose carbon steel is suitable for welding and mechanical fastening. Rockwell hardness is B68. Melting point is 2000°F. Yield strength is 36,000 psi. This is used primarily for structural and commercial grade steel.

12L14

A low-carbon steel that has excellent machining characteristics and good ductility that makes it easy to bend, crimp, and rivet. It is very difficult to weld and cannot be case hardened. Rockwell hardness is B75 – B90. Melting point is 2800°F. Yield strength is 60,000 – 80,000 psi. This grade can be used for grease fittings, clevis pins, and custom pins.

1144

A medium-carbon, resulferized steel with free-machining qualities. 1144 steel heat treats better than 1045 steel. Stress relieving allows it to obtain maximum ductility with minimum warping. Rockwell hardness is B97. Melting point is 2750°F. Yield strength is 95,000 psi. This is frequently used in keyed shafts, clevis pins, and detent pins.

4140 Alloy

Also called "chrome-moly" steel. Ideal for forging and heat treating, 4140 alloy is tough, ductile, and wear resistant. Rockwell hardness is B92. Melting point is 2750°F. Yield strength is 60,000 – 75,800 psi. It is the most common steel and is used in virtually all industries and applications. It is also used for clutch keys, clevis pins, and military clevis pins.

4140 ASTM-A193 Grade B7 Alloy

Similar to 4140 alloy, but it is already quenched, tempered, and stress relieved. Maximum Rockwell hardness is C35. It is commonly used for threaded rod.

8630 Alloy

This alloy is tough yet ductile. It responds well to heat treating, exhibits superb core characteristics, and has good weldability and machining properties. Maximum attainable Rockwell hardness is C15. Melting point is 2800°F. Yield strength is 79,800 psi. This grade is frequently used in machine keys, woodruff keys, gear drive keys, and keystock.

COMMON GRADES OF STAINLESS STEELS

Stainless steel is the term used for grades of steel that contain more than 11.00% chromium, with or without other alloying elements. Stainless steel resists corrosion, maintains its strength at high tolerances, and is easily maintained. It is used predominately in the automotive, aerospace, and construction industries.

302
A common heat-resisting stainless steel, 302 is austenitic, non-magnetic, extremely tough, and ductile. Cold-working will dramatically increase its hardness. It is amenable to stamping, spinning, and wire forming. 302 is commonly used for washers, springs, screens, and cables. It can be found in bridge pins, spring pins, and spiral rings.

303
303 is a popular free machining stainless steel providing excellent speed and feed capabilities. 303 is used extensively in the screw and machining industries to make hardware, fasteners such as lock nuts, valve parts, nozzles, and trim. It can also be used for keyed shafts, pins, and grease fittings.

304
Originally known as 18-8, 304 is the most commonly specified austenitic (chromium-nickel stainless class) stainless steel, accounting for more than half of the stainless steel produced in the world. This grade withstands ordinary corrosion in architecture, is durable in typical food processing environments, and resists most chemicals. 304 is available in virtually all product forms and finishes and is used for cookware, appliances, sinks, and tabletops. It can be found in bridge pins, thread inserts, hose clamps, and spring pins.

316
Austenitic (chromium-nickel stainless class) stainless steel containing 2.00% – 3.00% molybdenum (whereas 304 has none). The inclusion of molybdenum gives 316 greater resistance to various forms of deterioration. It is well-suited for extreme situations such as laboratory equipment, chloride environments, and sub-zero temperatures. 316 is frequently used for chemical, food, paper, mining, pharmaceutical, and petroleum equipment. It is one of the most common stainless steels and can be found in most types of pins, hose clamps, keyed shafts, threaded rod, machine keys, and keystock.

410
The most widely used martensitic (plain chromium stainless class with exceptional strength) stainless steel, featuring the high-level of strength conferred by martensitic steels. It is a low-cost, heat treatable grade suitable for non-severe corrosion applications. It is used for cutlery, turbine blades, bushings, valve components, fasteners, screens, kitchen utensils, and spring pins.

416
This was one of the first free machining stainless steels. It has excellent machinability and non-galling characteristics and is magnetic. It is used for nuts, bolts, screws, gears, and pinions, valve trim, shafts, axles, dowel pins, and keystock.

COMMON GRADES OF TOOL STEELS

W1 (Water-Hardened Steel)
This water-quenched steel heat treats evenly and provides good toughness and maximum wear resistance. High-carbon content and fine grain structure make it ideal for general use, even without heat treating. Maximum attainable Rockwell hardness is C57 – C60. Melting point is 2800°F. Yield strength is 55,000-100,000 psi. W1 is used for hand-operated metal cutting tools, cold-heading, embossing taps, reamers, cutlery, drill rod, high strength machine keys, and ground flat stock.

O1 (Oil-Hardened Steel)
A non-shrinking, general purpose tool steel with good abrasion resistance, toughness, and machinability. It is extremely stable with minimal deformation after hardening and tempering. Rockwell hardness is C57 – C62. Melting point is 2800°F. Yield strength is 50,000 – 99,000 psi. O1 is used for blanking dies, cold-forming dies, room temperature cutting tools, drill rod, and ground flat stock.

M2 (High-Speed Steel)
This steel resists softening when heated, maintaining a sharp cutting edge. It is easy to heat treat and has minimal loss of carbon (decarburization) after heat treating. Rockwell hardness is C65. Melting point is 2580°F. Yield strength is 105,000 psi. M2 is used primarily for cutting tools.

A2 (Air-Hardened Steel)
Made of a very fine grain structure, this steel has excellent abrasion and wear resistance. Ideal for thin parts that are prone to cracking during heat treating. Supplied in non-resulferized condition. Rockwell hardness is C62 – C65. Melting point is 2620°F. Yield strength is 108,000 psi. Used in situations where wear resistance is critical such as die shapes, slitters, and machine keys.

D2 (High-Chrome Air-Hardened Steel)
The high chromium and carbon content in this steel provides superior wear resistance and toughness. A low sulfur content makes it difficult to machine. Rockwell hardness is C62 – C65. Melting point is 2525°F. Yield strength is 111,000 psi. D2 is used for long run tooling such as blanking, forming, and thread rolling dies.

S7 (Shock-Resistant Air-Hardened Steel)
Strong and ductile, this steel is known for its ability to resist failure from shock. It combines high-impact strength with average wear and abrasion resistance. Rockwell hardness is C59 – C61. Melting point is 2640°F. Yield strength is 105,000 psi.

A6 (Low-Temperature Air-Hardened Steel)
This steel should be heat treated at low temperatures (1525°F – 1575°F). It experiences almost no dimensional changes after heat treating. Rockwell hardness is C61 – C62. Melting point is 2600°F. Yield strength is 110,000 psi.

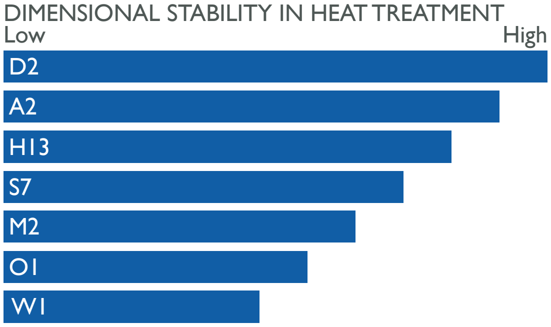
4142
This steel exhibits good wear resistance, toughness, machinability, and high mechanical properties. Prehardened to a Rockwell hardness of C30. Melting point is 2790°F. Yield strength is 130,000 psi. This grade is used for machine keys, keystock, and ground flat stock.

P20
This hardened, general purpose mold steel is suitable for production of machined or electrical discharge machining (EDM) plastic mold and zinc die-casting components. Supplied prehardened to a Rockwell hardness of C32. Melting point is 2790°F. Yield strength is 130,000 psi. P20 is used for die-casting dies and injection molds.

PROPERTIES OF TOOL STEELS

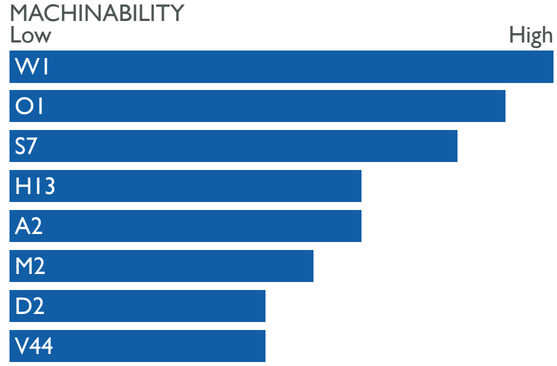
This chart summarizes metallurgical properties of the various grades of tool steel available. The first step in choosing a particular grade is to examine the specific application for the important properties involved. For example, an ejector pin for die-casting requires a top toughness with good wear resistance and hot hardness. The chart indicates H13 as a logical start. If the H13 part wears too rapidly, the next choice will be S7. Another application might involve a part for a short run cold-forming die setup. Considering die life and steel cost, W1 would be the first source. If wear or size change in heat treatment becomes a problem, the next choice will be A2; however, if size change in heat treatment was the only problem then O1 should be tried.

DIMENSIONAL STABILITY IN HEAT TREATMENT

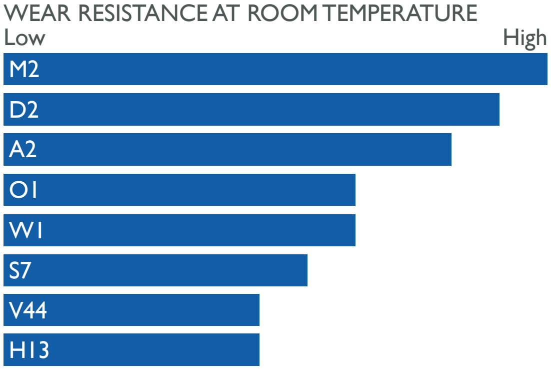


V44 is pre-hardened.

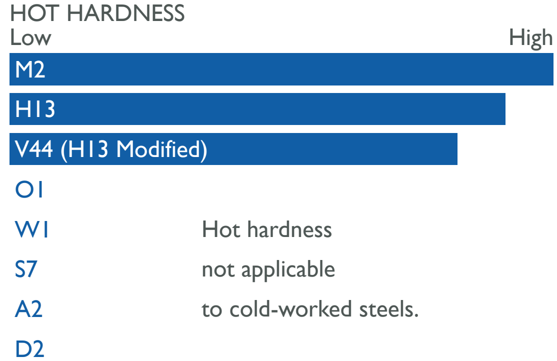
MACHINABILITY



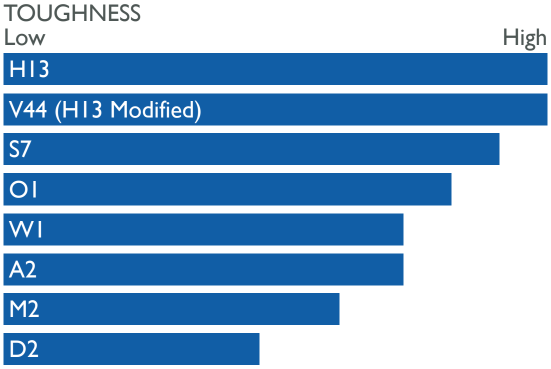
WEAR RESISTANCE AT ROOM TEMPERATURE



HOT HARDNESS



TOUGHNESS



WHAT IS THAT PART MADE FROM?

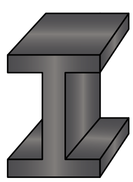
The diversity of steel achieved through various alloying and heating processes is impressive. The physical and mechanical properties are just as broad ranging. Some can withstand incredible temperature shifts while others crack in normal weather conditions. Some can withstand thousands of pounds of stress while others can be bent by hand. Choosing the right steel for the right application is paramount to the success of any engineering design.

Carbon steel is sometimes used to describe any steel that is not stainless steel. However, in its strictest sense, carbon steel is any steel in which the primary alloying element is carbon with no minimum contents of other alloying elements. The more carbon the steel contains the harder and stronger it is; however, it also becomes more brittle. Low-carbon steel is the most common and is used for structural steel because of its low cost and high malleability. Medium-carbon steel balances ductility and strength and is used for large parts, forging, and automotive components. High-carbon steel is very strong and is used for springs and high-strength wires.

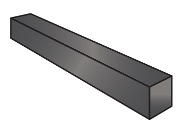
Tool steels, as the name suggests, are used for metal-working tools. They are alloyed to achieve distinctive hardness, abrasion resistant, and heat resistant qualities. Tool steels are used for tooling blanks, knives, axes, stamping dies, and metal-cutting tools.

Despite its name, **stainless steel** is not stain proof. However, it is highly resistant to corrosion and prevents rusting by creating a layer of chromium oxide preventing further surface oxidation. Stainless steel has a wide range of uses including decorative finishes, household hardware, cutlery, surgical instruments, food processing equipment, and jewelry.

Carbon Steel

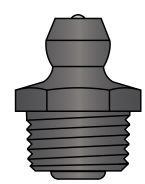


A36
Commercial Grade
Structural Steel

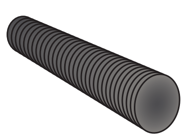


1018
Machine Keys
Keystock

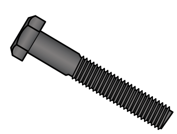
8630
Machine Keys
Keystock



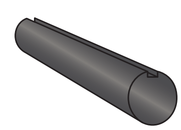
12L14
Grease Fittings



4140
Threaded Rod



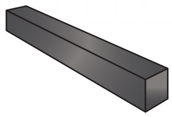
1045
Gears
Shafts
Axles
Bolts
Studs



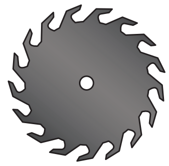
1144
Keyed Shafts

The products and grades shown here are only representative of common usages and not an exhaustive listing.

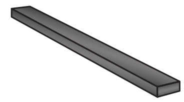
Tool Steel



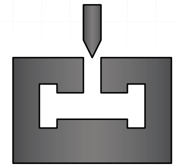
A2
Die Shapes
Machine Keys
Slitters



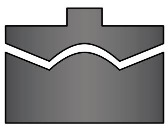
M2
Cutting Tools



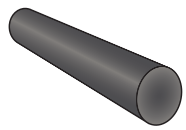
W1
Cutting Tools
Cold Heading
Ground Flat Stock
Embossing Taps
Drill Rod
Reamers



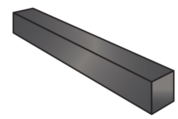
P20
Die-casting Dies
Injection Molds



D2
Blanking Dies
Thread Rolling Dies
Forming Dies

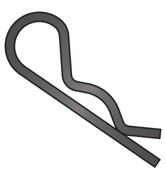


O1
Blanking Dies
Ground Flat Stock
Cutting Tools
Drill Rod

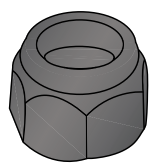


4142
Machine Keys
Ground Flat Stock
Keystock

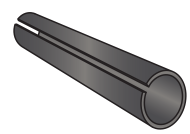
Stainless Steel



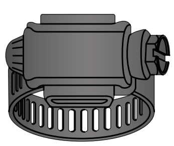
302
Washers
Bridge Pins
Spring Pins
Spiral Rings
Cables



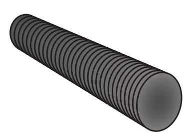
303
Lock Nuts
Valve Parts
Keyed Shafts
Nozzles
Trim



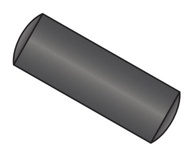
410
Cutlery
Turbine Blades
Fasteners
Bushings



304
Cookware
Appliances
Thread Inserts
Hose Clamps



316
Keyed Shafts
Hose Clamps
Threaded Rod
Machine Keys
Keystock



416
Nuts & Bolts
Screws
Dowel Pins
Keystock
Gears & Pinions
Axles

COMPARISONS OF TOOL STEELS

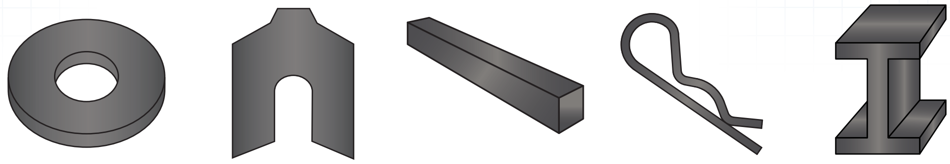
Substantial clarification has resulted from the development of a classification system that is now widely accepted throughout the industry, on the part of both the producers and the users of tool steels. That system is used in the following as a base for providing concise information on tool steel types, their properties, and methods of tool steel selection.

Comparative Properties of Tool Steels

Type	Comparative Properties	Use
O1	Dimensionally stable during hardening with high hardness response in low temperatures. Heat treatable up to HRC* 65.	Tool and die
W1	Also known as commercial carbon for use in general metal working. Used where simple heat treatment is desirable. Maximum HRC 68.	General purpose
A2	Used in place of O1 in applications requiring safer heat treatment, less distortion, and greater wear resistance. Maximum HRC 63.	Machining to finish job
D2	Offers better wear resistance and higher compressive strength than A2. Good for long duration runs. Maximum HRC 63.	Shock resistant, machine to finish
S7	Used in cold-work tools needing high shock resistance. Good toughness with ease of heat treat and machinability. Maximum HRC 58.	Mold dies
M2	High-speed steel with good abrasion resistance and good toughness. Resists softening at high temperatures. Maximum HRC 65.	High heat environments
H13	Air-hardening material that resists thermal fatigue cracking. Better hardenability and wear resistance than 4140. Maximum HRC 54.	Hot-work die steel
V44	Free machining version of H13 that is prehardened to HRC 42-46.	Prehardened for machine to finish
A8	Air-hardening grade that has higher toughness than D2, and better wear resistance than S7.	Pneumatic tools
1018	Very common cold-forming steel for bending, brazing, welding, and forming. Must be carburized during heat treatment.	Weldable
O6	Oil hardening, non-deforming type tool steel with good resistance to wear and abrasion. Especially suitable for dies and punches in drawing, forming, and shaping operations.	Tool and die
4142	Prehardened to HRC 30. Good wear resistance, toughness, and machinability.	Forging
1144	Medium-carbon resulferized steel with excellent free machining capabilities. Maximum HRC 22.	Free machining

**HRC - Rockwell Hardness C Scale*

APPLICATIONS FOR COMMON GRADES OF STEELS



Grade	Flat Washers	Shims	Machine Keys	Pins	Structural
303			♦	♦	
304	♦	♦	♦		
316	♦		♦		
416			♦		
1008	♦				
1010	♦	♦			
1018	♦		♦	♦	
1026	♦				
1035			♦		
1045	♦		♦	♦	♦
1075		♦			♦
1095		♦	♦		♦
1144				♦	
1215	♦			♦	
2024		♦		♦	
4037				♦	
4130	♦			♦	♦
4140	♦		♦		♦
6061	♦		♦		
8630			♦		
52100	♦			♦	♦
12L14	♦			♦	
A2				♦	♦
A36	♦				
Alloy 20			♦		
C110	♦	♦			
C360		♦	♦		
Ledloy 300				♦	
Monel 400	♦		♦		
O1				♦	♦
Oilite	♦				
SAE 660	♦				
W1				♦	♦

G.L.HUYETT

CHAPTER 4

MECHANICAL PROPERTIES

Comparisons of mechanical properties of metal.

Strength of materials deals with the relations between the external forces applied to steel, and the resulting deformations and stresses. In the design of structures and machines, the application of the principles of strength of materials is necessary if satisfactory steel is to be utilized and adequate proportions obtained to resist functional forces.

Did you know there are three kinds of stress: compressive, tensile, and shearing; and they can occur simultaneously and in cycles?

Forces are produced by the action of gravity, by accelerations and impacts of moving parts, by gases and fluids under pressure, by the transmission of mechanical power, etc. In order to analyze the stresses and deflections of a steel piece, the magnitudes, directions and points of application of forces acting on the piece must be known.

The time element in the application of force on a steel piece is an important consideration. A force may be static or change so slowly that its maximum value can be treated as if it were static; it may be suddenly applied, as with an impact, or it may have a repetitive or cyclic behavior.

The environment in which forces act on a machine or part is also essential. Factors such as high and low temperatures; the presence of corrosive gases, vapors, liquids, radiation, etc. may have a significant impact on how effectively parts are able to resist stresses.

Many mechanical properties of steel are determined from tests that show relationships between stresses and strains. These values can be charted to show specific relationship changes as the values progress.

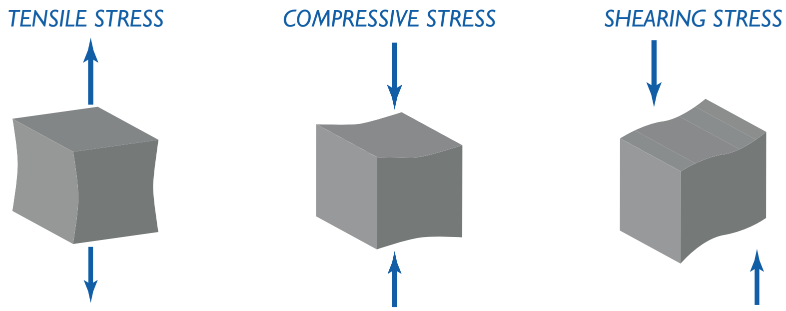
Stress

Stress is defined as the force per unit area and is usually expressed in pounds per square inch (psi). Tensile stress will stretch or lengthen steel. Compressive stress will compress or shorten steel. Shearing stress will break or tear steel into pieces. Tensile and compressive stresses always act at right angles to (normal to) the area being considered; shearing stresses are always in the plane of the area (at right angles to compressive or tensile stresses).

Unit Strain

Unit strain is the amount by which the dimension of steel changes when it is subjected to a load, divided by the original value of the dimension. The simpler term “strain” is often used instead of unit strain.

TYPES OF STRESS



Tensile stress pulls apart, compressive stress pushes together, and shearing stress pushes from opposite sides.

Proportional limit
The point on a stress/strain ratio curve at which it begins to deviate from the straight line relationship between stress and strain. This is a mathematical point and is not directly observable.

Elastic Limit
Elastic limit is the maximum stress to which a test specimen may be subjected and still return to its original length upon release of the load. Steel is said to be stressed within the elastic region when the working stress does not exceed the elastic limit, and to be stressed in the plastic region when the working stress exceeds the elastic limit. The elastic limit for steel is for all practical purposes the same as its proportional limit.

Yield

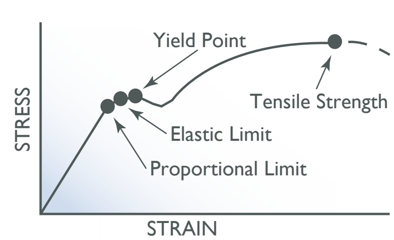
Yield Point
Yield point is a point on a stress/strain curve at which there is a sudden increase in strain without a corresponding increase in stress. Not all materials have a yield point.

Yield Strength
Yield strength is the maximum stress that can be applied without permanent deformation of the test specimen. This is the value of the stress at the elastic limit for materials for which there is an elastic limit. Because of the difficulty in determining the elastic limit, yield strength is often determined by the stress value on the stress/strain curve corresponding to a definite amount of permanent set or strain, usually 0.1 – 0.2% of the original dimension.

Tensile Strength
Tensile strength (also called ultimate strength) is the maximum stress value obtained on a stress/strain curve.

Shear Properties
The properties of shear yield strength are determined by direct shear and torsional tests. Single shear strength is the amount of force applied against the side of an object in one place causing it to break into two pieces. Double shear strength is the amount of force applied against the side of an object in two places causing is to break into three pieces. *See "Testing and Measuring Shear Strength," page 38.*

STRESS/STRAIN RATIO CURVE



Typical stress/strain ratio curve.

Fatigue

When steel is subjected to many cycles of stress reversal or fluctuation (variation in magnitude without reversal), failure may occur, even though the maximum stress at any cycle is considerably less than the value at which failure would occur if the stress were constant. Fatigue properties are determined by subjecting test specimens to stress cycles and counting the number of cycles to failure.

Fatigue failure is the result of a repeated cyclic stress or strain. Creep failure is the result of plastic flow of a material at high temperatures.

Ductility

Ductility is the ability of steel to undergo permanent changes in shape without fracturing at room temperature. Brittleness is the opposite of ductility.

Mechanical properties of metal are tested using fixtures and gauges for this purpose. Yield strength, tensile strength, and elongation are tested using a fixture that pulls a sample apart. *See "Testing and Measuring Tensile Strength," page 39.*

Shear strength is expressed as either single shear or double shear depending on the engineering application and the test used. *See "Testing and Measuring Shear Strength," below.*

Modes of Fatigue Failure

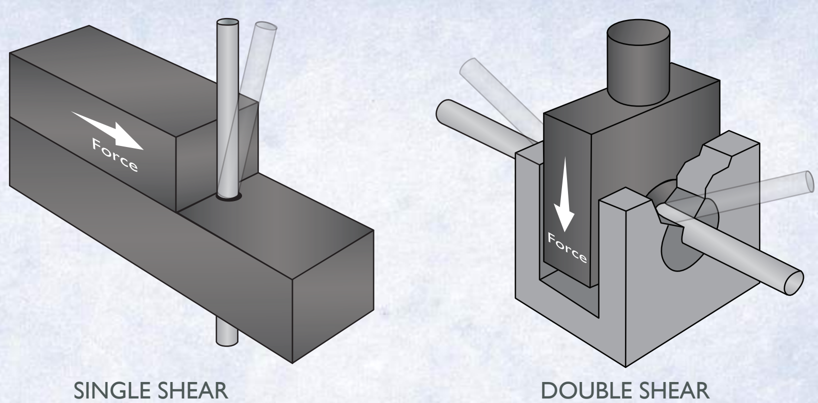
Fatigue is tested on fixtures that are unique to the application. These tests should account for all modes of failure, including thermal causes and the presence of corrosive elements. Several modes of fatigue failure are:

Low/High-Cycle Fatigue

This fatigue process covers cyclic loading in two significantly different domains with different physical mechanisms of failure. One domain, known as "high-cycle fatigue" is characterized by relatively low cyclic loads, strain cycles confined largely to the elastic range, and long lives or a high number of cycles to failure.

The other domain, known as "low-cycle fatigue" or cyclic strain-controlled fatigue, has cyclic loads that are relatively high, significant

Testing and Measuring Shear Strength



Shear strength is tested by measuring the force necessary to slice a sample into two pieces for single shear, or three pieces for double shear. In a single shear test the workpiece is supported on only one end whereas in a double shear test the workpiece is supported from both ends which requires greater force to break a middle piece free. Both tests result in strength ratings that categorize the metal.

amounts of plastic strain induced during each cycle, and short lives or a low number of cycles to failure.

The transition from low- to high-cycle fatigue behavior occurs in the range from approximately 10,000 to 100,000 cycles. Typical low-cycle fatigue is defined as failure that occurs in 50,000 cycles or less.

Thermal Fatigue

Cyclic temperature changes in a machine part will produce cyclic stresses and strains if natural thermal expansions and contractions are either wholly or partially constrained. These cyclic strains produce fatigue failure just as though they were produced by external mechanical loading. When strain cycling is produced by a fluctuating temperature field, the failure process is termed “thermal fatigue.”

Corrosion Fatigue

Corrosion fatigue is a failure mode where cyclic stresses and a corrosion producing environment combine to initiate and propagate cracks in fewer stress cycles and at lower stress amplitudes than would be required in a more inert environment. The corrosion process forms pits and surface discontinuities that act as stress raisers to accelerate fatigue cracking. The cyclic loads may also cause cracking and flaking of the corrosion layer, baring fresh metal to the corrosive environment. Each process accelerates the other, making the cumulative result more serious.

Surface or Contact Fatigue

Surface fatigue failure is usually associated with rolling surfaces in contact, and results in pitting, cracking, and spalling of the contacting surfaces from cyclic contact stresses that cause shear stresses to be slightly below the surface. The cyclic subsurface shear stresses generate cracks that propagate to the contacting surface, dislodging particles in the process.

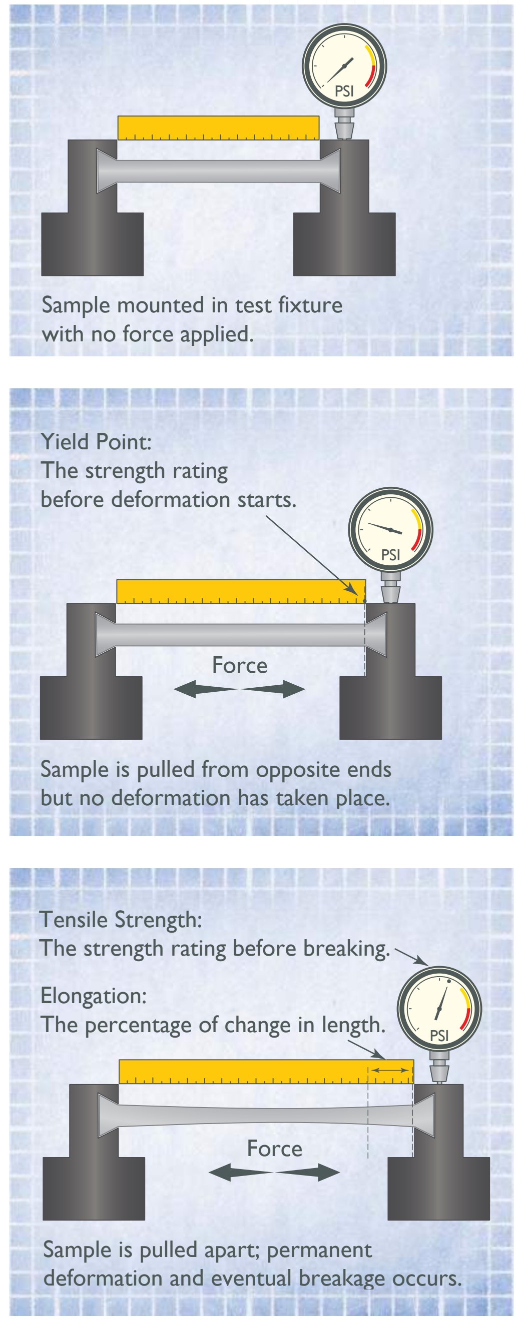
Creep Failure

Unlike fatigue failure, creep failure is the result of strain developing from long-term stress. A solid material can imperceptibly flow or deform when subjected to high temperatures or stresses over a long period. Common examples of creep are the visible distortions in antique glass, the slow movement of glaciers, and the filament pulling apart in household light bulbs.

Combined Creep and Fatigue

In this failure mode, all of the conditions for both creep failure and fatigue failure exist simultaneously. Each process influences the other in producing failure, but this interaction is not well understood. ■

Testing and Measuring Tensile Strength



A test sample is tooled to have large shoulders on the ends which are used by the testing apparatus to pull the sample apart to breaking. The point just before deformation begins is the yield point. Tensile strength is how much force it takes to stretch the sample before breaking. Elongation is how far it stretches as a percentage of change.

Expected Minimum Mechanical Properties of Cold-drawn Carbon Steel Rounds, Squares, and Hexagons

Size (″)	As cold-drawn					Cold-drawn followed by low temperature stress relief					Cold-drawn followed by high temperature stress relief				
	Strength (psi) Tensile	Strength (psi) Yield	Elongation in sq in (%)	Reduction in area (%)	Hardness (BHN)	Strength (psi) Tensile	Strength (psi) Yield	Elongation in sq in (%)	Reduction in area (%)	Hardness (BHN)	Strength (psi) Tensile	Strength (psi) Yield	Elongation in sq in (%)	Reduction in area (%)	Hardness (BHN)
AISI 1018 and 1025 Steels															
5/8 – 7/8	70,000	60,000	18	40	143	---	---	---	---	---	65,000	45,000	20	45	131
Over 7/8 – 1-1/4	65,000	55,000	16	40	131	---	---	---	---	---	60,000	45,000	20	45	121
Over 1-1/4 – 2	60,000	50,000	15	35	121	---	---	---	---	---	55,000	45,000	16	40	111
Over 2 – 3	55,000	45,000	15	35	111	---	---	---	---	---	50,000	40,000	15	40	101
AISI 1117 and 1118 Steels															
5/8 – 7/8	75,000	65,000	15	40	149	80,000	70,000	15	40	163	70,000	50,000	18	45	143
Over 7/8 – 1-1/4	70,000	60,000	15	40	143	75,000	65,000	15	40	149	65,000	50,000	16	45	131
Over 1-1/4 – 2	65,000	55,000	13	35	131	70,000	60,000	13	35	143	60,000	50,000	15	40	121
Over 2 – 3	60,000	50,000	12	30	121	65,000	55,000	12	35	131	55,000	45,000	15	40	111
AISI 1035 Steel															
5/8 – 7/8	85,000	75,000	13	35	170	90,000	80,000	13	35	179	80,000	60,000	16	45	163
Over 7/8 – 1-1/4	80,000	70,000	12	35	163	85,000	75,000	12	35	170	75,000	60,000	15	45	149
Over 1-1/4 – 2	75,000	65,000	12	35	149	80,000	70,000	12	35	163	70,000	60,000	15	40	143
Over 2 – 3	70,000	60,000	10	30	143	75,000	65,000	10	30	149	65,000	55,000	12	35	131
AISI 1045, 1145, and 1146 Steels															
5/8 – 7/8	95,000	85,000	12	35	187	100,000	90,000	12	35	197	90,000	70,000	15	45	179
Over 7/8 – 1-1/4	90,000	80,000	11	30	179	95,000	85,000	11	30	187	85,000	70,000	15	45	170
Over 1-1/4 – 2	85,000	75,000	10	30	170	90,000	80,000	10	30	179	80,000	65,000	15	40	163
Over 2 – 3	80,000	70,000	10	30	163	85,000	75,000	10	25	170	75,000	60,000	12	35	149
AISI 1050, 1137, and 1151 Steels															
5/8 – 7/8	100,000	90,000	11	35	197	105,000	95,000	11	35	212	95,000	75,000	15	45	187
Over 7/8 – 1-1/4	95,000	85,000	11	30	187	100,000	90,000	11	30	197	90,000	75,000	15	40	179
Over 1-1/4 – 2	90,000	80,000	10	30	179	95,000	85,000	10	30	187	85,000	70,000	15	40	170
Over 2 – 3	85,000	75,000	10	30	170	90,000	80,000	10	25	179	80,000	65,000	12	35	163
AISI 1144 Steel															
5/8 – 7/8	110,000	100,000	10	30	223	115,000	105,000	10	30	229	105,000	85,000	15	40	212
Over 7/8 – 1-1/4	105,000	95,000	10	30	212	110,000	100,000	10	30	223	100,000	85,000	15	40	197
Over 1-1/4 – 2	100,000	90,000	10	25	197	105,000	95,000	10	25	212	95,000	80,000	15	35	187
Over 2 – 3	95,000	85,000	10	20	187	100,000	90,000	10	20	197	90,000	75,000	12	30	179

Source: Machinery's Handbook, 26 ed.

Typical Mechanical Properties of Selected Hot-Rolled, Normalized, and Annealed Carbon and Alloy Steels

AISI No.[a]	Treatment	Strength (psi)		Elongation (%)	Reduction in Area (%)	Hardness (BHN)	Impact Strength, Izod (ft/lb)
		Tensile	Yield				
1015	As Rolled	61,000	45,500	39.0	61.0	126	81.5
	Normalized (1700°F)	61,500	47,000	37.0	69.6	121	85.2
	Annealed (1600°F)	56,000	41,250	37.0	69.7	111	84.8
1020	As Rolled	65,000	48,000	36.0	59.0	143	64.0
	Normalized (1600°F)	64,000	50,250	35.8	67.9	131	86.8
	Annealed (1600°F)	57,250	42,750	36.5	66.0	111	91.0
1022	As Rolled	73,000	52,000	35.0	67.0	149	60.0
	Normalized (1700°F)	70,000	52,000	34.0	67.5	143	86.5
	Annealed (1600°F)	65,250	46,000	35.0	63.6	137	89.0
1030	As Rolled	8,0000	50,000	32.0	57.0	179	55.0
	Normalized (1700°F)	75,000	50,000	32.0	60.8	149	69.0
	Annealed (1550°F)	67,250	49,500	31.2	57.9	126	51.2
1040	As Rolled	90,000	60,000	25.0	50.0	201	36.0
	Normalized (1650°F)	85,500	54,250	28.0	54.9	170	48.0
	Annealed (1450°F)	75,250	51,250	30.2	57.2	149	32.7
1050	As Rolled	105,000	60,000	20.0	40.0	229	23.0
	Normalized (1650°F)	108,500	62,000	20.0	39.4	217	20.0
	Annealed (1450°F)	92,250	53,000	23.7	39.9	187	12.5
1060	As Rolled	118,000	70,000	17.0	34.0	241	13.0
	Normalized (1650°F)	112,500	61,000	18.0	37.2	229	9.7
	Annealed (1450°F)	90,750	54,000	22.5	38.2	179	8.3
1080	As Rolled	140,000	85,000	12.0	17.0	293	5.0
	Normalized (1650°F)	146,500	76,000	11.0	20.6	293	5.0
	Annealed (1450°F)	89,250	54,500	24.7	45.0	174	4.5
1095	As Rolled	140,000	83,000	9.0	18.0	293	3.0
	Normalized (1650°F)	147,000	72,500	9.5	13.5	293	4.0
	Annealed (1450°F)	95,250	55,000	13.0	20.6	192	2.0
1117	As Rolled	70,600	44,300	33.0	63.0	143	60.0
	Normalized (1650°F)	67,750	44,000	33.5	63.8	137	62.8
	Annealed (1575°F)	62,250	40,500	32.8	58.0	121	69.0
1118	As Rolled	75,600	45,900	32.0	70.0	149	80.0
	Normalized (1700°F)	69,250	46,250	33.5	65.9	143	76.3
	Annealed (1450°F)	65,250	41,250	34.5	66.8	131	78.5
1137	As Rolled	91,000	55,000	28.0	61.0	192	61.0
	Normalized (1650°F)	97,000	57,500	22.5	48.5	197	47.0
	Annealed (1450°F)	84,750	50,000	26.8	53.9	174	36.8

Table continued on next page.

Typical Mechanical Properties of Selected Hot-Rolled, Normalized, and Annealed Carbon and Alloy Steels (cont.)

AISI No.[a]	Treatment	Strength (psi)		Elongation (%)	Reduction in Area (%)	Hardness (BHN)	Impact Strength, Izod (ft/lb)
		Tensile	Yield				
1141	As Rolled	98,000	52,000	22.0	38.0	192	8.2
	Normalized (1650°F)	102,500	58,750	22.7	55.5	201	38.8
	Annealed (1500°F)	86,800	51,200	25.5	49.3	163	25.3
1144	As Rolled	102,000	61,000	21.0	41.0	212	39.0
	Normalized (1650°F)	96,750	58,000	21.0	40.4	197	32.0
	Annealed (1450°F)	84,750	50,250	24.8	41.3	167	48.0
4130	Normalized (1600°F)	97,000	63,250	25.5	59.5	197	63.7
	Annealed (1585°F)	81,250	52,250	28.2	55.6	156	45.5
4140	Normalized (1700°F)	148,000	95,000	17.7	46.8	302	16.7
	Annealed (1600°F)	95,000	60,500	25.7	56.9	197	40.2
4150	Normalized (1600°F)	167,500	106,500	11.7	30.8	321	8.5
	Annealed (1500°F)	105,750	55,000	20.2	40.2	197	18.2
4340	Normalized (1600°F)	185,500	125,000	12.2	36.3	363	11.7
	Annealed (1490°F)	108,000	68,500	22.0	49.9	217	37.7
6150	Normalized (1600°F)	136,250	89,250	21.8	61.0	269	26.2
	Annealed (1500°F)	96,750	59,750	23.0	48.4	197	20.2
8620	Normalized (1675°F)	91,750	51,750	26.3	59.7	183	73.5
	Annealed (1600°F)	77,750	55,875	31.3	62.1	149	82.8
8630	Normalized (1600°F)	94,250	62,250	23.5	53.5	187	69.8
	Annealed (1550°F)	81,750	54,000	29.0	58.9	156	70.2
8650	Normalized (1600°F)	148,500	99,750	14.0	40.4	302	10.0
	Annealed (1465°F)	103,750	56,000	22.5	46.4	212	21.7

Source: Machinery's Handbook, 26 ed.
a) All grades are fine-grained except those in the 1100 series that are coarse-grained. Heat treated specimens were oil quenched unless otherwise indicated. Austenizing temperatures are given in parentheses.

Typical Mechanical Properties of Selected Quenched and Tempered Carbon and Alloy Steels

AISI No.[a]	Tempering Temperature (°F)	Strength		Elongation (%)	Reduction in Area (%)	Hardness (BHN)
		Tensile (psi)	Yield (psi)			
1030[b]	400	123,000	94,000	17	47	495
	600	116,000	90,000	19	53	401
	800	106,000	84,000	23	60	302
	1000	97,000	75,000	28	65	255
	1200	85,000	64,000	32	70	207
1040[b]	400	130,000	96,000	16	45	514
	600	129,000	94,000	18	52	444
	800	122,000	92,000	21	57	352
	1000	113,000	86,000	23	61	269
	1200	97,000	72,000	28	68	201
1040	400	113,000	86,000	19	48	262
	600	113,000	86,000	20	53	255
	800	110,000	80,000	21	54	241
	1000	104,000	71,000	26	57	212
	1200	92,000	63,000	29	65	192
1050[b]	400	163,000	117,000	9	27	514
	600	158,000	115,000	13	36	444
	800	145,000	110,000	19	48	375
	1000	125,000	95,000	23	58	293
	1200	104,000	78,000	28	65	235
1050	400	---	---	---	---	---
	600	142,000	105,000	14	47	321
	800	136,000	95,000	20	50	277
	1000	127,000	84,000	23	53	262
	1200	107,000	68,000	29	60	223
1060	400	160,000	113,000	13	40	321
	600	160,000	113,000	13	40	321
	800	156,000	111,000	14	41	311
	1000	140,000	97,000	17	45	277
	1200	116,000	76,000	23	54	229
1080	400	190,000	142,000	12	35	388
	600	189,000	142,000	12	35	388
	800	187,000	138,000	13	36	375
	1000	164,000	117,000	16	40	321
	1200	129,000	87,000	21	50	255

Table continued on next page.

Typical Mechanical Properties of Selected Quenched and Tempered Carbon & Alloy Steels (cont.)

AISI No.[a]	Tempering Temperature (°F)	Strength		Elongation (%)	Reduction in Area (%)	Hardness (BHN)
		Tensile	Yield			
		(psi)				
1095[b]	400	216,000	152,000	10	31	601
	600	212,000	150,000	11	33	534
	800	199,000	139,000	13	35	388
	1000	165,000	110,000	15	40	293
	1200	122,000	85,000	20	47	235
1095	400	187,000	120,000	10	30	401
	600	183,000	118,000	10	30	375
	800	176,000	112,000	12	32	363
	1000	158,000	98,000	15	37	321
	1200	130,000	80,000	21	47	269
1137	400	157,000	136,000	5	22	352
	600	143,000	122,000	10	33	285
	800	127,000	106,000	15	48	262
	1000	110,000	88,000	24	62	229
	1200	95,000	70,000	28	69	197
1137[b]	400	217,000	169,000	5	17	415
	600	199,000	163,000	9	25	375
	800	160,000	143,000	14	40	311
	1000	120,000	105,000	19	60	262
	1200	94,000	77,000	25	69	187
1141	400	237,000	176,000	6	17	461
	600	212,000	186,000	9	32	415
	800	169,000	150,000	12	47	331
	1000	130,000	111,000	18	57	262
	1200	103,000	86,000	23	62	217
1144	400	127,000	91,000	17	36	277
	600	126,000	90,000	17	40	262
	800	123,000	88,000	18	42	248
	1000	117,000	83,000	20	46	235
	1200	105,000	73,000	23	55	217
1330[b]	400	232,000	211,000	9	39	459
	600	207,000	186,000	9	44	402
	800	168,000	150,000	15	53	335
	1000	127,000	112,000	18	60	263
	1200	106,000	83,000	23	63	216

Table continued on next page.

Typical Mechanical Properties of Selected Quenched and Tempered Carbon & Alloy Steels (cont.)

AISI No.[a]	Tempering Temperature (°F)	Strength Tensile (psi)	Strength Yield (psi)	Elongation (%)	Reduction in Area (%)	Hardness (BHN)
1340	400	262,000	231,000	11	35	505
	600	230,000	206,000	12	43	453
	800	183,000	167,000	14	51	375
	1000	140,000	120,000	17	58	295
	1200	116,000	90,000	22	66	252
4037	400	149,000	110,000	6	38	310
	600	138,000	111,000	14	53	295
	800	127,000	106,000	20	60	270
	1000	115,000	95,000	23	63	247
	1200	101,000	61,000	29	60	220
4042	400	261,000	241,000	12	37	516
	600	234,000	211,000	13	42	455
	800	187,000	170,000	15	51	380
	1000	143,000	128,000	20	59	300
	1200	115,000	100,000	28	66	238
4130[b]	400	236,000	212,000	10	41	467
	600	217,000	200,000	11	43	435
	800	186,000	173,000	13	49	380
	1000	150,000	132,000	17	57	315
	1200	118,000	102,000	22	64	245
4140	400	257,000	238,000	8	38	510
	600	225,000	208,000	9	43	445
	800	181,000	165,000	13	49	370
	1000	138,000	121,000	18	58	285
	1200	110,000	95,000	22	63	230
4150	400	280,000	250,000	10	39	530
	600	256,000	231,000	10	40	495
	800	220,000	200,000	12	45	440
	1000	175,000	160,000	15	52	370
	1200	139,000	122,000	19	60	290
4340	400	272,000	243,000	10	38	520
	600	250,000	230,000	10	40	486
	800	213,000	198,000	10	44	430
	1000	170,000	156,000	13	51	360
	1200	140,000	124,000	19	60	280

Table continued on next page.

Typical Mechanical Properties of Selected Quenched and Tempered Carbon & Alloy Steels (cont.)

AISI No.[a]	Tempering Temperature (°F)	Strength (psi)		Elongation (%)	Reduction in Area (%)	Hardness (BHN)
		Tensile	Yield			
6150	400	280,000	245,000	8	38	538
	600	250,000	228,000	8	39	483
	800	208,000	193,000	10	43	420
	1000	168,000	155,000	13	50	345
	1200	137,000	122,000	17	58	282
81B45	400	295,000	250,000	10	33	550
	600	256,000	228,000	8	42	475
	800	204,000	190,000	11	48	405
	1000	160,000	149,000	16	53	338
	1200	130,000	115,000	20	55	280
8630	400	238,000	218,000	9	38	465
	600	215,000	202,000	10	42	430
	800	185,000	170,000	13	47	375
	1000	150,000	130,000	17	54	310
	1200	112,000	100,000	23	63	240
8640	400	270,000	242,000	10	40	505
	600	240,000	220,000	10	41	460
	800	200,000	188,000	12	45	400
	1000	160,000	150,000	16	54	340
	1200	130,000	116,000	20	62	280
8650	400	281,000	243,000	10	38	525
	600	250,000	225,000	10	40	490
	800	210,000	192,000	12	45	420
	1000	170,000	153,000	15	51	340
	1200	140,000	120,000	20	58	280

Source: Machinery's Handbook, 26 ed.
a) All grades are fine-grained except those in the 1100 series that are coarse-grained. Heat treated specimens were oil quenched unless otherwise indicated.
b) Water quenched.

Typical Mechanical Properties of Selected Standard Stainless Steels

Grade	Condition	Tensile Strength (psi)	0.2% Yield Strength (psi)	Elongation in sq in (%)	Reduction of Area (%)	Hardness Rockwell	Hardness BHN
Austenitic Steels							
302	Annealed	90,000	37,000	55	65	B82	155
	1.4 hard (sheet, strip)	125,000[a]	75,000[a]	12[a]	---	C25	---
	Cold-drawn (bar, wire)	to 350,000	---	---	---	---	---
303, 303 (Se)	Annealed	90,000	35,000	50	55	B84	160
304	Annealed	85,000	35,000	55	65	B80	150
304L	Annealed	80,000	30,000	55	65	B76	140
310, 310S	Annealed	95,000	40,000	45	65	B87	170
316	Annealed	85,000	35,000	55	70	B80	150
	Cold-drawn (bar, wire)[b]	to 300,000	---	---	---	---	---
321	Annealed	87,000	35,000	55	65	B80	150
Martensitic Steels							
403, 410, 416, 416Z (Se)	Annealed	75,000	40,000	30	65	B82	155
	Hardened[c]	---	---	---	---	C43	410
	Tempered at 400°F	190,000	145,000	15	55	C41	390
	600°F	180,000	140,000	15	55	C39	375
	800°F	195,000	150,000	17	55	C41	390
	1000°F	145,000	115,000	20	65	C31	300
	1200°F	110,000	85,000	23	65	B97	225
	1400°F	90,000	60,000	30	70	B89	180
420, 420F	Annealed	95,000	50,000	25	55	B92	195
440C, 440F	Hardened[d]	---	---	---	---	C54	---
	Tempered at 600°F	285,000	275,000	2	10	C57	---
	Annealed	110,000	65,000	13	25	B97	230

Source: Machinery's Handbook, 26 ed.
a) Minimum.
b) Depending on size and amount of cold reduction.
c) Hardening temperature 1800°F, one inch diameter bars.
d) Hardening temperature 1900°F, one inch diameter bars.

CHAPTER 5

HEAT TREATMENT

Quenching, hardening, and other thermal modifications.

Hardenability is the property of steel that determines the depth and distribution of hardness induced by quenching from the austenitizing temperature. Hardenability should not be confused with hardness or maximum hardness. Hardness is a measure of the ability of a metal to resist penetration as determined by any one of a number of standard tests (Brinell, Rockwell, Vickers, etc.). The maximum attainable hardness of any steel depends solely on carbon content and is not significantly affected by alloy content. Maximum hardness is only realized when the cooling rate in quenching is rapid enough to ensure full transformation to martensite. The as-quenched surface hardness of a steel part is dependent on carbon content and cooling rate, but the depth to which a particular hardness level is maintained with given quenching conditions is a function of its hardenability. Hardenability is largely determined by the percentage of alloying elements in the steel; however, austenite grain size, time and temperature during austenitizing, and prior microstructure also significantly affect the hardness depth.

Did you know steel can exist in five distinct phases between solid and liquid and manipulating these phases with heat gives a steel its particular characteristics?

Steel's versatility is due to its response to thermal treatment. Although most steel products are used in the as-rolled or un-heat treated condition, thermal treatment greatly increases the number of properties that can be obtained, because at certain "critical temperatures" iron changes from one type of crystal structure to another. This structural change, known as an allotropic transformation, is spontaneous and reversible and can be made to occur by simply changing the temperature of the metal.

In steel, the transformation in crystal structure occurs over a range of temperatures, bounded by lower and upper critical points. When heated, most carbon and low alloy steels have a critical temperature range 1300°F – 1600°F. Steel above this temperature, but below the melting range, has a crystalline structure known as austenite, in which the carbon and alloying elements are dissolved in a solid solution. Below this critical range, the crystal structure changes to a phase known as ferrite, which is capable of maintaining only a very small percentage of carbon in solid solution. The remaining carbon exists in the form of carbides, which are compounds of carbon and iron and small amounts of the other alloying elements. Depending primarily on the cooling rate, carbides may be present as thin plates alternating with the ferrite (pearlite); as spheroidal globular particles at ferrite grain boundaries or dispersed throughout the ferrite;

or as a uniform distribution of extremely fine particles throughout a "ferrite-like" phase, which has an acicular (needle-like) appearance, named martensite. In some of the highly alloyed stainless steels, the addition of certain elements stabilizes the austenite structure so that it persists even at very low temperatures (austenitic grades). Other alloying elements can prevent the formation of austenite entirely up to the melting point (ferritic grades). *See "Steel Phases" illustration, page 27.*

Fundamentally, all steel heat treatments are intended to either harden or soften the metal. They involve one or a series of operations in which the solid metal is heated and cooled under specified conditions to develop required structures and properties.

Quenching

Quenching refers to the rapid cooling of heated metal. Quenching can be controlled through either application or medium (quenchant). Some of the more common quenchants include air, nitrogen, argon, helium, brine (salt water), oil, and water. The most common quenching methods are direct, fog, hot, interrupted, selective, slack, and spray.

Direct quenching is a performed during the carburizing process. Fog quenching is the process of passing the workpiece through a cooling mist. Hot quenching refers to holding the quenchant at a temperature above 160°F while a workpiece is cooled. Interrupted quenching occurs when the workpiece is removed from the quenchant while it is still substantially warmer than the quenchant and then subjected to a different quenching method. Selective quenching refers to cooling only selected portions of the workpiece. Slack quenching is cooling at a slower rate to allow one or more transformational products besides martensite. Spray quenching subjects the workpiece to a spray quenchant. Time quenching carefully monitors the time the workpiece is subjected to the quenchant.

The choice of quenching media is often a critical factor in the selection of steel of the proper hardenability for a particular application. Quenching severity can be varied by selection of quenching medium, agitation control, and additives that improve the cooling capability of the quenchant. Increasing the quenching severity permits the use of less expensive steels of lower hardenability; however, consideration must also be given to the amount of distortion that can be tolerated and the susceptibility to quench cracking. In general, the more severe the quenchant and the less symmetrical the part being quenched, the greater the size and shape changes that result from quenching and the greater the risk of quench cracking. Although water quenching is less costly than oil quenching, and water quenched steels are less expensive than those requiring oil quenching, it is important to know that the parts being hardened can withstand the resulting distortion and the possibility of cracking.

Fundamentally, all steel heat treatments are intended to either harden or soften the metal.

Oil, salt, and synthetic water-polymer quenchants are also used, but they often require steels of higher alloy content and hardenability. The general rule for the selection of steel and quenchant for a particular part is that the steel should have a hardenability not exceeding that required by the severity of the quenchant selected. The carbon content of the steel should also not exceed what is required to meet specified hardness and strength, because quench cracking susceptibility increases with carbon content. The choice of quenching media is important in hardening, but another factor is agitation of the quenching bath. The more rapidly the bath is agitated, the more rapidly heat is removed from the steel and the more effective the quench. ■

THERMAL MODIFICATION OF STEEL

Metallic materials consist of a microstructure of small crystals called "grains" or crystallites. The size of these grains and their composition is one of the leading factors that determines the overall mechanical behavior of the metal. Heat treatment provides an efficient way to manipulate the properties of the metal by controlling the rate of internal diffusion and the rate of cooling within this microstructure of metallic grains. Alloys are often heat treated to alter their hardness, strength, toughness, and ductility.

Manufacturing of steel frequently causes friction, which introduces heat to the material. Thermal modification of steel diminishes the potential for adverse consequences, such as deformation caused by heating.

Listed below are some terms and processes that are associated with the thermal modification of steel for compatibility with manufacturing.

Annealing
A treatment consisting of heating to and holding at a suitable temperature followed by cooling at a suitable rate. It is used primarily to soften steel and simultaneously to produce desired changes in other properties or microstructure. The purpose of these changes may be, but is not confined to, improvement of machinability; facilitation of cold-working; improvement of mechanical properties; or increase in stability of dimensions. The time/temperature cycles used vary widely both in maximum temperature attained and in cooling rate employed depending on the composition of the material, its condition, and the desired results.

Baking
Hydrogen embrittlement is the process by which steel becomes brittle and fractures following exposure to hydrogen. Hydrogen embrittlement is usually the result of unintentional introduction of hydrogen into the steel during forming or finishing operations such as electroplating, coating, and arc welding. It usually manifests itself as increased cracking in the material and is caused by the metal absorbing hydrogen which collects within voids in the steel grain. This creates pressure within the voids eventually cracking them open.

If the metal has not yet started to crack, the condition can be reversed by removing the hydrogen source and baking the metal which causes the hydrogen within the metal to diffuse out. Susceptible alloys are often subjected to heat treatment to remove absorbed hydrogen produced by chemical or electrical treatments. Usually, hydrogen embrittlement can be counteracted if the alloy is baked within four hours of being plated or treated.

Due to the time needed for hydrogen atoms to re-combine into harmful hydrogen molecules, hydrogen cracking due to welding can occur more than 24 hours after the welding operation is completed. Metal is often pre- and post-heated to allow the hydrogen to diffuse out before it can cause damage. This is specifically done with high-strength steels and low alloy steels such as chrome/molybdenum/vanadium alloys.

Stress Relieving
A process to reduce internal residual stresses in a metal object by heating the object to a suitable temperature and holding for a proper time at that temperature. This treatment may be applied to relieve stresses induced by casting, quenching, normalizing, machining, cold-working, or welding.

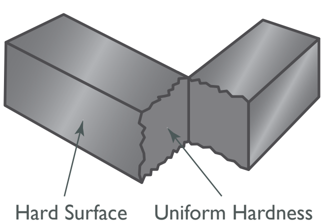
Tempering
Heating a quench-hardened or normalized ferrous alloy to a temperature below the transformation range to produce desired changes in properties.

DIRECT HARDENING VS. INDIRECT HARDENING

Before any hardening technique can be considered it is imperative to know what kind of steel is being used. Mild steel is any steel containing less than 0.25% carbon. Those steels classified as medium or high-carbon contain over 0.25% carbon. Through hardening is used on medium and high-carbon steels while case hardening is used on mild steels. For moderate strength choose a medium steel that is through hardened. For a very hard surface and lower inner core strength choose a mild steel that is case hardened. Mild steel cannot be through hardened and medium and high-carbon steel are not typically case hardened.

Direct or Through Hardening

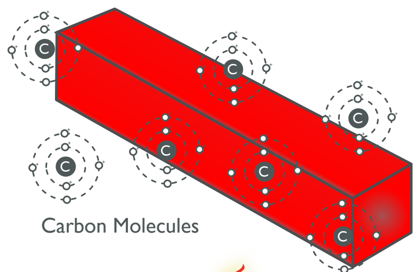
Through hardening is applied to **medium and high-carbon** parts that possess sufficient carbon content for hardening through the entire depth of the part. The steel is heated to its critical temperature (usually 1500°F – 1900°F) then rapidly quenched (cooled) to fix the structure of the part in a hardened state. Mild steels do not possess enough carbon to stimulate the hardening process. The best recognized through hardened part in the world is a diamond.

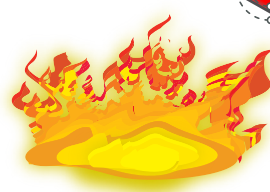


RESULTING HARDNESS

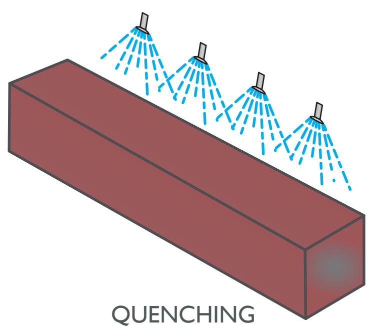
Hardening should not be confused with tempering. Hardening occurs at a substantially higher temperature than tempering. Steel is brittle when hardened. This is overcome by tempering – the process of reheating the piece to a much lower temperature. This retains the hardness of the steel but allows the ductile nature of austenite to return to the metal.

Case Hardening

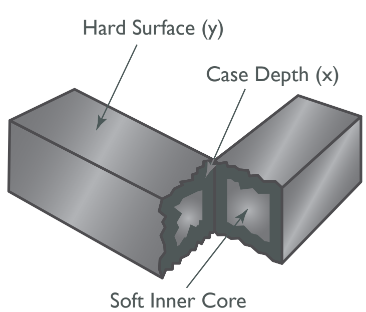




HEATING



QUENCHING



RESULTING CASEMENT

Indirect or Case Hardening

Case hardening is applied to **low-carbon** parts to increase surface hardness. During case hardening a solid iron-base alloy is heated above the transformation temperature range while carbon molecules are introduced to the part via solids, liquids, or gases in a process known as carburizing. The molecules penetrate the surface of the part, forming a casement, which is identified by the case depth (x) and surface hardness (y).

Quenching locks the casement producing a surface that is substantially harder than the interior or core.

More exacting specifications will identify a sufficient case or a specific hardness requirement at a particular depth. Case hardness cannot be measured effectively using a Rockwell test. Readings must be taken from a cross section of the part using a microhardness tester.

Typical Heat Treatments for SAE Carbon Steels (Direct Hardening)

SAE No.	Normalize (°F)	Anneal (°F)	Harden (°F)	Quench[a]	Temper[b] (°F)
1030	---	---	1575 – 1600	W	To desired hardness
1035	---	---	1550 – 1600	W	
1037	---	---	1525 – 1575	W	
1038[c]	---	---	1525 – 1575	W	
1039[c]	---	---	1525 – 1575	W	
1040[c]	---	---	1525 – 1575	W	
1042	---	---	1500 – 1550	W	
1043[c]	---	---	1500 – 1550	W	
1045[c]	---	---	1500 – 1550	W	
1046[c]	---	---	1500 – 1550	W	
1050[c]	1600 – 1700	---	1500 – 1550	W	
1053	1600 – 1700	---	1500 – 1550	W	
1060	1600 – 1700	1400 – 1500	1575 – 1625	O	
1074	1550 – 1650	1400 – 1500	1575 – 1625	O	
1080	1550 – 1650	1400 – 1500[d]	1575 – 1625	O[e]	
1084	1550 – 1650	1400 – 1500[d]	1575 – 1625	O[e]	
1085	1550 – 1650	1400 – 1500[d]	1575 – 1625	O[e]	
1090	1550 – 1650	1400 – 1500[d]	1575 – 1625	O[e]	
1095	1550 – 1650	1400 – 1500[d]	1575 – 1625	WO	
1137	---	---	1550 – 1600	O	
1141	---	1400 – 1500	1500 – 1550	O	
1144	1600 – 1700	1400 – 1500	1500 – 1550	O	
1145	---	---	1475 – 1500	WO	
1146	---	---	1475 – 1500	WO	
1151	1600 – 1700	---	1475 – 1500	WO	
1536	1600 – 1700	---	1500 – 1550	WO	
1541 (1041)	1600 – 1700	1400 – 1500	1500 – 1550	WO	
1548 (1048)	1600 – 1700	---	1500 – 1550	O	
1552 (1052)	1600 – 1700	---	1500 – 1550	O	
1566 (1066)	1600 – 1700	---	1575 – 1625	O	

a) Symbols: W = water or caustic; WO = water or oil; O = oil.
b) Even where tempering temperatures are shown, tempering is not mandatory in many applications. Tempering is usually employed for partial stress relief and improves resistance to grinding cracks.
c) Commonly used on parts where induction hardening is employed. However, all steels from SAE 1030 and up may have induction hardening applications.
d) Slow cooling or isothermic transformation produces a spheroidal structure in these high-carbon steels that is sometimes required for machining purposes.
e) May be water or brine quenched by special techniques such as partial immersion or time quenched; otherwise, they are subject to quench cracking.

Typical Heat Treatments for SAE Carbon Steels (Indirect Hardening)

SAE No.[b]	Carburize (°F)	Cool[a]	Reheat (°F)	Cool[a]	Carbonitriding (°F)[c]	Cool[a]	Temper[d] (°F)
1010	---	---	---	---	1450 – 1650	O	250 – 400
1015	---	---	---	---	1450 – 1650	O	
1016	1650 – 1700	WC	---	---	1450 – 1650	O	
1018	1650 – 1700	WC	1450	WC[e]	1450 – 1650	O	
1019	1650 – 1700	WC	1450	WC[e]	1450 – 1650	O	
1020	1650 – 1700	WC	1450	WC[e]	1450 – 1650	O	
1022	1650 – 1700	WC	1450	WC[e]	1450 – 1650	O	
1026	1650 – 1700	WC	1450	WC[e]	1450 – 1650	O	
1030	1650 – 1700	WC	1450	WC[e]	1450 – 1650	O	
1109	1650 – 1700	WO	1400 – 1450	WC[e]	---	---	
1117	1650 – 1700	WO	1450 – 1600	WC[e]	1450 – 1650	O	
1118	1650 – 1700	O	1450 – 1600	O	---	---	
1513	1650 – 1700	O	1450	O	---	---	
1518	---	---	---	---	---	---	
1522	1650 – 1700	O	1450	O	---	---	
1524 (1024)	1650 – 1700	O	1450	O	---	---	
1525	1650 – 1700	O	1450	O	---	---	
1526	1650 – 1700	O	1450	O	---	---	
1527 (1027)	1650 – 1700	O	1450	O	---	---	

a) Symbols: WC = water or caustic; WO = water or oil; O = oil.
b) Normalizing is generally unnecessary for fulfilling either dimensional or machinability requirements of parts made from these steel grades. However, where dimension is of vital importance, normalizing temperatures of a least 50°F above the carburizing temperature are sometimes required to minimize distortion.
c) The higher manganese steels such as 1118 and the 1500 series are not usually carbonitrided. If carbonitriding is performed, care must be taken to limit the nitrogen content because high nitrogen will increase their tendency to retain austenite.
d) Even where tempering temperatures are shown, tempering is not mandatory in many applications. Tempering is usually employed for partial stress relief and improves resistance to grinding cracks. Higher temperatures than those shown may be employed where the hardness specification on the finished part permits.
e) 3% sodium hydroxide.

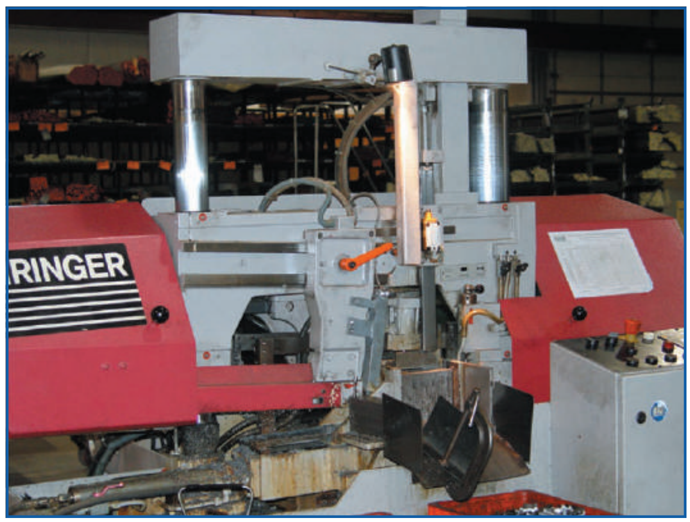
CHAPTER 6

MANUFACTURING

G.L. Huyett's distinct manufacturing processes and capabilities.

Unique to G.L. Huyett is the breadth of its manufacturing operations. These operations are complemented with a state-of-the-art world class warehouse containing over 95,000 non-threaded fasteners and industrial components. This section defines some of the major manufacturing operations often performed when manufacturing products from raw steel.

Did you know G.L. Huyett started as a hardware store supplying local farmers with hard-to-source replacement hardware?



Automated industrial band saws are used to manufacture machine keys, keystock, and spacers to tight tolerances for a wide range of applications and industries.

Band Sawing

A band saw is a computer-controlled multi-point cutting machine designed to cut off barstock, tubing, pipe, or other metal stock. The band saw functions by bringing a continuously moving, endless metal blade with teeth along one edge in contact with the workpiece to be cut. The blade travels continuously between a drive wheel and an idler wheel to produce a uniform cutting action. At least two teeth must be in contact with the workpiece at all times to avoid stripping of the teeth. The cutting blade stands on edge with the teeth facing down as it passes through material held firmly in place by hydraulic jaws on both sides of the blade to produce tight tolerance cutting accuracy. At G.L. Huyett cold-finished barstock is welded into a pack to prevent the bars from sliding back and forth as they are fed through the band saw.

G.L. Huyett has pioneered the use of proprietary fixtures, materials handling, and band sawing equipment to automate this process.

Cold-drawing

Cold-drawing is a metalworking process that uses tensile force to stretch metal by pulling steel bars or sheets through a progressive set of rollers or dies at room temperature in order to modify their shape and structure.

G.L. Huyett, in conjunction with steel mills in the U.S. and Europe, has perfected a number of profiling techniques that are conducive to the manufacturing of high quality keystock.

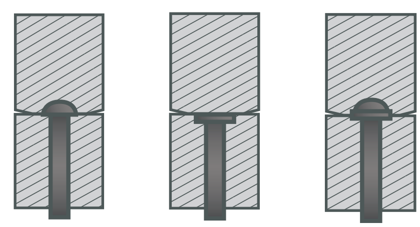
Cold-drawing is used when extremely tight tolerances are required because it produces extremely straight lines, tight corners, and bright finishes.

Cold-heading

Cold-heading, also known as cold-forging, is a higher production format used to make pins and other solid parts. The cold-heading process uses dies, and a drive system to ram parts into a die cavity where they are upset, or enlarged, to the form of the die cavity. Forging may involve multiple strokes to progressively form a part, or to overcome the horsepower of a smaller cold-heading machine. The multiple strokes can also be used to add numerous features to a single part in one overall production run.

Holes and certain transverse features (including threading on a bolt) are performed as a secondary operation. Cold-heading is suitable for production runs over 1,000 pieces on large parts, and 5,000 pieces on smaller parts due to setup time and punch and die costs.

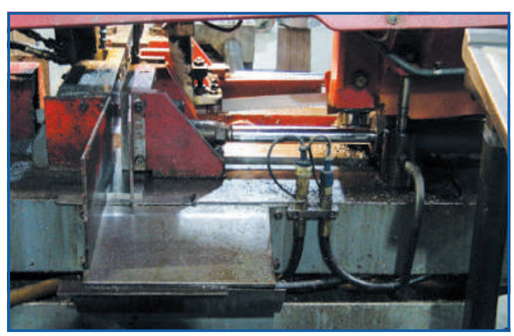
EXAMPLES OF COLD-HEADING



Cold-heading rams material into the void of a die or punch forcing the metal to reshape itself to fill the void.

Cold-sawing

Compared to band saws, cold-saws use a slow-moving angular blade that provides highly accurate finish-quality cuts, but in lower volume. Due to improved accuracy, cold-sawing is typically used when fine length tolerances are desired as it produces minimal burrs and dust while cutting and does not discolor the metal.



Cold-sawing is slower than band sawing, but is highly accurate and does not scar the metal. It is used to make products such as woodruff keys and spacers with keyways.

Cold-sawing gets its name because the heat generated during cutting is transferred to the chip and carried away rather than transferring to the workpiece or blade.

Grinding

Grinding, also called surface grinding, is a machining operation in which material is removed using a powered abrasive wheel, stone, belt, paste, sheet, compound, etc. to realize fine finish tolerances and surface finishes. While there are a number of ways to grind parts,

Grinding is employed when extremely tight tolerances are required on flat surfaces such as shims and thrust washers.

grinding is a more precise method of tolerance modification.

Parts are laid on a table that has a chuck or holder. The holder uses magnets to hold parts on the table, or in the case of non-magnetic materials like stainless steel, a vacuum chuck or adhesive is used. The magnetism of the chuck has limitations based on the size of the workpiece as well as the holding power around the outer edges of the chuck (about 1″ in total).

The table reciprocates, or moves back and forth, beneath an abrasive turning wheel. As the table moves back and forth, the entire table moves so that over time, the grinding wheel passes over the entire surface area of the table. This process, while slow, is precise. With each pass, as much as 0.001″ of material is removed. The maximum thickness to be removed using this process is 0.008″. Otherwise, milling should be used.

In order to develop a constant datum point, a minimum amount of material is needed, which is 0.001″ for part lengths under 4″. For parts over 4″ in length, a minimum removal of 0.003″ is required. Cold-drawn steel has some permissible twist that is revealed in longer length parts. The extra stock allows the grinder to pass through the twists so that a common datum point is achieved. Under the best of circumstances, a tolerance of 0.0005″ can be held using this method, although a maximum of +/–0.0005″ (0.001″ total) is recommended.

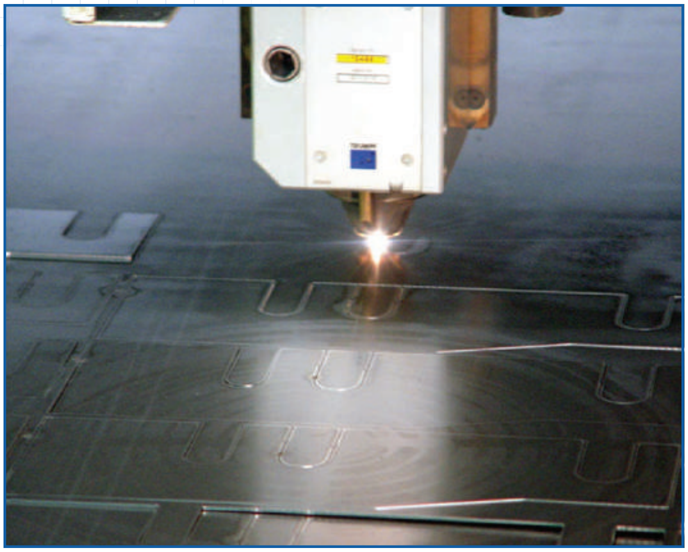
Lasering

Lasering, or laser cutting, is a metal forming process that uses intensified beams of light to drill or cut forms into metal to finished tolerances. Lasers use a high-energy beam supported by a coaxial supply of cutting gas to melt, vaporize, or combust material in a small and concentrated area. Lasering should be considered for production runs up to 500 pieces where tooling costs can be prohibitive. Lasered parts are flat, such as washers and other forms, but parts can be bent at angles following laser work.

Milling

Special end designs or special dimensions on non-standard parts require a milling process. Milling is a multi-point cutting process used to remove material from the face or periphery of a workpiece by a rotating cutting tool (also commonly referred to as a cutter or insert).

The cutting tool rotates rapidly as the workpiece is moved relatively to the cutting tool on a fixture. A fixture is a work-holding device designed specifically to hold one or more workpieces tightly in place in order to reduce the amount of time needed to position or lock workpieces to the machine table. Milling is a violent and stressful process that is far more technical than it appears. The process requires rigidity in the fixtures as even slight movements can affect the finished results.



Laser drilling and cutting is a new technology replacing cutting and stamping when extremely accurate shapes are required. It is highly efficient on smaller quantity items such as prototypes as no tooling is required.

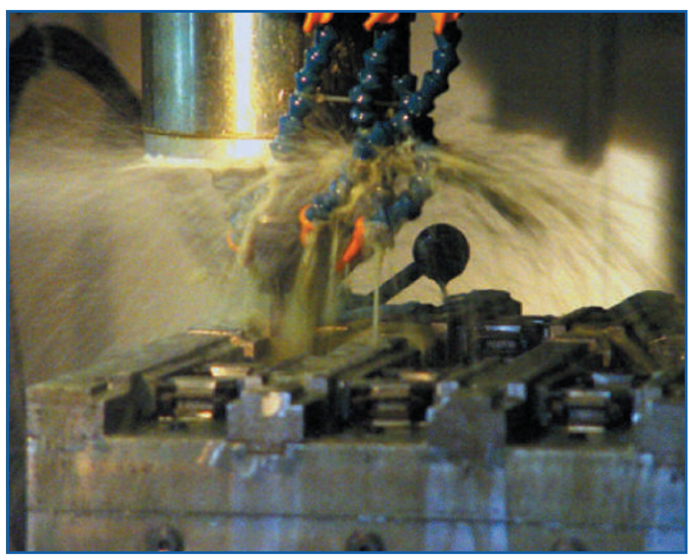
The travel path of the workpiece (via a worktable in the case of vertical milling – our primary production method), as well as the height of the spindle holding the rotating tool, is controlled numerically using Computer Numerically Controlled (CNC) technology. The rotating tool itself may be a solid piece or an insert – a lower cost method of high-speed milling where tool wear and tool life are major considerations. With inserts, small teeth are installed and reused on three or more different corners, as opposed to one large end-mill.

To increase operator throughput, pallets are deployed with changers on them. These pallet systems allow the operator to load and clamp unfinished pieces while the machine is in operation. The clamps themselves may deploy air or hydraulic systems helping to diminish machine downtime and operator fatigue from manual clamping of the parts onto the pallet or table.

Milling is used to modify the tolerances (dimensions) of parts, to install steps or cutouts in a part, or to drill and tap holes. Parts can be deburred in the machine after an operation using a tool change. Milling can also be used to modify the ends, such as Form A radial ends on shaft keys. Any process that uses a rotating cutter can be used in our mills, and with a wide range of tooling, tool holders, and insert choices, the options are almost endless.

Milling creates heat and as cold-finished material is removed on the outside of a part, stresses that were reintroduced into the steel during cold-finishing can affect the part and cause it to warp and bend. Warpage can be problematic when milling to modify tolerances and dimensions. Not only can the straightness of the finished part be compromised, but the ability to perform other secondary operations can be impaired as well. These distortions can be countered in one of two manners: first, the material can be stress relieved prior to milling. If this method is used, the parts may require heat treating after milling so as to return the material to the proper hardness. The second method is to mill both sides of the part, and to

G.L. Huyett has one of the lowest shop rates anywhere. Our laser department is equipped to run even "one-off" orders for prototypes and repairs.



Milling uses a rotating cutter to create shapes such as gib keys and step keys from blocks of metal. Radiused ends and countersunk holes are also possible.

control the amount of material removed on each side of a part, as a percentage of total thickness.

Generally, the maximum amount of material that can be removed on carbon steel parts is 0.125″. For greater tolerance modifications, the part requires milling on both sides. Stainless steel is generally always milled on both sides, because of the presence of more stresses than carbon steel.

The minimum tolerance that can be held in tolerance modification using milling is 0.003″. Tighter tolerances can be realized using grinding as a secondary operation, but keep in mind that these operations are both time consuming and expensive. *See "Chapter 5: Heat Treatment" for additional information on metallurgical stress and strain, page 48.*

A punched shear or burnished area is the area where a substrate has been cut by a punch. It is smooth, well-defined, and consistent in size. A rollover is the rounded edge made as a punch compresses a substrate before it shears the material. A breakout is the rough edge created on the underside of the substrate as the punch breaks through.

Non-Milling Processes that Mimic Milling

Arbor Milling

Arbor milling can be used to produce keyed shafts, keyways, or the steps on keyways. An arbor mill works the same as an end-mill except that the cutting takes place on a surface that runs parallel to the axis of rotation.

Broaching

Broaching is used to cut internal keyways into the inside diameter of a gear or sprocket, and to form the radius on a Form A shaft key. Broaching is a cutting operation where stock removal is built into the tool by having each successive tooth cut deeper into the material. The tools are long and tapered.

Shaping

Shaping is used to form the ends of radial shaft keys. Material is removed by a single-point cutting tool that reciprocates across the face of a stationary workpiece to produce a sculpted surface. For shaft keys, the parts are stood up in the fixture and shaped in batches in just a few passes.

Shearing

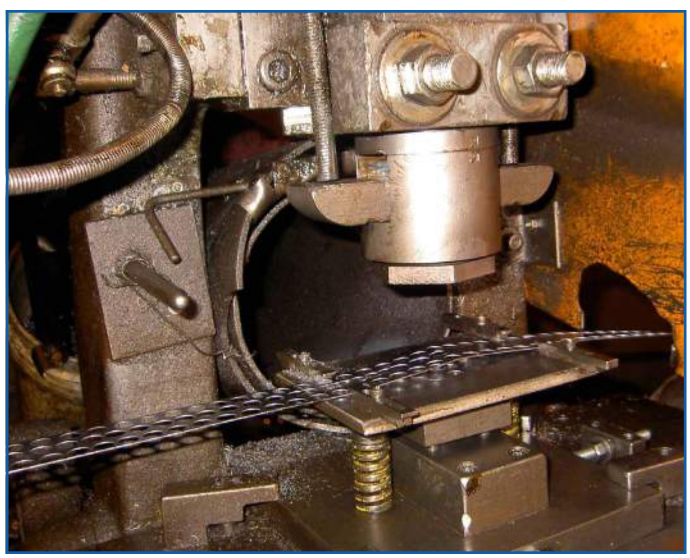
Shearing is a high-speed cutting process where an upper cutoff blade is passed by a lower blade, one of which is stationary, with a desired offset. It is an excellent production method for high-speed production of shaft keys, both with square (Form B) and radial (Form A) ends.

G.L. Huyett has developed proprietary state-of-the-art fixtures for milling shaft keys and profiles.

Punching/Stamping

Punching, also referred to as stamping, is a process of using a punch press to punch through material and into a die to create a hole in a workpiece with expert precision. As the punch pushes through the material, it shears off, and the sidewall of the resulting hole displays a burnished area, a rollover, and a breakout.

There are several variations of the basic punch design. For starters, more than one part can be punched in a single stroke for higher volume applications. A progressive set of dies can be

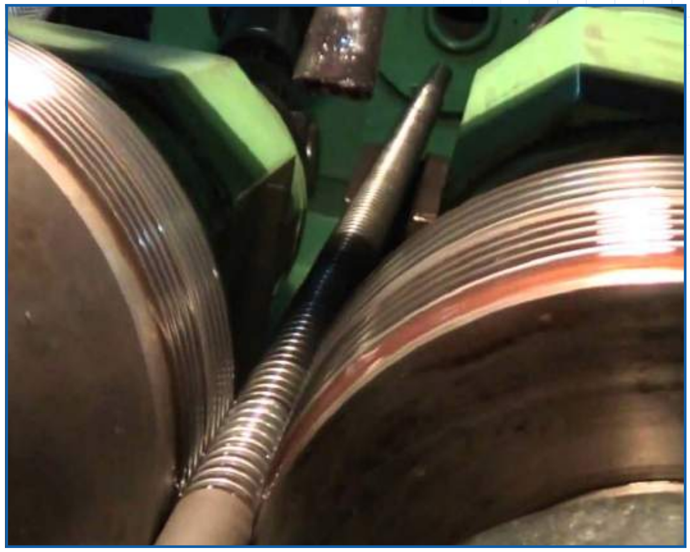


Stamping/punching creates a series of pieces from a single sheet of metal and is generally used for washers or bushings with internal cut-outs.

used to form more complicated designs. In a progressive die, each stroke progresses toward a finished part. Deep drawn parts such as a cup are made this way.

There are also variations in tooling. Compound dies – which have more than one die component – are often used to make flat washers, where the formed part is basically the same, but there are different combinations of inside and outside diameter. One ID punch can be used in combination with OD punches so that overall tooling costs are less than if there is a one piece die for each set up.

G.L. Huyett has developed tooling and processes that yield a near universal low cost/no cost setup on stamping of 10,000 pieces and less.



A thread rolling machine can cut right or left threads without retooling. Threading is used on parts that attach with either external or internal threads.

Threading

There are three distinct methods used to thread a part: cutting, milling, and forming. Thread cutting is a process of using a single-point tool to produce a uniform helical thread form. Thread cutting involves removal of material and is used when full thread depth is required, the production quantity is small, the blank is not very accurate, threading up to the shoulder is required, or when the material is brittle. Thread cutting can be performed on a lathe.

Thread milling is related to thread cutting in that material is removed from the workpiece to create threads. Thread milling is generally used on larger threads (over 1.5″ diameter) and uses a multi-point tool. The advantages of thread milling versus thread cutting are a better surface finish, improved concentricity, and a left or right hand thread can be created with the same tool. Thread milling is normally done on a dedicated thread milling machine.

Thread rolling, also known as thread forming, is a cold-forming process in which external threads are formed by rolling workpieces between shaped, hardened dies. The process is fast and is used for high production runs. The forming process itself increases the outside (major diameter) of the part and thus a smaller blank size can be used as opposed to the blanks used for cut threads. There is a typical 15–20% savings in blanks, measured by weight, in rolled versus cut thread parts. Rolled threads are recognizable to the observer because the threads are larger than the blank rod from which they are formed. While cut and milled threads can be both internal and external, rolled threads are only external because of the forming process.

Tumbling

After sawing, parts are often tumbled to ensure that burrs are removed prior to shipment or plating. Tumbling consists of submitting the parts to vibration while in the presence of media, which in technical terms is known as vibratory finishing. The media is specially designed to cause friction with the parts, and in effect polish the parts in a controlled manner. There are established parameters governing the mixture of media and parts, and the amount of time the parts remain in the tumbler.

A vibratory tumbler is a large doughnut-shaped drum with parts that rotate in a circular direction while the drum shakes at a high

Tumbling removes burrs resulting from machining and black scale resulting from heat treatments.

speed. This causes the tumbling media and parts to scrub against each other abrading the parts and removing burrs. After a proper amount of production time, the tumblers empty into a conveyor belt and are sent through a cleaner and dryer. The cleaner and dryer contain rust inhibitor ingredients that extend the shelf life of plain finish parts. Shelf life can be adversely affected by environmental factors and improper handling and storage. Efforts must be made to avoid dropping parts long distances, where the edges can ping, or from handling the parts using bare hands, where oils and impurities present on your skin can damage the finish on the parts. For this reason, G.L. Huyett personnel wear gloves when handling plain finished parts.

The tumbling process is performed after each production process that creates burrs, or after heat treating, where black scale resides on the parts and must be removed. In some instances up to 0.0005″ of material can be removed using especially aggressive vibratory media and an extended finishing time. Generally this is a cost effective means of altering tolerances and dimensions compared to machine removal such as milling or grinding. Removal is uniform but not precise on all surfaces.

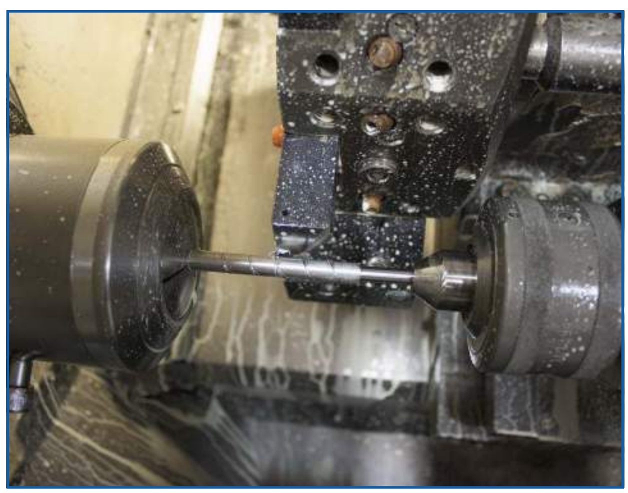
Turning

Turning is a machining operation performed on a lathe in which the workpiece rotates at high speeds while a fixed cutting tool removes material.

The most obvious use for a lathe is to manufacture pins. A lathe can turn complete parts including the formation of a head or radial grooves such as those found on a headless pin.

Lathes can be equipped with live tooling that consists of a second small spindle that is positioned perpendicular to the workpiece (in the same plane as the tool). Live tooling is used to produce transverse features such as a cross hole in a pin.

Lathes have a tailstock that interferes with the end of the workpiece opposite the turret (which holds the chuck and spins the workpiece). The tailstock provides rigidity to the workpiece to minimize chatter and deformation when the part is being cut. Chatter is an undesirable



The workpiece is mounted into the chuck. As it rapidly spins, a cutting tool can shape the piece into a round form, cut grooves, or produce radiused corners.

attribute because it can interrupt the contact of the tooling with the workpiece. If the cutting tool does not maintain rigid and constant contact with the workpiece excessive chatter can bend or deform the workpiece.

Turning and Facing

Among the more basic processes of a lathe are turning and facing. Turning is a material removal process where the tool is primarily parallel to the workpiece rotation. With facing, the tool is located at a right angle to the turret.

Parting and Grooving

Parting and grooving are other common lathe processes. Parting is a turning operation that uses a single-point cutoff tool to sever a section of a workpiece from raw stock. Grooving works similarly except the workpiece is not severed. There are many different groove styles that can be produced by using specialized tooling.

Boring

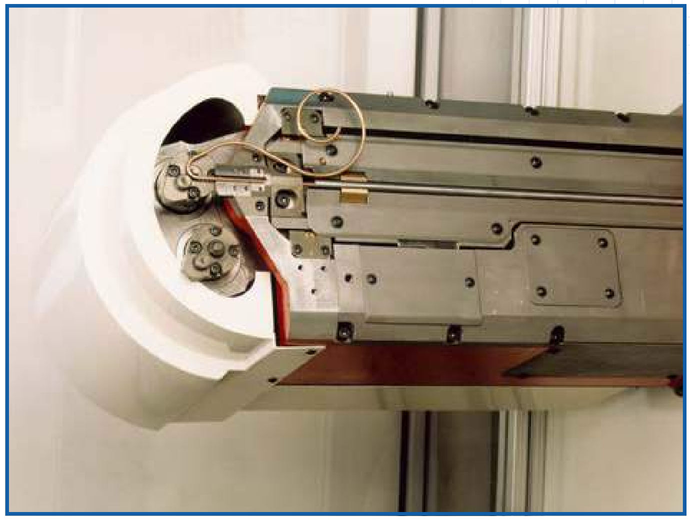
Lathes can be used to bore tapered or cylindrical holes by using a single-point cutting tool mounted to the tail stock that moves parallel to the axis of rotation. The tail stock can also be equipped with drilling or reaming tools to create holes in the axis at one end of (or all the way through) a part. All drilling and reaming performed on G.L. Huyett lathes is done using a multi-station tool turret.

G.L. Huyett uses automatic bar feed equipment and off-line programming to increase production and minimize setup time.

Wire Forming

Wire forming can be done in a number of ways. Cotter pins are formed similarly to cold-heading, except that the dies are designed so that the wire is pushed around them, and the wire forms around the die.

A four-slide is often used to form bridge pins and other complicated wire forms. The four-slide is wire fed and uses cams and a single motor that are timed to four dies that sit around the outside perimeter of a rotary table. The cams time the die impact into the wire, with the wire formed around the dies, similar to a cotter pin. Each machine stroke advances the part one more station forward progressively. After the fourth impact, the formed part is ejected through a hole in the middle of the rotary table. The opportunity for four impacts allows for rather complicated design capabilities. Four-slides can also design in-line, but are based on the same operating principles.



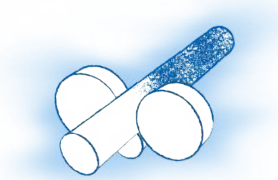
CNC wire forming machines use a system of computer controlled cams to bend the wire as it is pushed through the machine. The entire head of the machine rotates to allow bending in varying degrees in any direction.

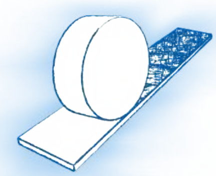
Newer machines incorporate CNC technology into heads capable of rotating in two directions simultaneously. As the wire is pushed through the machine, cams bend it in virtually any direction in varying degrees producing extremely complicated forms in high volumes. ■

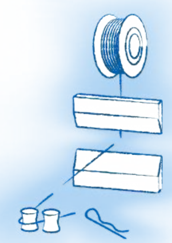
G.L. HUYETT MANUFACTURING CAPABILITIES AND CASE STUDIES

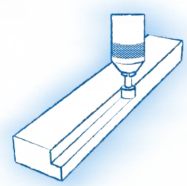
G.L. Huyett is a manufacturer, master distributor, and importer of non-threaded fasteners and grease fittings for industrial, agricultural, and construction equipment; material handling equipment; power transmission and motion control components; outdoor power equipment; rigging and scaffolding; automobiles and trucks; and more.

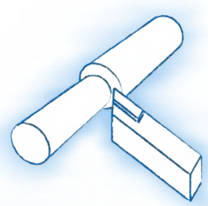
We have engineering support staff along with a complete in-house manufacturing facility where we can produce one-offs and specials. The case studies featured on the following pages are just a few examples of some of the challenges we've solved with cost-effective solutions. Give us a call to find out what we can do for you.

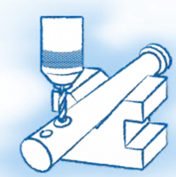

CENTERLESS GRINDING

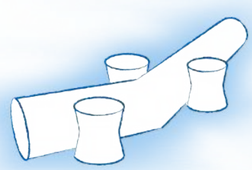

SURFACE GRINDING


WIRE FORMING


MILLING


TURNING

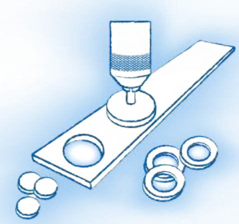

DRILLING

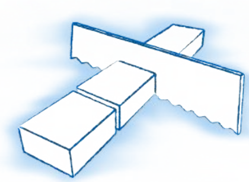

FORMING


LASER CUTTING


TUMBLING


MARKING


STAMPING


SAWING

MANUFACTURING CASE STUDY

PROBLEM:

AN AGRICULTURAL EQUIPMENT COMPANY WAS USING TUBE CONNECTORS, TUBING, AND A GREASE FITTING TO PROVIDE A SERVICE LOCATION TO A RECESSED BEARING. THE RECESS EXCEEDED THE TOTAL LENGTH OF COMMERCIALLY AVAILABLE GREASE FITTINGS, AND THE LEGACY DESIGN WAS COMPLICATED TO USERS. IN ADDITION, THE LEGACY DESIGN WAS UNRELIABLE IN AN OUTDOOR ENVIRONMENT.

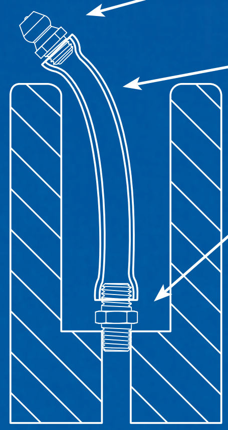
OPPORTUNITY:

A SOLID DESIGN SUFFICIENTLY ROBUST TO ALLOW DEEP SEATED INSTALLATION AND EXTERIOR WEAR AND TEAR WAS REQUIRED. THE ABILITY TO CHANGE OUT FAULTY OR CONTAMINATED PARTS WAS ALSO CONSIDERED; PROVIDED THAT THERE WAS SUFFICIENT SEAL TO ALLOW "FLOW THROUGH" OF GREASE FROM A GREASE GUN DOWN INTO THE BEARING.

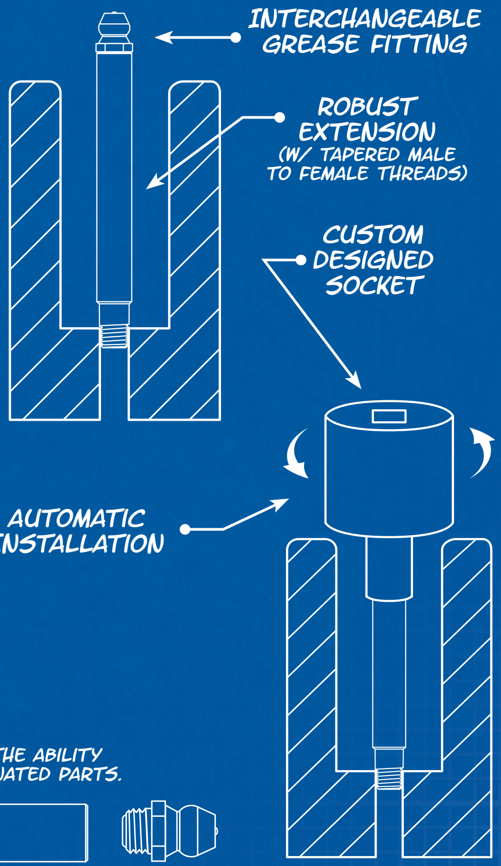
SOLUTION:

THE G.L. HUYETT MANUFACTURING TEAM DESIGNED A THICK WALLED EXTENSION WITH TAPERED MALE THREADS TO PROVIDE A "PILOT" INTO THE RECESSED HOLE. THE TAPERED THREADS WERE DESIGNED TO PROVIDE A DRY SEAL, AS WELL AS TO MATE INTO THE FEMALE THREADS ON THE OTHER END. IN ADDITION, A MATING DEEP SEATED "SOCKET" WAS DESIGNED FOR A MORE AUTOMATED ASSEMBLY. IT ALLOWED INTERCHANGEABLE PARTS FOR REPAIR AND REPLACEMENT. SPECIAL PRODUCTION PROCESSES WERE USED TO MAKE THE LONGER SHANKED PART STRAIGHT AND TRUE. THE FINAL DESIGN PROVIDED BETTER RELIABILITY, SIMPLER AND MORE ROBUST DESIGN AND INTERCHANGEABILITY AT SLIGHTLY LESS THAN LEGACY COSTS.

LEGACY METHOD



REDESIGNED METHOD



TWO PIECE DESIGN PROVIDES THE ABILITY TO CHANGE FAULTY OR CONTAMINATED PARTS.

Drawing No.: GLH-MCS-002-R01	Case No.: GLH-MCS-002-R01	Case Description: EXTENDED SHANK GREASE FITTING	
Drawn By: BH / Verified By: GLH	Revision Notes: REVISION NO. R01	Company Address: P.O. Box 232, Minneapolis, KS 67467	
	NOT DRAWN TO SCALE	Company Phone: (785) 392-3017	Company Fax: (785) 392-2845

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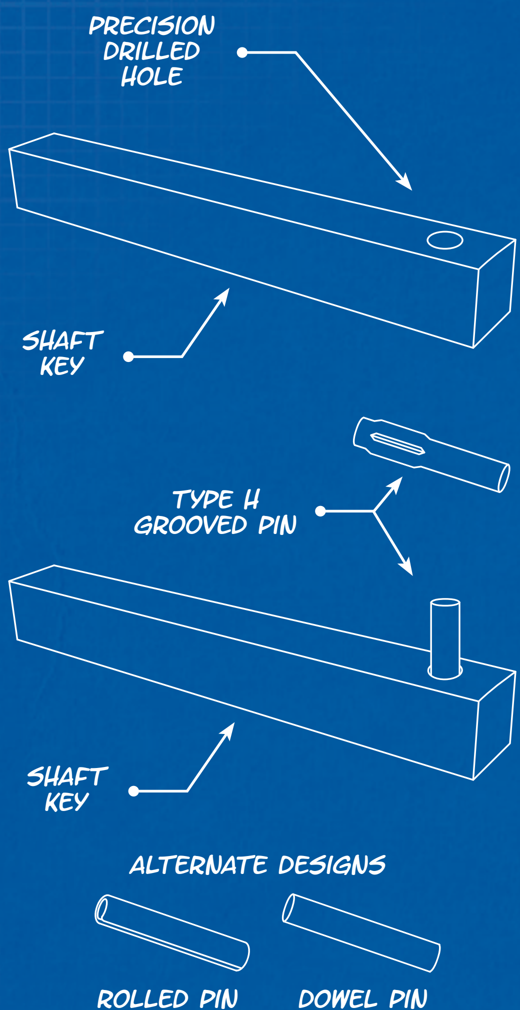
MANUFACTURING CASE STUDY

LEGACY METHOD



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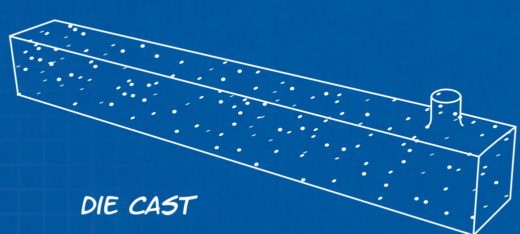

PROBLEM:

ENGINEERS WERE LOOKING TO IDENTIFY COST SAVINGS IN AN "END-STOP KEY." THE KEY SLID BACK AND FORTH IN A CHANNEL, WITH A PIN SERVING AS A "STOP." THE LEGACY PART CONSISTED OF A STAINLESS STEEL KEY, PARTIALLY DRILLED, WITH A GROOVED PIN ON ONE END.

OPPORTUNITY:

DOWEL PINS ARE MORE EXPENSIVE TO PRODUCE THAN ALTERNATE DESIGNS SUCH AS A ROLLED PIN. ROLLED PINS HAVE A LESS PRECISE OUTSIDE DIAMETER THAN MANY DOWEL PINS. ORIENTATION MAY BE REQUIRED OF THE ROLLED PIN, WHICH CAN COMPLICATE INSTALLATION. A "TYPE H" GROOVED PIN WAS THE BEST SOLID PIN APPLICATION BECAUSE IT REQUIRED A LESS PRECISE HOLE THAN A DOWEL PIN, AND THE GROOVED END PROVIDED A MORE STURDY GRIP.

AN ALTERNATE DESIGN AND BUILD STRATEGY WAS CONSIDERED. DIE-CASTING PROVIDED SUFFICIENTLY PRECISE DIMENSIONS, WITH A SOLID STOPPING MECHANISM. WITH DIE-CASTING, THERE WAS NO PIN INSTALLATION COST, AND OVERALL DESIGN WAS MORE CONSISTENT. IN ADDITION, THERE WAS NO NEED FOR OPERATOR INTERVENTION IN PIN DEPTH AND PLACEMENT.

SOLUTION:

USING G.L. HUYETT ENGINEERING AND GLOBAL SOURCING, A DIE-CASTING CONTRACTOR WAS LOCATED. LOW TOOLING AND SETUP COSTS, COUPLED WITH THE INSTALLATION AND PRODUCTION COST ADVANTAGES OVER MULTIPLE-PIECE DESIGNS YIELDED AN ACCEPTABLE PART AT A FRACTION OF THE LEGACY COST. OVERALL, THE CUSTOMER'S GOAL OF COST REDUCTION WAS EXCEEDED BY A WIDE MARGIN.

Drawing No.: GLH-MCS-001-R01		Case No.: GLH-MCS-001-R01	Case Description: END-STOP KEY	G.L.HUYETT MANUFACTURING
Drawn By: BH	Verified By: GLH	Revision Notes: REVISION NO. R01	Company Address: P.O. Box 232, Minneapolis, KS 67467	
		NOT DRAWN TO SCALE	Company Phone: (785) 392-3017 / Company Fax: (785) 392-2845	

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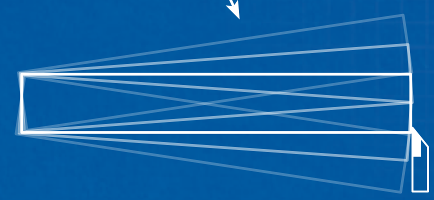
MANUFACTURING CASE STUDY

PROBLEM:

A SQUARE HANDLE USED ON ELECTRICAL BOXES REQUIRED A RADIUSED EDGE TO EASE INSTALLATION, AND HAD A PRECISE EFFECTIVE LENGTH BETWEEN GROOVES TO ENSURE A TIGHT FIT. BECAUSE THE PART WAS SQUARE SHAPED, A LOT OF "CHATTER" IS CREATED DURING PRODUCTION BY THE "INTERRUPTED CUT" DURING TURNING. THE EDGES OF THE MATERIAL "BEAT" ON THE TOOL UNTIL PENETRATED AND TURNED SMOOTH. THIS "CHATTER" IMPAIRS ACCURACY AND THUS MACHINE TIME MUST BE INCREASED AS SPINDLE SPEED IS REDUCED.



OPPORTUNITY:

G.L. HUYETT'S GLOBAL SOURCING TEAM WAS ABLE TO LOCATE PROFILE MILLS TO MAKE RAW MATERIAL WITH PRE-RADIUSED EDGES. THE RAW STEEL WAS SPECIFIED TO PRECISE LENGTHS TO REDUCE WASTE ON THE CHUCKED END.

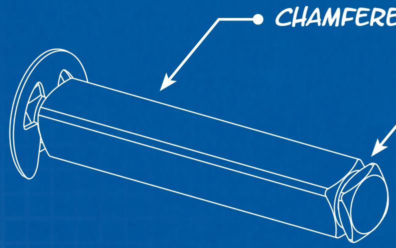
SOLUTION:

THE RADIUSED RAW STOCK REDUCED "CHATTER" AND ALLOWED SPINDLE SPEED TO BE INCREASED. MACHINE TIME IS REDUCED BY HIGHER THROUGHPUT, AS WELL AS THE ELIMINATION OF THE RADIUS AS A TURNED OPERATION. SCRAP WAS REDUCED BY 12% BY COORDINATING RAW MATERIAL LENGTH TO CONSUMPTION AND PRODUCTION SETUPS. IN ADDITION, A TEST ELECTRICAL BOX ASSEMBLY WAS DEPLOYED AS A "GO-NO-GO" GAUGE TO ENSURE PERFECT GROOVE WIDTH ACCURACY.

REDUCTION IN WASTE
PRECISE RAW MATERIAL LENGTH SPECIFIED TO REDUCE COSTS

BEFORE

AFTER
12% SAVINGS



SPECIAL NOTE:
THE G.L. HUYETT TEAM ALSO PROPOSED TO SHIP PARTS WITH ONE E-CLIP ASSEMBLED, FURTHER REDUCING THE COST OF THE ASSEMBLED PART.

Drawing No.:	Case No.:	Case Description:
GLH-MCS-004-R01	GLH-MCS-004-R01	ELECTRICAL BOX HANDLE

Drawn By:	Verified By:	Revision Notes:	Company Address:	
BH	GLH	REVISION NO. R01	P.O. Box 232, Minneapolis, KS 67467	
		NOT DRAWN TO SCALE	Company Phone: (785) 392-3017	Company Fax: (785) 392-2845

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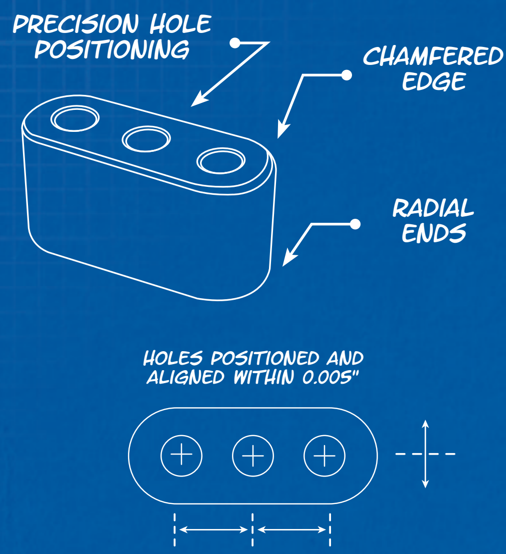
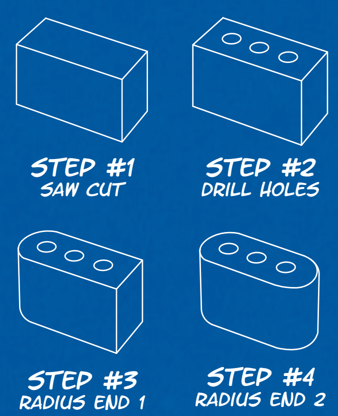
MANUFACTURING CASE STUDY



LEGACY METHOD



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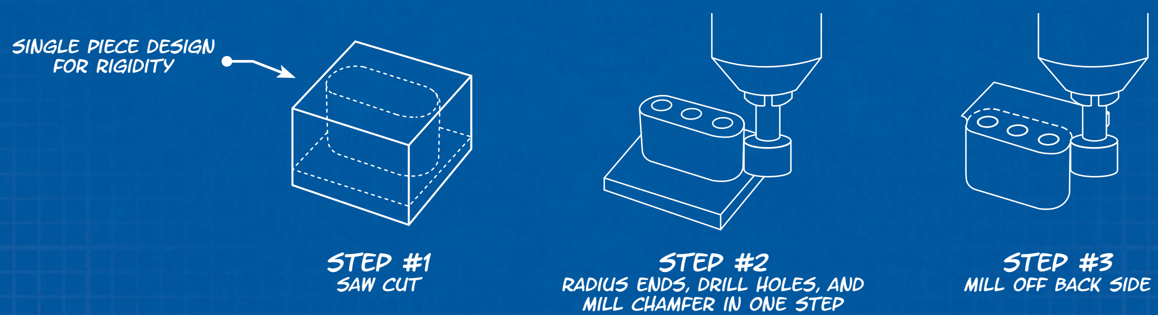

PROBLEM:

A POWER TRANSMISSION CUSTOMER WAS USING A PRECISION DRILLED MACHINE KEY AS A POSITIONING REFERENCE IN AN IMPORTANT MECHANICAL APPLICATION. THE THREE HOLES IN THE PART POSSESSED HIGHLY PRECISE TOLERANCES FOR ALIGNMENT AND POSITIONING. THE LEGACY MANUFACTURING METHOD YIELDED HIGH SCRAP RATES AND SETUP COSTS. THIS WAS DUE TO THE ACCUMULATED MANUFACTURING TOLERANCES INHERENT IN THE CONVENTIONAL PROCESS.

OPPORTUNITY:

G.L. HUYETT HAS PROPRIETARY AIR-OVER HYDRAULIC MILLING FIXTURES THAT ARE SEATED ON PALLETS. THE AIR-OVER HYDRAULIC DESIGN PROVIDES HIGH RIGIDITY, CLAMPING POWER, AND THROUGHPUT. THE THROUGHPUT IS INCREASED BECAUSE THE OPERATOR LOADS PARTS WHILE THE MACHINING CENTER OPERATES.

SOLUTION:

USING AN OVERSIZED BLANK PART, THE G.L. HUYETT MANUFACTURING TEAM DESIGNED PRODUCTION TO RUN ON THE AIR-OVER HYDRAULIC FIXTURES. THE ENTIRE KEY IS FORMED AND DRILLED FROM A SOLID PIECE, TURNED OVER, AND IN A SECOND PASS, THE BOTTOM IS REMOVED. THE RIGID ONE-PIECE PRODUCTION DESIGN AND TWO-PART PRODUCTION OPERATION RESULTED IN COST SAVINGS OF 56%.

Drawing No.:	Case No.:	Case Description:
GLH-MCS-003-R01	GLH-MCS-003-R01	PRECISION DRILLED MACHINE KEY

Drawn By:	Verified By:	Revision Notes:	Company Address:
BH	GLH	REVISION NO. R01	P.O. Box 232, Minneapolis, KS 67467

NOT DRAWN TO SCALE

Company Phone: (785) 392-3017
Company Fax: (785) 392-2845

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MANUFACTURING CASE STUDY

PROBLEM:

A FEW YEARS AGO, A MEDICAL SUPPLY COMPANY APPROACHED US WITH A CHALLENGE TO CREATE A RING PULL PIN WITH A THREADED SHAFT. OUR SALES TEAM AND ENGINEERS WORKED WITH THE COMPANY TO DEVELOP A COST-EFFECTIVE SOLUTION. RECENTLY, THEY CAME BACK TO US WITH A NEED FOR A LOCKING MECHANISM THAT WOULD ALLOW THEM TO KEEP THE PIN IN AN OPEN POSITION. THEY ONLY NEEDED A SMALL QUANTITY, AND THEY NEEDED THEM AS QUICKLY AS POSSIBLE.

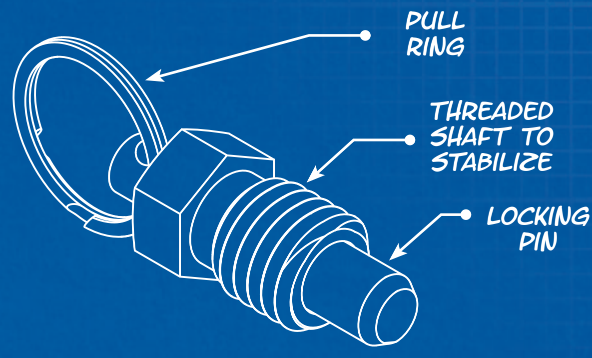
OPPORTUNITY:

ALONG WITH OUR CUSTOMER, THE G.L. HUYETT MANUFACTURING TEAM WORKED QUICKLY TO DEVELOP SEVERAL POTENTIAL SOLUTIONS. ONE WAS A COSTLY, TIME-CONSUMING SIDE PIN THAT WOULD SERVE THEIR NEEDS, BUT WASN'T AN AFFORDABLE OPTION. ANOTHER WAS A NOTCHED PIN THAT COULD BE LOCKED, BUT WAS NOT A VIABLE SOLUTION SINCE CLEARANCE WAS TOO TIGHT TO ALLOW THE SHAFT OF THE PIN TO SLIDE INTO A LOCKED POSITION. A THIRD SOLUTION PROVIDED A COST-EFFECTIVE, CUSTOM MANUFACTURED, HEX-SHAPED LOCKING COLLAR THAT COULD BE QUICKLY ADDED TO OR REMOVED FROM THE ORIGINAL PIN.

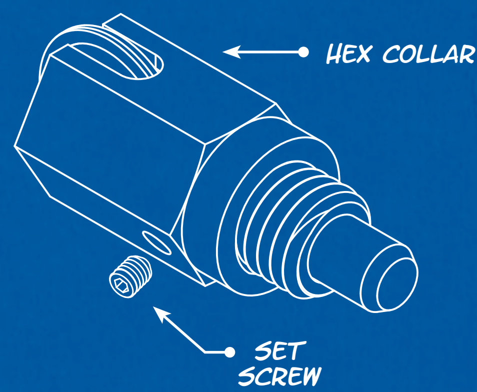
SOLUTION:

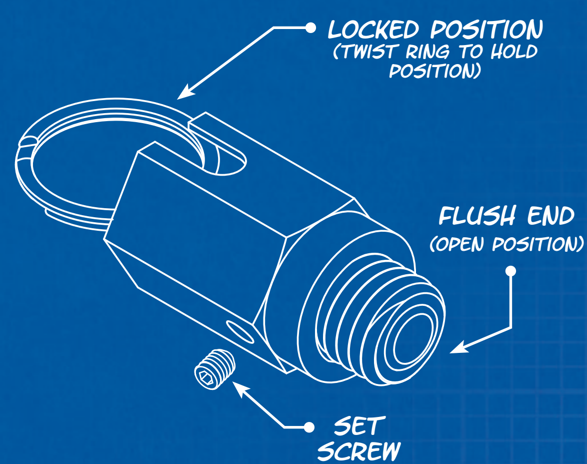
A CORROSION RESISTANT HEX SHAFT WAS USED TO CREATE COLLARS FOR THE LOCKING PINS. AFTER THE SHAFT WAS CUT TO LENGTH, EACH COLLAR WAS TURNED, THREADED, FINISHED, AND COMBINED WITH THE EXISTING RING PULL PIN. THE FINISHED ASSEMBLY ALLOWED THE RING PIN TO BE PULLED, TWISTED, AND LOCKED IN AN OPEN POSITION. ADDITIONALLY, A HOLE WAS THREADED IN ONE SIDE OF THE COLLAR SO THAT A SET SCREW COULD BE ADDED TO THE ASSEMBLY TO SAFELY LOCK THE RING PIN IN AN OPEN OR CLOSED POSITION.

ORIGINAL DESIGN



REDESIGNED METHOD





A B C D E F G H I

1 2 3 4 5 6 7

Drawing No.: GLH-MCS-005-R01		Case No.: GLH-MCS-005-R01	Case Description: THREADED PULL PIN WITH LOCKING HANDLE	
Drawn By: BH	Verified By: GLH	Revision Notes: REVISION NO. R01	Company Address: P.O. Box 232, Minneapolis, KS 67467	
		NOT DRAWN TO SCALE	Company Phone: (785) 392-3017	Company Fax: (785) 392-2845

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CHAPTER 7

HARDNESS TESTS

Comparisons of metal hardness tests.

Steel is used for a multitude of different applications; from forming the skeleton of tall skyscrapers to decorating the face of a watch. Measuring its hardness is critical in determining its suitability for a given function.

Hardness Testing

Did you know the diamond is one of the hardest substances on earth, yet it can be shattered with a simple tap of a hammer?

Unlike height, weight, and width, hardness is not a fundamental property. Hardness is most closely related to tensile strength and is a reliable indicator of ductility and wear resistance. The principle of any hardness testing method is to force an indenter (penetrator) into a material sample under a specific load at a controlled rate and then measure the dimensions (depth or surface area) of the indentation. Unlike length, mass, or time which have exact measures, hardness testing is a comparative measure: accurate testing results can only be achieved with calibrated machines and previous test results taken from a material of known hardness.

In metallurgy, the hardness of a material depends on a combination of yield strength, tensile strength, and modulus of elasticity – the stiffness of a material and its ability to resist deformation under applied force. It is measured by indenting a small sample piece of material without destroying it.

A variety of tests exist to measure the hardness of a material by indentation. Macro-hardness tests use larger indentation forces in the range of 50 to 3000N (9.807 Newtons = 1 kilogram-force = 2.204 pounds-force); examples include Rockwell, Brinell, and Vickers tests. Microhardness tests use smaller indentation forces in the range of 10 to 1000gf (1 gram-force = 0.00220462262941 pound-force); examples include Micro-Vickers and Knoop tests.

For rapid on-site testing, macro-hardness tests are the most widely used. They test normal-sized materials with standard loads, indenters, and dwells: controlled intervals of time in which an indenter is held under load against a material to ensure accurate hardness ratings.

Brinell Hardness Test

The Brinell test for determining the hardness of metallic materials consists of applying a known load to the surface of the material to be tested through a hardened steel ball of known diameter. The diameter of the resulting permanent impression in the metal is measured, and the Brinell Hardness Number (BHN) is then calculated from the following formula in which D = diameter of the ball in millimeters, d = measured diameter at the rim of the impression in millimeters, and P = applied load in kilograms force:

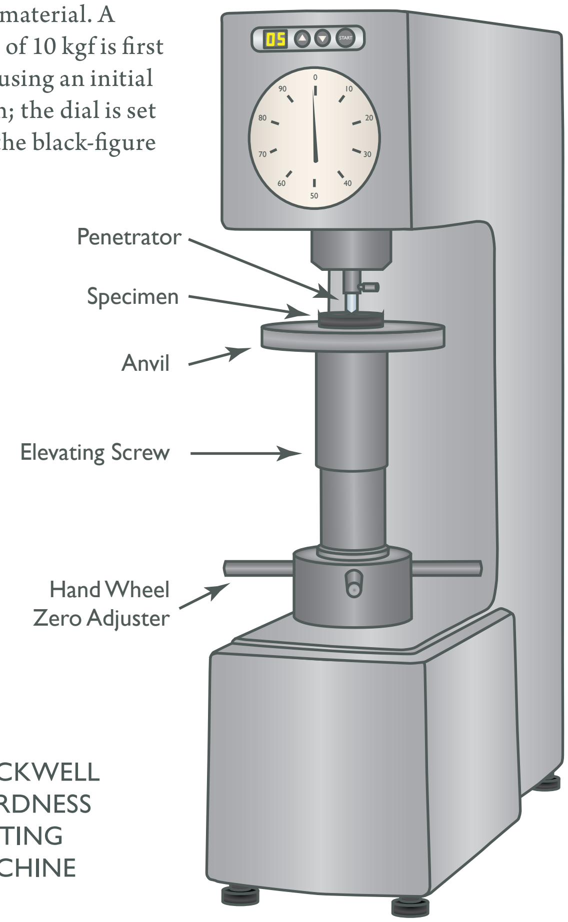
$$BHN = \frac{\text{load on indenting tool in kgf}}{\text{surface area of indentation in sq. mm}} = \frac{P}{\frac{\pi D}{2}\left(D - \sqrt{D^2 - d^2}\right)}$$

If the steel ball were not deformed under the applied load and if the impression were truly spherical, then the preceding formula would be a general one, and any combination of applied load and size of the ball could be used. The impression, however, is not quite a spherical surface because there must always be some deformation of the steel ball and some recovery of form of the metal in the impression; hence, for a standard Brinell test, the size and characteristics of the ball and the magnitude of the applied load must be standardized. In the standard Brinell test, a ball 10 mm in diameter and a load of 3000, 1500, or 500 kgf is used. It is desirable, although not mandatory, that the test load be of such magnitude that the diameter of the impression is in the range 2.50 mm – 4.75 mm. The following test loads and approximate Brinell numbers for this range of impression diameters are 3000 kgf, 160 BHN – 600 BHN; 1500 kgf, 80 BHN – 300 BHN; 500 kgf, 26 BHN – 100 BHN. In making a Brinell test, the load should be applied steadily and without a jerk for at least 15 seconds for iron and steel, and at least 30 seconds in testing other metals. A minimum period of 2 minutes, for example, has been recommended for magnesium and magnesium alloys. (For softer metals, loads of 250, 125, or 100 kgf are sometimes used.)

According to the ASTM Standard E10-66, a steel ball may be used on material having a BHN less than 450, a Hultgren ball on material less than 500, or a carbide ball on material less than 630. The Brinell Hardness Test is not recommended for material having a BHN above 630.

Rockwell Hardness Test

The Rockwell hardness tester is essentially a machine that measures hardness by determining the depth of penetration of a penetrator into the specimen under certain fixed conditions of test. The penetrator may be either a steel ball or a diamond sphero-conical penetrator. The hardness number is related to the depth of indentation and, the higher the number, the harder the material. A minor load of 10 kgf is first applied, causing an initial penetration; the dial is set at zero on the black-figure



A Rockwell Hardness Testing Machine measures the hardness of a metal by making an indentation in a specimen and measuring the depth of the penetration.

scale, and the major load is applied. This major load is customarily 60 kgf or 100 kgf when a steel ball is used as a penetrator, but other loads may be used when necessary. The ball penetrator is 1/16″ in diameter normally, but other penetrators of larger diameter, such as 1/8″, may be employed for soft metals. When a diamond sphero-conical penetrator is employed, the load is usually 150 kg. Experience decides the best combination of load and penetrator for use. After the major load is applied and removed, according to standard procedure, the reading is taken while the minor load is still applied.

Vickers Hardness Test

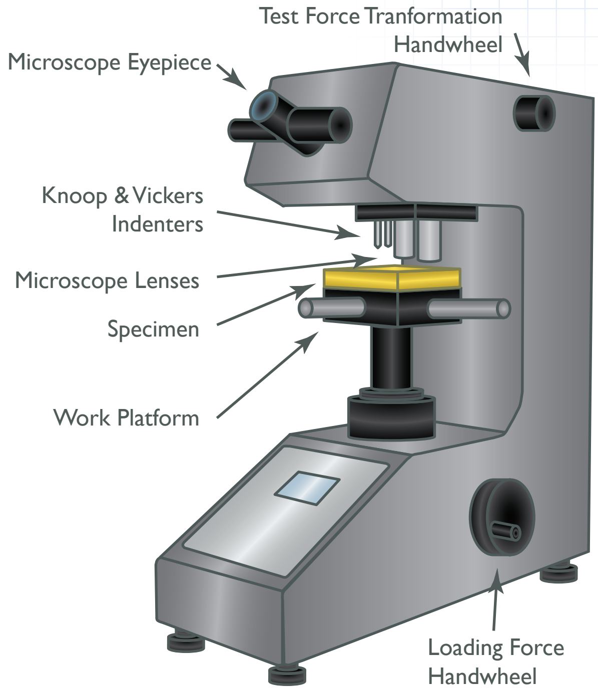
The Vickers test is similar in principle to the Brinell test. The standard Vickers penetrator is a square-based diamond pyramid having an included point angle of 136°. The numerical value of the hardness number equals the applied load in kilograms divided by the area of the pyramidal impression: a smooth, firmly supported, flat surface is required. The load, which is usually applied for 30 seconds, may be 5, 10, 20, 30, 50, or 120 kgf – 50 kgf being the most usual. The hardness number is based on the diagonal length of the square impression. The Vickers test is considered to be very accurate and may be applied to thin sheets as well as to larger sections with proper load regulation.

Microhardness Testing

To test very small or brittle materials or to study fine scale changes in hardness during multi-phase processes that alter surface hardness – intentionally or accidentally, microhardness (or micro-indentation) tests use light loads, indenters, and dwells. These tests are used for material evaluation, to measure the success of hardening treatments or maintain quality control of the manufacturing process, to detect and assess decarburization, and allow analysts to evaluate homogeneity in material samples.

Though microhardness may imply that the tests are used to measure "softer" materials, this is not the case. The microhardness test results are aligned with other testing equipment in that the indentions and applied loads produce the same hardness numbers as bulk tests.

The Micro-Vickers test and the Knoop tests are the two most common micro-indentation tests, however, a single material sample test may not reliably represent bulk hardness as they both reveal hardness variations.



MICROHARDNESS TESTING MACHINE

Micro-Vickers Test

The Micro-Vickers indenter usually produces a geometrically similar indentation at all test forces. Except for tests at very low forces that produce indentations with diagonals smaller than about 25 µm, the hardness number will essentially be the same as produced by Vickers machines with test forces greater than 1 kgf, as long as the material being tested is reasonably homogeneous. For isotropic materials, the two diagonals of a Micro-Vickers indentation are equal in size.

HOW A ROCKWELL TEST IS PERFORMED

The Rockwell Hardness Number is the difference between two controlled indentations superimposed on each other.

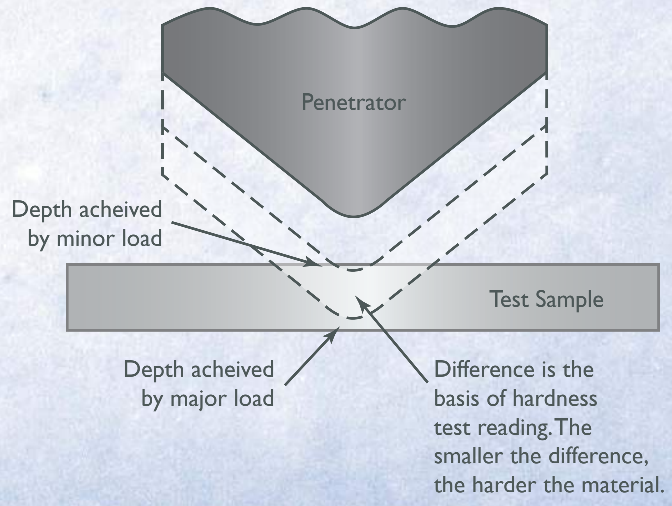
The first indentation is made by a minor load applied to a steel ball or diamond penetrator. Then, without moving the penetrator, a major load is applied at a precisely controlled rate.

The hardness determination is made by measuring the additional indentation made by the second major force. The scale is proportionally inverse, so that the higher the number, the shallower the indentations, therefore the harder the material.

In the Regular (R) Rockwell Scale the minor load is 10 kilograms of force (kgf) and the major load is 60, 100, or 150 kgf. In the Superficial (S) Rockwell Scale the minor load is 3 kgf and the major load is 15, 30, or 45 kgf.

To ensure accuracy, the major load is applied with precise control and the penetrators are manufactured to exact tolerances. Each point on the R hardness scale represents 0.00008″ and 0.00004″ on the S hardness scale, making the precision and control of these tests readily apparent.

ROCKWELL HARDNESS TEST



Knoop Test

The Knoop indenter does not produce a geometrically similar indentation as a function of test force. Consequently, Knoop hardness will vary with test force. Due to its rhombic shape, the indentation depth is shallower for a Knoop indentation compared to a Micro-Vickers indentation under identical test conditions. The two diagonals of a Knoop indentation are markedly different. Ideally, the long diagonal is 7.114 times longer than the short diagonal, but this ratio is influenced by elastic recovery. Thus, the Knoop indenter is very useful for evaluating hardness gradients or thin coatings of sectioned samples.

Relationship Between Hardness and Tensile Strength

The approximate relationship between the hardness and tensile strength is shown by the following formula:

Tensile strength (psi) = BHN x 515 (for Brinell numbers up to 175).

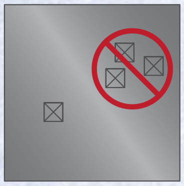
Tensile strength (psi) = BHN x 490 (for Brinell numbers larger than 175).

The above formulas give the tensile strength in pounds per square inch for steels. These approximate relationships between hardness and tensile strength do not apply to nonferrous metals with the possible exception of certain aluminum alloys.

Durometer Test

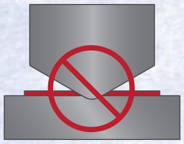
The durometer is a portable hardness tester for measuring hardness of rubber, plastics, and some soft metals. The instrument is designed to apply pressure to the specimen and the hardness is read from a scale while the pressure is maintained. Various scales can be used by changing the indenter and the load applied. ■

AVOIDING FAULTY ROCKWELL TESTS



Proximity

Penetrator indentions must be spaced at least two indentation diameters from the edge of the work piece and a minimum of two indentation diameters from any other indentions to determine true hardness.

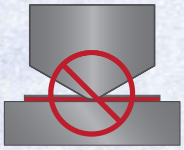


Material Thickness

Use a correct load/indenter combination relative to the thickness of the material. Tests will end up measuring anvil hardness and results will not be indicative of the true hardness of the sample piece.

No Stacking

Never stack multiple pieces of sample material. The interfaces between the strip will negatively affect the reading. Testing strip thickness needs to be at least 10x greater than the expected major load indentation depth.

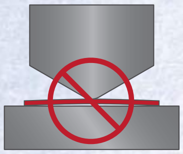


Do Not Test Plating

Plated and finished samples must be tested in cross sections so that indentations can be made entirely in the base metal. Plating and finishing materials are typically harder or softer than base metals.

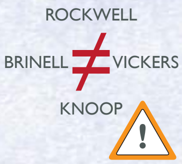
Calibration

Hardness testing devices must be kept in good working condition and calibrated every year. Use a test block of known hardness daily to verify that your equipment is calibrated correctly.



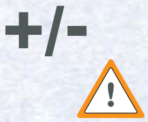
Curves

Bowed or twisted material will generate erroneous test results. Sample material must be flat and placed so that the bottom surface of the tested materials sits directly on the anvil.



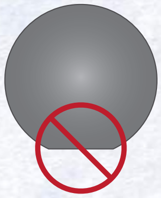
Avoid Conversions

Converting test results from one hardness scale to another may produce faulty results. If a material is certified to a specific test's hardness, the final part should be tested on the same scale.



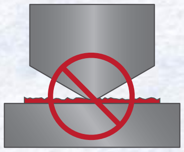
Tolerances

Hardness testing is toleranced with variables for plus or minus results. Refer to ASTM E10, ASTM E18, ASTM 392, ASTM E140, or ASTME E384 for specific allowances for your testing equipment.



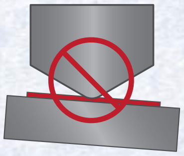
Indentors

Round ball indentors must be round. While steel ball indentors are less expensive than their tungsten carbide counterparts, steel is more likely to flatten during tests of very hard material samples.



Surface Preparation

Test surfaces need to be smooth in order to produce accurate results. Rough surfaces will not allow the penetrator to create clearly defined, measurable indentations.



Test Surface

In order to achieve consistent, accurate results, the test surface must be parallel or perpendicular to the indenter.

Portable Testers

Handheld testers are cost-effective and convenient, but they are not reliable substitutes for bench testing. They are best suited for comparison testing of unknown samples vs. known samples of the same type.

Rockwell Hardness Scales and Applications

Scale	Indenter	Minor Load (kgf)	Major Load (kgf)	Typical Application
Regular (R) Scale Applications				
HRA	Brale Diamond	10	60	Cemented carbides, thin steel, and shallow case hardened steel
HRB	1/16″ ball	10	100	Copper alloys, soft steels, aluminum alloys, and malleable iron
HRC	Brale Diamond	10	150	Steel, hard cast irons, pearlitic malleable iron, titanium, deep case hardened steel, and other materials harder than B100
HRD	Brale Diamond	10	100	Thin steel, medium case hardened steel and pearlitic malleable iron
HRE	1/16″ ball	10	100	Cast iron, aluminum and magnesium alloys, and bearing metals
HRF	1/16″ ball	10	60	Annealed copper alloys and thin soft sheet metals
HRG	1/16″ ball	10	150	Phosphor bronze, beryllium copper, malleable irons. Upper limit G92 to avoid possible flattening of ball
HRH	1/8″ ball	10	60	Aluminum, zinc, lead
HRK	1/8″ ball	10	150	Bearing metals and other very soft or thin materials, including plastics. Use the smallest ball and heaviest load that do not give anvil effect.
HRL	1/4″ ball	10	60	
HRM	1/4″ ball	10	100	
HRP	1/4″ ball	10	150	
HRR	1/2″ ball	10	60	
HRS	1/2″ ball	10	100	
HRV	1/2″ ball	10	150	
Superficial (S) Scale Applications				
15N	Brale Diamond	3	15	The Superficial Scale is suited to testing materials that do not have sufficient width or thickness to be tested on the Regular (R) Scale. These are typically very thin sheet metal, strip metal, wire, small rounds, nitrided steel, lightly carburized steel, heavily cyanided steel, tin plate, and other similar specimens or materials.
30N	Brale Diamond	3	30	
45N	Brale Diamond	3	45	
15T	1/16″ ball	3	15	
30T	1/16″ ball	3	30	
45T	1/16″ ball	3	45	
15W	1/8″ ball	3	15	
30W	1/8″ ball	3	30	
45W	1/8″ ball	3	45	
15X	1/4″ ball	3	15	
30X	1/4″ ball	3	30	
45X	1/4″ ball	3	45	
15Y	1/2″ ball	3	15	
30Y	1/2″ ball	3	30	
45Y	1/2″ ball	3	45	

COMPARISON OF HARDNESS SCALES

All tables are based on the assumption that the metal tested is homogeneous to a depth several times that of the indentation. To the extent that the metal being tested is not homogeneous, errors are introduced because different loads and different shapes of penetrators meet the resistance of metal of varying hardness, depending on the depth of indentation. Another source of error is introduced in comparing the hardness of different materials as measured on different hardness scales. This error arises from the fact that in any hardness test, metal that is severely cold-worked actually supports the penetrator, and different metals, different alloys, and different analyses of the same type of alloy have different cold-working properties. In spite of the possible inaccuracies introduced by these factors, it is of considerable value to be able to compare hardness values in a general way.

The data shown is based on extensive tests of carbon and alloy steels mostly in the heat treated condition, but have been found to be reliable on constructional alloy steels and tool steels in forged, annealed, normalized, quenched, and tempered conditions, providing they are homogeneous. These hardness comparisons are not as accurate for special alloys such as high manganese steel, 18/8 stainless steel, and other austenitic steels, nickel based alloys, constructional alloy steels, and cold-worked nickel based alloys.

The data shown is for hardness measurements of unhardened steel, steel of soft temper, gray and malleable cast iron, and most nonferrous metals. These hardness comparisons are not as accurate for annealed metals of high Rockwell B hardness such as austenitic stainless steel, nickel and high nickel alloys, and cold-worked metals of low B scale hardness such as aluminum and softer alloys.

Comparative Hardness Scales for Steel

Rockwell C Scale Hardness Number	Diamond Pyramid Hardness Vickers	Brinell Hardness Number 10-mm Ball, 3000 kgf Load			Rockwell Hardness Number		Rockwell Superficial Hardness Number Superficial Diameter Penetrator		
		Ball Type			Scale – Load Diameter Penetrator				
		Standard	Hultgren	Tungsten Carbide	A (60 kgf)	D (100 kgf)	15-N (15 kgf)	30-N (30 kgf)	45-N (45 kgf)
68	940	---	---	---	85.6	76.9	93.2	84.4	75.4
67	900	---	---	---	85.0	76.1	92.9	83.6	74.2
66	865	---	---	---	84.5	75.4	92.5	82.8	73.3
65	832	---	---	739	83.9	74.5	92.2	81.9	72.0
64	800	---	---	722	83.4	73.8	91.8	81.1	71.0
63	772	---	---	705	82.8	73.0	91.4	80.1	69.9
62	746	---	---	688	82.3	72.2	91.1	79.3	68.8
61	720	---	---	670	81.8	71.5	90.7	78.4	67.7
60	697	---	613	654	81.2	70.7	90.2	77.5	66.6
59	674	---	599	634	80.7	69.9	89.8	76.6	65.5
58	653	---	587	615	80.1	69.2	89.3	75.7	64.3
57	633	---	575	595	79.6	68.5	88.9	74.8	63.2

Table continued on next page.

Comparative Hardness Scales for Steel (cont.)

Rockwell C Scale Hardness Number	Diamond Pyramid Hardness Vickers	Brinell Hardness Number 10-mm Ball, 3000 kgf Load			Rockwell Hardness Number		Rockwell Superficial Hardness Number Superficial Diameter Penetrator		
		Ball Type			Scale – Load Diameter Penetrator				
		Standard	Hultgren	Tungsten Carbide	A (60 kgf)	D (100 kgf)	15-N (15 kgf)	30-N (30 kgf)	45-N (45 kgf)
56	613	---	561	577	79.0	67.7	88.3	73.9	62.0
55	595	---	546	560	78.5	66.9	87.9	73.0	60.9
54	577	---	534	543	78.0	66.1	87.4	72.0	59.8
53	560	---	519	525	77.4	65.4	86.9	71.2	58.6
52	544	500	508	512	76.8	64.6	86.4	70.2	57.4
51	528	487	494	496	76.3	63.8	85.9	69.4	56.1
50	513	475	481	481	75.9	63.1	85.5	68.5	55.0
49	498	464	469	469	75.2	62.1	85.0	67.6	53.8
48	484	451	455	455	74.7	61.4	84.5	66.7	52.5
47	471	442	443	443	74.1	60.8	83.9	65.8	51.4
46	458	432	432	432	73.6	60.0	83.5	64.8	50.3
45	446	421	421	421	73.1	59.2	83.0	64.0	49.0
44	434	409	409	409	72.5	58.5	82.5	63.1	47.8
43	423	400	400	400	72.0	57.7	82.0	62.2	46.7
42	412	390	390	390	71.5	56.9	81.5	61.3	45.5
41	402	381	381	381	70.9	56.2	80.9	60.4	44.3
40	392	371	371	371	70.4	55.4	80.4	59.5	43.1
39	382	362	362	362	69.9	54.6	79.9	58.6	41.9
38	372	353	353	353	69.4	53.8	79.4	57.7	40.8
37	363	344	344	344	68.9	53.1	78.8	56.8	39.6
36	354	336	336	336	68.4	52.3	78.3	55.9	38.4
35	345	327	327	327	67.9	51.5	77.7	55.0	37.2
34	336	319	319	319	67.4	50.8	77.2	54.2	36.1
33	327	311	311	311	66.8	50.0	76.6	53.3	34.9
32	318	301	301	301	66.3	49.2	76.1	52.1	33.7
31	310	294	294	294	65.8	48.4	75.6	51.3	32.5
30	302	286	286	286	65.3	47.7	75.0	50.4	31.3
29	294	279	279	279	64.7	47.0	74.5	49.5	30.1
28	286	271	271	271	64.3	46.1	73.9	48.6	28.9
27	279	264	264	264	63.8	45.2	73.3	47.7	27.8
26	272	258	258	258	63.3	44.6	72.8	46.8	26.7
25	266	253	253	253	62.8	43.8	72.2	45.9	25.5

Table continued on next page.

Comparative Hardness Scales for Steel (cont.)

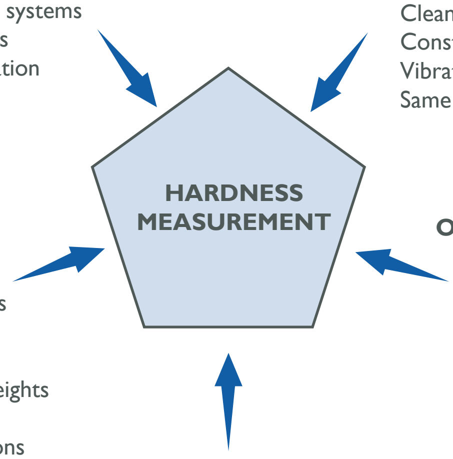
Rockwell C Scale Hardness Number	Diamond Pyramid Hardness Vickers	Brinell Hardness Number 10-mm Ball, 3000 kgf Load			Rockwell Hardness Number		Rockwell Superficial Hardness Number Superficial Diameter Penetrator		
		Ball Type			Scale – Load Diameter Penetrator				
		Standard	Hultgren	Tungsten Carbide	A (60 kgf)	D (100 kgf)	15-N (15 kgf)	30-N (30 kgf)	45-N (45 kgf)
24	260	247	247	247	62.4	43.1	71.6	45.0	24.3
23	254	243	243	243	62.0	42.1	71.0	44.0	23.1
22	248	237	237	237	61.5	41.6	70.5	43.2	22.0
21	243	231	231	231	61.0	40.9	69.9	42.3	20.7
20	238	226	226	226	60.5	40.1	69.4	41.5	19.6
(18)	230	219	219	219	---	---	---	---	---
(16)	222	212	212	212	---	---	---	---	---
(14)	213	203	203	203	---	---	---	---	---
(12)	204	194	194	194	---	---	---	---	---
(10)	196	187	187	187	---	---	---	---	---
(8)	188	179	179	179	---	---	---	---	---
(6)	180	171	171	171	---	---	---	---	---
(4)	173	165	165	165	---	---	---	---	---
(2)	166	158	158	158	---	---	---	---	---
(0)	160	152	152	152	---	---	---	---	---

Source: Machinery's Handbook, 26 ed.

Factors Influencing Hardness Testing

MEASUREMENT –
Verification of each measurement
Calibration of loading systems
Magnification of lenses
Uniformity of illumination

ENVIRONMENT –
Smooth specimen surface
Clean specimen
Constant temperature and humdity
Vibration free
Same conditions for each test



INSTRUMENT –
Load constant on all tests
Indentation
Indenter free of defects
Load cells rather than weights
Regularly calibrated
Widely spaced indentations

OPERATOR –
Clear understanding of equipment operation
Knowledge of surface requirements
Well versed in fixture techniques

MATERIAL –
Quality of specimen preparation
Reflectivity of specimen surface
Type of material
Shape of material

Tensile Strength Hardness Number Comparisons

Tensile Strength (approx.) ksi	Rockwell Hardness Number		Brinell Hardness Number
	B Scale	C Scale	
40	---	---	---
56	65.7	---	111
60	69.8	---	121
65	74.0	---	131
71	78.7	---	143
76	82.9	---	156
81	86.0	---	167
85	87.8	---	174
90	90.7	---	187
95	92.8	---	197
100	94.6	---	207
105	96.4	---	217
110	97.8	20.0	226
114	99.0	22.0	237
117	100.0	23.0	243
120	---	24.0	247
122	---	25.0	253
125	---	26.0	258
128	---	27.0	264
132	---	28.0	271
135	---	29.0	279
138	---	30.0	286
142	---	31.0	294
145	---	32.0	301
149	---	33.0	311
153	---	34.0	319
157	---	35.0	327
162	---	36.0	336
168	---	37.0	344
171	---	38.0	353
176	---	39.0	362
181	---	40.0	371
188	---	41.0	381
194	---	42.0	390
201	---	43.0	400
208	---	44.0	409
215	---	45.0	421
222	---	46.0	432

CHAPTER 8

FINISHING PROCESSES

Surface textures, conversion coatings, platings, and colorings.

In most cases, raw steel must be finished using one or more treatments – or secondary processes – to increase its surface hardness and durability. Though the primary purpose of finishing is to protect steel from oxidation and corrosion to extend its shelf life, a variety of other processes have been developed to increase wear resistance, electrical conductivity or resistance, or to improve its appearance by making it brighter or reflective, alter its color, or enhance it by etching, grinding, or polishing its surface. Some finishing processes affect torque tolerance, increase – or decrease – surface friction, improve solderability, or prep the surface for bonding to other materials such as adhesives, rubber (also known as vulcanizing), other metals, or organic coatings. *See "Steel Corrosion," page 82.*

Did you know that while plating is several hundred years old, the process has evolved to the point of being able to layer a metal coating a single atom thick.

Determining which finishing process will generate the best result depends on the application for which the steel is to be used. It is relatively common to simply clean and deburr finished parts by grinding or sandblasting them to remove rough edges and smooth out the surface of metal. Metal vibratory finishing equipment (tumblers) is also frequently used to remove minor imperfections such as dings and scratches in order to produce a uniform surface or appearance and to round and smooth sharp edges.

Anodizing Aluminum Alloys

In the anodizing process, aluminum objects to be treated are immersed as the anode in an acid electrolyte and a direct current is applied. Oxidation of the surface occurs producing a hard, porous film of aluminum oxide. The object is then immersed in boiling water, nylon, or other plastic to seal the porosity and render the film impermeable. Before sealing, the film can be colored by impregnation with dyes or pigments. Special electrolytes may also be used to produce colored anodic films directly in the anodizing bath. The anodic coatings are used primarily for corrosion protection and abrasion resistance, and as a paint base.

Black Oxide Coatings

Thin black oxide coatings are applied to steel by immersing the parts to be coated in a boiling solution of sodium hydroxide and mixtures of nitrates, and nitrites. These coatings serve as paint bases and, in some cases, final finishes. When the coatings are impregnated with oil or wax, they furnish fairly good corrosion resistance. These finishes are relatively inexpensive compared to other coatings and can be performed on large batches of small parts. Unlike paint or other plating processes, at only a micrometer thickness black oxide coatings do not alter the dimensions of finished parts.

Brushed Metal

A wire brush or a 120 grit – 180 grit rotating abrasive belt is used to remove surface imperfections and polish metal to create a uniform, parallel grain surface texture while slightly rounding edges perpendicular to the grain. While brushing produces an attractive pattern of very fine lines, the process exposes the bare metal to the environment making it prone to corrosion.

Buff Polishing

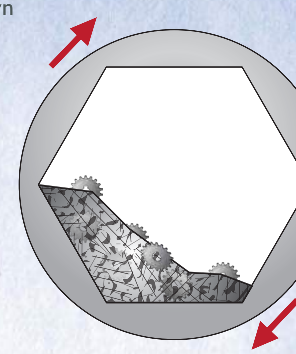
Similar to wet/dry sanding, a cloth wheel is used along with various grades of powdered aluminum oxide compounds and wax to buff metal surfaces to a smooth, non-textured finish with a high-gloss sheen. It is usually necessary to clean any residual compound from the surface and treat it with a corrosion-resistant coating.

Chromate Conversion Coatings

Conversion coatings are thin, adherent chemical compounds that are produced on metallic surfaces by chemical or electrochemical treatment. These coatings are insoluble, passive (less affected by environmental factors such as air and water), and protective; and are divided into two basic systems: oxides or mixtures of oxides with other compounds, usually chromates or phosphates. Conversion coatings are used for corrosion protection, as an adherent paint base; and for decorative purposes because of their inherent color and because they can absorb dyes and colored sealants.

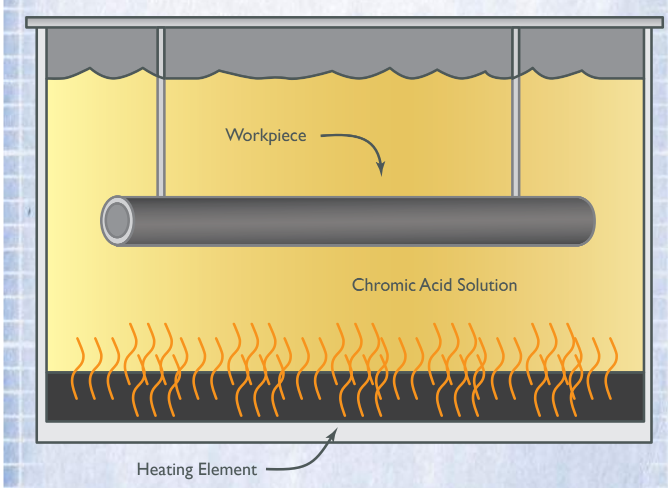
Conversion coatings are produced in three or four steps. First there is a pretreatment, which often involves mechanical surface preparation followed by degreasing and/or chemical or electrochemical cleaning or etching. Then

Mechanical Plating



Mechanical plating, also known as "ping plating," is an alternate coating method to electroplating and is used on heat treated parts in order to eliminate any opportunity for hydrogen embrittlement. *See "Baking," page 50.* In this method, parts are placed into a tumbler or vibrating device with zinc nuggets. The parts are vibrated, "pinging" the zinc into the surface. The absence of water and heat in the process does not enable hydrogen atoms to absorb into the parts. Mechanically plated parts have a dull finish and are not as bright as electroplated parts.

Chromate Conversion



After electroplating, chromate conversion is used to color parts and provide additional protection. Chromate conversion chemically alters the surface of a workpiece through the use of an acidic solution which decomposes the surface and creates a protective film of chromium compounds.

thermal, chemical, or electrochemical surface conversion processes take place in acid or alkaline solutions applied by immersion spraying, or brushing. A post treatment follows, which includes rinsing and drying, and may also include sealing or dyeing. If coloring is the main purpose of the coating, then oiling, waxing, or lacquering may be required.

Dip-Spin Coating

As the name suggests, parts pre-treated with zinc-phosphate coatings are dipped and spun to apply uniform coats of molydisulfides, zinc coatings, and dry film lubricants before they are dried and baked. Though considerably more expensive than traditional zinc plating, dip-spin coating is cost-effective when coating small parts in bulk in order to prevent the parts from sticking to each other. Benefits include higher transfer efficiency, and a significant reduction of problems related to hydrogen embrittlement. Dip-Spin coatings are an environmentally friendly alternative to traditional plating processes.

Dry Film Lubricants

Thin coatings of chemicals called dry or solid film lubes such as polytetrafluoroethylene (PTFE), Xylan, or a compound of graphite and molybdenum disulfide (MoS_2) are applied to metals to act as a lubricant for moving parts. These coatings provide an exceptional finish that minimizes friction and prevents seizing and galling in high or low temperature environments where traditional greases and oils might freeze or vaporize. Abrasion, chemical, and corrosion resistant, dry film coatings are nonflammable and durable enough to provide lubrication and wear resistance for the life of the part. However, dry film lubricants are not as corrosion resistant as other surface treatments.

Electroless Plating

Electroless plating is a nonelectrical plating process that uses a reducing chemical bath (an oxidation-reduction reaction) to deposit layers of complexed metals – such as copper, nickel, silver, gold, or palladium – to parts, evenly distributing on every exposed surface regardless of the complexity of the parts. This process is also used to deposit a conductive surface on a nonconductive object (like plastic) to allow it to be electroplated.

Electroplating

The most common process used to coat parts, electroplating (or electro-depositing) uses an electric potential to coat conductive parts with a thin layer of another metal to improve appearance, increase thickness, or improve wear and corrosion resistance. The metal to be plated, the cathode, is negatively charged and submerged into a solution of salt and metal sulfates that contains a bar of a positively charged metal, the anode – such as copper, chromium, silver, gold, zinc, or tin. When electric power is applied, electrolysis occurs and the anode gives up positive ions that migrate to and bond with the cathode to form an alloy coating as thin as 0.002″. The thickness of the coating on the cathode increases with the duration of the process.

Electropolishing

Similar to electroplating, electropolishing works in reverse to smooth and/or brighten metal surfaces anodically in a bath of concentrated acid or an alkaline solution. The metal to be polished is the positively charged anode and another conducting metal serves as the cathode. When electrified, oxygen gassing occurs and microscopic metal ions migrate from the anode to the cathode effectively cleaning the part through metallic dissolution. Electropolishing is often done to stainless steel as a final finish, or to base metals as a pre-plating operation.

Metal Grinding

A grinding machine uses a rotating drum affixed with an abrasive substrate to shape parts or remove small amounts of material to a desired tolerance through friction and compression to smooth a parts surface.

Substrates are comprised of materials of various hardness including aluminum oxide, silicon carbine, and super-abrasives such as cubic boron nitride (CBN) or diamonds. Grinding can produce finishes that are up to ten times more precise than turning or milling.

Passivation

Similar to anodizing, passivation is a process used to clean and prevent corrosion of stainless steel. Parts are cleaned with sodium hydroxide and citric acid before being immersed in a solution of nitric acid to dissolve iron and form a thin transparent chrome oxide film that produces a bright surface finish.

Phosphate Coatings

Phosphate coatings are applied to iron and steel parts by reacting them with a dilute solution of phosphoric acid and other chemicals. The surface of the metal is converted into an integral, mildly protective layer of insoluble crystalline phosphate. Small items are coated in tumbling barrels; large items are spray coated on conveyors.

The three types of phosphate coatings in general use are zinc, iron, and manganese. Zinc phosphate coatings vary from light to dark gray. The color depends on the carbon content and pretreatment of the steel's surface, as well as the composition of the solution. Zinc phosphate coatings are generally used as a base for paint or oil, as an aid in cold-working, for increased wear resistance, or for rustproofing. Iron phosphate coatings were the first type to be used; they produce dark gray coatings and their chief application is as a paint base. Manganese phosphate coatings are usually dark gray; however, since they are used almost exclusively as an oil base for break in and to prevent galling, they become black in appearance.

In general, stainless steels and certain alloy steels cannot be phosphated. Most cast irons and alloy steels accept coating with various degrees of difficulty depending on alloy content.

Vibratory Finishing

Machined parts are placed in a drum along with a substrate and abrasive pellets and vibrated to remove burrs and sharp edges while producing a uniform surface appearance.

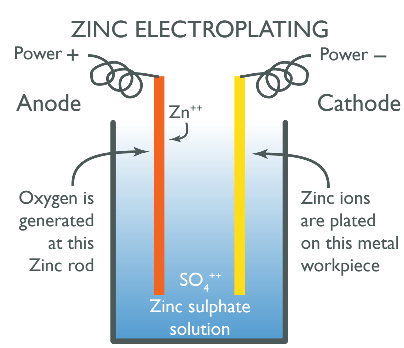
Powder Coating

Melted dry plastic powder is applied to parts as a decorative finish that removes surface defects while producing a textured, matte, or glossy coating similar to paint, but with greater durability.

Zinc Electroplating

Due to its low cost, versatility, corrosion resistance, and attractive appearance, zinc plating is one of the most common types of electroplating and serves as a barrier to oxidation for iron, steel, and other metals. Combined with nickel, cobalt, tin, or iron alloys, zinc forms a coating on the base metal that when exposed to corrosion sacrifices itself to delay the formation of rust on bare metal even after portions of the coating have been dissolved, scratched, or punctured.

Additionally, it provides excellent receptivity for chromate conversion coatings, does not undergo hydrogen embrittlement, and is a safer alternative to metal plating processes that use toxic materials such as cadmium. It is ductile and offers excellent adhesion and provides an effective undercoat for paint.



This examples describes zinc plating; however, many metals can be used as plating material.

Need help choosing a metal finishing process? G.L. Huyett has knowledgeable engineering support along with the ability to perform custom manufacturing. Give us a call today.

STEEL CORROSION

Corrosion is the gradual degradation or destruction of materials (usually metals) by electrochemical reaction with its environment. In the case of metals, it is the process of rusting – oxidation in reaction to oxygen forming iron oxides. It requires the simultaneous presence of water and oxygen and in the absence of either corrosion does not occur.

The process of steel corrosion occurs in stages. Initially, corrosion begins at anodic areas on the surface where ferrous ions go into solution. Electrons are released from the anodic surface site and travel through the metallic structure to adjacent cathodic sites where they combine with oxygen and water to form hydroxyl ions. These react with the ferrous ions from the anodic site to produce ferrous hydroxide, which itself is further oxidized in air to produce hydrated ferric oxide (rust). The chemical process can be represented with this equation:

Anodic sites release electrons and cathodic sites receive electrons forming the basis of the electrical circuit driving the corrosion process.

$$Fe + 3O_2 + 2H_2O = 2Fe_2O_3H_2O$$

Steel + Oxygen + Water = Rust (Hydrated ferric oxide)

After a period of time, accumulation of rust on the surface can cause the corrosion process to be suppressed. New anodic sites may form in adjacent areas allowing further corrosion. In this case, over long periods of time, the loss of metal is reasonably uniform over the surface, and this is usually described as general or uniform corrosion.

Common Forms of Corrosion

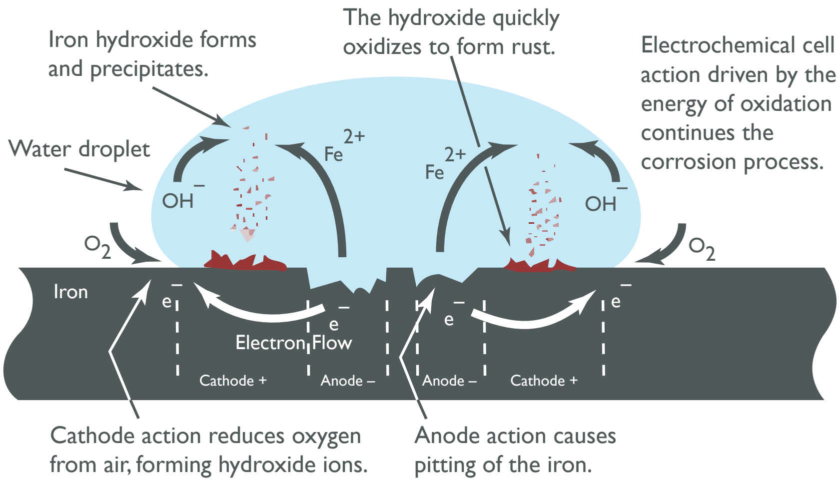
Many alloys corrode merely from exposure to moisture in air, but the process can be strongly affected by exposure to other substances. In addition to wide-area damage, corrosion can be concentrated locally to form a pit or crack. Because corrosion is a diffusion-controlled process, it occurs on exposed surfaces. As a result, methods to reduce the activity of the exposed surface, such as passivation and chromate conversion, can increase a material's corrosion resistance. However, some corrosion mechanisms are less visible and less predictable.

Uniform Attack Corrosion

Also known as general attack corrosion, this type is the most common and is caused by a chemical or electrochemical reaction that results in the deterioration of the entire exposed surface of a metal. Ultimately, the metal deteriorates to the point of failure.

Uniform attack corrosion accounts for the greatest amount of metal destruction by corrosion, but is considered a safe form of corrosion because it is predictable, manageable, and often preventable.

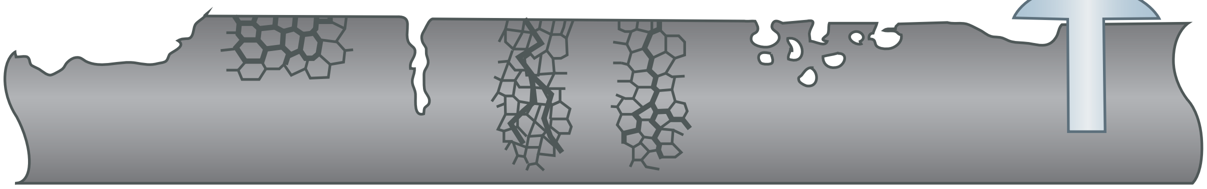
ELECTROCHEMICAL CORROSION PROCESS



Intergranular Corrosion

Intergranular corrosion is a chemical or electrochemical attack on the grain boundaries of a metal while the individual grains remain relatively intact. This often occurs due to impurities in the metal, which tend to be present in higher concentrations near grain boundaries, causing the boundaries to be more vulnerable than the bulk of the metal. The alloy eventually loses strength as the grains fall out.

COMMON TYPES OF STEEL CORROSION



Pitting Corrosion
Pitting results when a small hole or cavity forms in the metal, usually as a result of a small scratch, damage to the protective coating, or some other depassivation of a small area. This area becomes anodic, while part of the remaining metal becomes cathodic, producing a localized reaction. The deterioration of this small area penetrates the metal and can lead to failure. Pitting is often difficult to detect because it is usually relatively small and may be hidden by a layer of rust.

Stress Corrosion Cracking
This form of corrosion is caused by the combination of tensile stress and a corrosive medium. The surface of the structure can remain relatively untouched while fine cracks progress through the interior These cracks can be intergranular – proceeding along grain boundaries – or transgranular – cutting through individual grains. This type of stress can be disastrous because failure can occur within the design specifications of both stress and corrosion. Hydrogen embrittlement can also cause stress cracks and failure, but its mechanism and treatment is vastly different.

Selective Leaching Corrosion
Also known as dealloying corrosion, this type of corrosion attacks a specific element in an alloy. The most common type of dealloying is dezincification of unstabilized brass resulting in deteriorated and porous copper. Other alloy systems can lose aluminum, iron, cobalt, chromium, and other elements. Rather than describing each with its own label such as dezincification, they are all known as selective leaching.

Crevice Corrosion
Similar to pitting, crevice corrosion occurs in hidden locations such as under gaskets, washers, clamps, bolts, and screws. Acidic conditions or a depletion of oxygen in a crevice can lead to crevice corrosion.

Galvanic Corrosion
Galvanic corrosion, or dissimilar metal corrosion, occurs when two different metals are placed together in a corrosive electrolyte. A galvanic couple forms between the two metals, where one metal becomes the anode and the other the cathode. The anode, or sacrificial metal, corrodes and deteriorates faster than it would alone, while the cathode deteriorates more slowly than it would otherwise. Three conditions must exist for galvanic corrosion to occur: electrochemically dissimilar metals must be present, the metals must be in electrical contact, and the metals must be exposed to an electrolyte.

Flow-Assisted Corrosion
Flow-assisted corrosion, or flow-accelerated corrosion, results when a protective layer of oxide on a metal surface is dissolved or removed by wind or water, exposing the underlying metal to further corrode and deteriorate.

Fretting Corrosion
Fretting corrosion occurs in the form of pits and grooves on the surface as a result of repeated wearing, weight, and/or vibration on an uneven, rough surface. It is often found in rotation and impact machinery, bolted assemblies and bearings, and surfaces exposed to vibration during transportation.

G.L. Huyett applies a thin coating of rust inhibitor to all of its machined products to prevent the onset of corrosion.

Common Platings and Finishes

Plating, Coating, or Finish	For Use On	Degree of Corrosion Resistance	Characteristics
Rust inhibitors	All metals	Varies with type	Oils, greases, etc. Vary in color and film thickness. Usually applied to black oxide finishes. Used to protect parts in temporary storage.
Zinc, electroplated	All metals	Very good	Blue to blue-white-gray color.
Cadmium, electroplated	Most metals	Excellent	Bright, silver-gray, or black finish. Particularly effective corrosion protection in marine applications. Used for decorative purposes. High lubricity.
Clear chromate finish	Zinc and cadmium plated parts	Very good to excellent	Clear bright or iridescent chemical conversion coating applied to plated parts to enhance corrosion protection, coloring, and paint bonding.
Dichromate	Zinc and cadmium plated parts	Very good to excellent	Yellow, brown, green, or iridescent colored coating same as chromate.
Color chromate finish	Zinc and cadmium plated parts	Very good to excellent	Olive drab, blue, gold, bronze, etc. Same as clear chromate.
Zinc or manganese phosphate	Steel	Good	Black in color. Added protection when oiled with a nondrying petroleum oil containing corrosion inhibitors. Good lubricity.
Color phosphate coatings	Steel	Superior to regular phosphate and oiled surfaces	Chemically produced color coating. Available in blue, green, red, purple, etc.
Hot-dip zinc	All metals	Very good	Gives maximum corrosion protection. Dull grayish color. Necessitates thread size adjustments to permit assemblability.
Hot-dip aluminum	Steel	Very good	Gives maximum corrosion protection. Dull grayish color. Necessitates thread size adjustments to permit assemblability.
Mechanically deposited zinc	Steel	Very good	Dull gray, smooth finish. Corrosion protection depends on coating thickness. Good coverage in recesses and thread roots.
Tin, electroplated	All metals	Excellent	Silver-gray color. Excellent corrosion protection for parts in contact with food.
Hot-dip tin	All metals	Excellent	Same as electroplated but thickness is harder to control.
Lead-tin	Steel, usually	Fair to good	Silver-gray, dull coating. Applied by hot-dip method. Helps lubricity.
Silver, electroplated	All metals	Excellent	Decorative, expensive, excellent electrical conductor.
Chromium, electroplated	Most metals	Good (improves with copper and nickel undercoats)	Bright, blue-white, lustrous finish. Has relatively hard surface. Used for decorative purposes or to add wear resistance.

Table continued on next page.

Common Platings and Finishes (cont.)

Plating, Coating, or Finish	For Use On	Degree of Corrosion Resistance	Characteristics
Copper, electroplated	Most metals	Fair	Used for nickel and chromium plate undercoat. Can be blackened and relieved to obtain Antique, Statuary, and Venetian finishes.
Brass, electroplated, lacquered	Steel, usually	Fair	Brass electroplated which is then lacquered. Recommended only for indoor decorative use.
Bronze, electroplated, lacquered	Steel, usually	Fair	Has color similar to 80% copper, 20% zinc alloy. Electroplated and then lacquered. Recommended only for indoor decorative use.
Copper, brass, bronze, miscellaneous finishes	Most metals	Indoor, very good	Decorative finishes. Applied to copper, brass, and bronze plated parts to match colors. Color and tone vary from black to almost the original color. Finish names are: Antique, Black Oxide, Statuary, Old English, Venetian, and Copper Oxidized.
Bright nickel	Most metals	Indoor, excellent. Outdoor, good if thickness at least 0.0005″.	Electroplated silver-colored finish. Used for appliances, hardware, etc.
Dull nickel	Most metals	Same as bright nickel	Whitish cast. Can be obtained by mechanical surface finishing or a special plating bath.
Lacquering, clear or color-matched	All metals	Improves corrosion resistance. Some types designed for humid or other severe applications.	Used for decorative finishes. Clear or colored to match mating color or luster.
Anodizing	Aluminum	Excellent	Acid electrolytic treatment. Frosty-etched appearance. Hard oxide surface gives excellent protection.
Passivating	Stainless Steel	Excellent	Chemical treatment. Removes iron particles and produces a passive surface.

MILITARY PLATING & COATING SPECIFICATIONS

Anodizing (Chromic and Sulfuric), MIL-A-8625F
Conventional types I, IB, and II anodic coatings are intended to improve surface corrosion protection under severe conditions or as a base for paint systems. Coatings can be colored with a large variety of dyes and pigments. Class 1 is nondyed; Class 2 is dyed. Color is to be specified on the contract. Prior to dying or sealing, coatings shall meet weight requirements.

Type I and IB coatings should be used on fatigue critical components (due to thinness of coating). Type I, unless otherwise specified, shall not be applied to aluminum alloys with over 5% copper or 7% silicon or total alloying constituents over 7.5%. Type IC is a mineral or mixed mineral/organic acid that anodizes. It provides a non-chromate alternative for type I and IB coatings where corrosion resistance, paint adhesion, and fatigue resistance are required. Type IIB is a thin sulfuric anodizing coating for use as non-chromate alternatives for type I and IB coatings where corrosion resistance, paint adhesion, and fatigue resistance are required. Be sure to specify the class of anodic coating and any special sealing requirements.

Types I, IB, IC, and IIB must have a thickness 0.00002″ – 0.0007″. Type II must have a thickness 0.0007″ – 0.0010″.

Black Oxide Coating, MIL-C-13924C
A uniform, mostly decorative black coating for ferrous metals used to decrease light reflection. Provides only very limited corrosion protection under mild corrosion conditions. Black oxide coatings should normally be given a supplementary treatment.

Used for moving parts that cannot tolerate the dimensional change of a more corrosion resistant finish. Use alkaline oxidizing for wrought iron, cast and malleable irons, plain carbon, low alloy steel, and corrosion resistant steel alloys. Alkaline-chromite oxidizing may be used on certain corrosion resistant steel alloys tempered at less than 900°F. Salt oxidizing is suitable for corrosion resistant steel alloys that are tempered at 900°F or higher.

Cadmium Plating, QQ-P-416F
Cadmium plating is required to be smooth, adherent, uniform in appearance, free from blisters, pits, nodules, burning, and other defects when examined visually without magnification. Unless otherwise specified in the engineering drawing or procurement documentation, the use of brightening agents in the plating solution to modify luster is prohibited on components with a specified heat treatment of 180 ksi minimum tensile strength (or 40 Rockwell C) and higher. Either a bright (not caused by brightening agents) or dull luster shall be acceptable. Baking on types II and III shall be done prior to application of supplementary coatings. For Classes 1, 2, and 3 the minimum required thicknesses is 0.0005″, 0.0003″, and 0.0002″ respectively.

Type I is to be used as plated. Types II and III require supplementary chromate and phosphate treatment respectively. Chromate treatment required for type II may be colored iridescent bronze to brown including olive drab, yellow and forest green. Type II is recommended for corrosion resistance. Type III is used as a paint base and is excellent for plating stainless steels that are to be used in conjunction with aluminum to prevent galvanic corrosion. For types II and III the minimum cadmium thickness requirement must be met after the supplementary treatment.

Lubrication, Solid Film, MIL-L-46010D
This specification establishes the requirements for three types of heat cured solid film lubricants that are intended to reduce wear and prevent galling, corrosion, and seizure of metals. For use on aluminum, copper, steel, stainless steel, titanium, chromium, and nickel bearing surfaces.

Types I, II, and III must have a thickness 0.008 mm – 0.013 mm with no single reading less than 0.005 mm or greater than 0.018 mm.

Type I has a curing temperature of 150 ± 15°C and an endurance life of 250 minutes; type II, 204 ± 15°C and 450 minutes; and type III is a low volatile organic compound (VOC) content lubricant with cure cycles of 150 ± 15°C for two hours, or 204 ± 15°C for one hour with an endurance life of 450 minutes. Color 1 has a natural product color and Color 2 has a black color.

Nickel Plating, QQ-N-290A

There is a nickel finish for almost any need. Nickel can be deposited soft, hard, dull, or bright, depending on the process used and conditions employed in plating. Thus, hardness can range 150 – 500 Vickers. Nickel can be similar to stainless steel in color, or can be a dull gray (almost white) color. Corrosion resistance is a function of thickness. Nickel has a low coefficient of thermal expansion.

All steel parts having a tensile strength of 1517 MPa (megapascal) or greater cannot be nickel plated without specific approval of procuring agency.

Class 1 is used for corrosion protection. Plating must be applied over an underplating of copper or yellow brass on zinc and zinc based alloys. In no case, may the copper underplating be substituted for any part of the specified nickel thickness. Class 2 is used in engineering applications.

Grade A has a thickness of 0.0016″; Grade B, 0.0012″; Grade C, 0.001″; Grade D, 0.0008″; Grade E, 0.0006″; Grade F, 0.0004″; and Grade G, 0.002″.

Phosphate Coating – Heavy, DOD-P-16232-F

The primary differences are that type M is used as a heavy manganese phosphate coating for corrosion and wear resistance and type Z is used as a zinc phosphate coating.

Type M has a thickness 0.0002″ – 0.0004″ and type Z, 0.0002″ – 0.0006″. Class 1, for both types, has a supplementary preservative treatment or coating as specified; Class 2 has a supplementary treatment with lubricating oil; and Class 3 does not require a supplementary treatment.

For type M, Class 4 is chemically converted (may be dyed to color as specified) with no specified supplementary coating. For type Z, Class 4 is the same as Class 3.

This coating is for medium and low alloy steels. The coatings range from gray to black in color. The “heavy” phosphate coatings covered by this specification are intended as a base for holding/retaining supplemental coatings which provide the major portion of the corrosion resistance. “Light” phosphate coatings used for a paint base are covered by other specifications. Heavy zinc phosphate coatings may be used when paint and supplemental oil coatings are required on various parts or assemblies.

Zinc Coatings, ASTM-B633

This specification covers requirements for electro-deposited zinc coatings applied to iron or steel articles to protect them from corrosion. It does not cover zinc-coated wire or sheets. Type I will be as plated; type II will have colored chromate conversion coatings; type III will have colorless chromate conversion coatings; and type IV will have phosphate conversion coatings.

High strength steels (tensile strength over 1700 MPa) must not be electroplated.

Stress relief: All parts with an ultimate tensile strength of 1000 MPa and above must be baked at a minimum of 190°C for three hours or more **before** cleaning and plating.

Hydrogen embrittlement relief: All electroplated parts with an ultimate tensile strength of 1200 MPa or higher must be baked at 190°C for three hours or more within four hours **after** electroplating.

Environmental Concerns

G.L. Huyett is committed to maintaining the safety of our environment. The processes for plating and coating steels have the potential of introducing harmful chemical substances to the environment and are strictly controlled. G.L. Huyett complies with all environmental regulations and laws which apply to our products and services.

Two major directives introduced by the European Union address the effort to control hazardous substances and find alternatives to their use.

REACH – Registration, Evaluation, Authorization, and Restriction of Chemical Substances

As defined by the European Commission: "REACH is the European Community Regulation on chemicals and their safe use (EC 1907/2006). It deals with the Registration, Evaluation, Authorization, and Restriction of Chemical substances. The law entered into force on June 1, 2007. The aim of REACH is to improve the protection of human health and the environment through the better and earlier identification of the intrinsic properties of chemical substances. The REACH Regulation places greater responsibility on industry to manage the risks from chemicals and to provide safety information on the substances. Manufacturers and importers are required to gather information on the properties of their chemical substances, which will allow their safe handling, and to register the information in a central database run by the European Chemicals Agency (ECHA) in Helsinki, Finland. The Agency acts as the central point in the REACH system: it manages the databases necessary to operate the system, coordinates the in-depth evaluation of suspicious chemicals and is building up a public database in which consumers and professionals can find hazard information.

"The Regulation also calls for the progressive substitution of the most dangerous chemicals when suitable alternatives have been identified. For more information visit http://ec.europa.eu/environment/chemicals/reach/publications_en.htm.

"One of the main reasons for developing and adopting the REACH Regulation was that a large number of substances have been manufactured and placed on the market in Europe for many years, sometimes in very high amounts, and yet there is insufficient information on the hazards that they pose to human health and the environment. There is a need to fill these information gaps to ensure that industry is able to assess hazards and risks of the substances, and to identify and implement the risk management measures to protect humans and the environment."

IMDS – International Material Data System

IMDS is a global data repository for product content used by the automotive industry and used to gather information for use in reporting requirements for directives such as REACH. It is the global standard for the industry and has been in place since the 1990's with over 90,000 participating companies and suppliers. Because it is a computer-based system, IMDS recognizes hazardous substances by comparing the entered data with the lists of prohibited substances. Hence OEMs can trace hazardous substances back to the part and work on eliminating them through the supply chain.

All substances have to be stated in the material data sheet (MDS) of the IMDS with a resolution of 1 gram or better – not just the

G.L. Huyett is committed to maintaining the safety of our environment and complies with all regulations and laws which apply to our products and services.

declarable and prohibited substances (Cr (VI), Hg, etc.). That is why substances and materials of products must be known in detail.

The basic premise of the system is that the flow of data through IMDS companies mimics the flow of the product through companies in the physical world with each link in the supply chain supplying data in IMDS to their customer as they deliver product to their customer.

RoHS – Restriction of Hazardous Substances

European Union legislation restricting the use of hazardous substances in electrical and electronic equipment (RoHS Directive 2002/95/EC) and promoting the collection and recycling of this equipment (WEEE Directive 2002/96/EC) has been in force since February 2003. The legislation provides for the creation of collection schemes where consumers return their used e-waste free of charge. The objective of these schemes is to increase the recycling and/or re-use of these products. It also requires heavy metals such as lead, mercury, cadmium, and hexavalent chromium and flame retardants such as polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) to be substituted by safer alternatives.

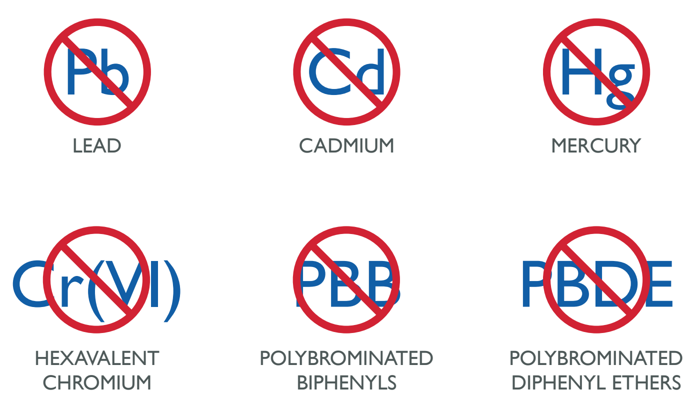
Inadequately treated e-waste poses environmental and health risks. In December 2008, the European Commission therefore proposed to revise the directives on electrical and electronic equipment in order to tackle the fast increasing waste stream of these products. The aim is to increase the amount of e-waste that is appropriately treated and to reduce the volume that goes to disposal. The aim of the RoHS recast was also to reduce administrative burdens and ensure coherency with newer policies and legislation covering, for example, chemicals and the new legislative framework for the marketing of products in the European Union. The RoHS Recast Directive was published in the Official Journal on July 01, 2011. ■

Dodd-Frank Section 1502: Conflict Minerals

On August 22, 2012, the Securities and Exchange Commission of the U.S. issued a final rule on conflict minerals pursuant to Dodd-Frank Section 1502. The rule describes the assessment and reporting requirements for manufacturers whose products contain conflict minerals, with these minerals being specifically named in the SEC rule – tin, tantalum, tungsten, and gold.

As stated by the SEC, "Section 1502 requires persons to disclose annually whether any conflict minerals that are necessary to the functionality or production of a product of the person, as defined in the provision, originated in the Democratic Republic of the Congo or an adjoining country and, if so, to provide a report describing, among other matters, the measures taken to exercise due diligence on the source and chain of custody of those minerals, which must include an independent private sector audit of the report that is certified by the person filing the report. Certain aspects of this rule-making will require consultation with other federal agencies, including the State Department, the Government Accountability Office, and the Commerce Department. Persons are not required to comply with these rules until their first full fiscal year after the date on which the Commission issues its final rules."

BANNED ROHS MATERIALS



CHAPTER 9

CONVERSION CHARTS

Converting between imperial and metric measurements.

The following charts are provided for convenience. Generally, G.L. Huyett parts possessing U.S. standard (inch) based numbers will have all dimensions expressed in inches, while metric number specifications will be metric dimensions. As an example, a one foot piece of metric keystock will be called out as 305 mm – the metric equivalent of one foot.

Did you know the metric system we use today is a direct result of the French Revolution?

Linear Measure Conversions

1 kilometer = 0.6214 mile
1 meter = 39.37 inches
1 meter = 3.2808 feet
1 meter = 1.0936 yards
1 centimeter = 0.3937 inch
1 millimeter = 0.03937 inch
1 mile = 1.609 kilometers
1 yard = 0.9144 meter
1 foot = 0.3048 meter
1 foot = 304.8 millimeters
1 inch = 2.54 centimeters
1 inch = 25.4 millimeters

To convert millimeters to inches:
multiply millimeters by 0.03937

To convert inches to millimeters:
divide inches by 0.03937

Weight Conversions

1 metric ton = 1.1023113 ton (U.S. short)
1 kilogram = 2.2046226 pounds (U.S.)
1 kilogram = 35.273962 ounces (U.S.)
1 kilogram/millimeter^2 = 1422.32 pounds/inch^2
1 ton (U.S. short) = 0.90718474 metric ton
1 pound (U.S.) = 0.45359237 kilogram
1 ounce (U.S.) = 0.028349523 kilogram
1 pound/inch^2 = 0.00703 kilogram/millimeter^2

Metric Conversion Factors

Multiply	By	To Obtain
Length		
centimeter	0.03280840	foot (′)
centimeter	0.3937008	inch (″)
foot	0.3048[a]	meter (m)
inch	25.4[a]	millimeter (mm)
kilometer	0.6213712	mile [U.S. statute]
microinch	0.0254[a]	micrometer [micron] (μm)
micrometer [micron]	39.37008	microinch
mile [U.S. statute]	1.609344[a]	kilometer (km)
millimeter	0.003280840	foot (′)
millimeter	0.03937008	inch (″)
Area		
$foot^2$	0.09290304[a]	$meter^2$ (m^2)
$inch^2$	645.16[a]	$millimeter^2$ (mm^2)
$meter^2$	10.763910	$foot^2$
$mile^2$	2.5900	$kilometer^2$
Volume (including Capacity)		
gallon {U.S. liquid]	3.785412	liter
liter	0.2641720	gallon [U.S. liquid]
Velocity, Acceleration, Flow		
kilometer/hour	0.6213712	mile/hour [U.S. statute]
mile/hour	1.609344[a]	kilometer/hour
Force and Force/Length		
newton/meter	0.005710148	pound/inch
pound-foot	1.355818	newton-meter (N-m)
$newton/meter^2$	0.0001450377	$pound/inch^2$
Convert From	**Formula**	**Convert To**
Temperature		
temperature Celsius, t_C	$(1.8\ t_C) + 32$	temperature Fahrenheit, t_F
temperature Fahrenheit, t_F	$(t_F - 32) / 1.8$	temperature Celsius, t_C

a) The figure is exact.
Symbols of International System of Units (SI units), multiples and sub-multiples are given in parentheses in the right-hand column.

Metric and English Equivalents – Use of Conversion Tables

On the following pages, tables are provided that permit conversion from imperial to metric units and vice versa over a wide range of values. Where the desired value cannot be obtained directly from these tables, a simple addition of two or more values taken directly from the table will suffice as shown in the following examples:

Example 1: Find the millimeter equivalent of 0.4476 inch.

0.4″	=	10.16000 mm
0.04″	=	1.01600 mm
0.007″	=	0.17780 mm
+ 0.0006″	=	0.01524 mm
0.4476″	=	11.36904 mm

Example 2: Find the inch equivalent of 84.9 mm.

80.0 mm	=	3.14961″
4.0 mm	=	0.15748″
+ 0.9 mm	=	0.03543″
84.9 mm	=	3.34252″

U.S. Pound to Kilogram and Kilogram to U.S. Pound Conversion Table

Pound to Kilogram (1 lb. = 0.4535924 kg)

lb.	kg	lb.	kg	lb.	kg	lb.	kg	lb.	kg
1,000	453.59	100	45.36	10	4.54	1	0.45	0.1	0.05
2,000	907.18	200	90.72	20	9.07	2	0.91	0.2	0.09
3,000	1,360.78	300	136.08	30	13.61	3	1.36	0.3	0.14
4,000	1,814.37	400	181.44	40	18.14	4	1.81	0.4	0.18
5,000	2,267.96	500	226.80	50	22.68	5	2.27	0.5	0.23
6,000	2,721.55	600	272.16	60	27.22	6	2.72	0.6	0.27
7,000	3,175.15	700	317.51	70	31.75	7	3.18	0.7	0.32
8,000	3,628.74	800	362.87	80	36.29	8	3.63	0.8	0.36
9,000	4,082.33	900	408.23	90	40.82	9	4.08	0.9	0.41
10,000	4,535.92	1,000	453.59	100	45.36	10	4.54	1.0	0.45

Kilograms to Pounds (1 kg = 2.204622 lb.)

kg	lb.	kg	lb.	kg	lb.	kg	lb.	kg	lb.
1,000	2,204.62	100	220.46	10	22.05	1	2.20	0.1	0.22
2,000	4,409.24	200	440.92	20	44.09	2	4.41	0.2	0.44
3,000	6,613.87	300	661.39	30	66.14	3	6.61	0.3	0.66
4,000	8,818.49	400	881.85	40	88.18	4	8.82	0.4	0.88
5,000	11,023.11	500	1,102.31	50	110.23	5	11.02	0.5	1.10
6,000	13,227.73	600	1,322.77	60	132.28	6	13.23	0.6	1.32
7,000	15,432.35	700	1,543.24	70	154.32	7	15.43	0.7	1.54
8,000	17,636.98	800	1,763.70	80	176.37	8	17.64	0.8	1.76
9,000	19,841.60	900	1,984.16	90	198.42	9	19.84	0.9	1.98
10,000	22,046.22	1,000	2,204.62	100	220.46	10	22.05	1.0	2.20

Inches to Millimeters and Millimeters to Inches Conversion Table

Inches to Millimeters (1″= 25.4 mm)

in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
10	254.00	1	25.40	0.1	2.54	0.01	0.254	0.001	0.0254	0.0001	0.00254
20	508.00	2	50.80	0.2	5.08	0.02	0.508	0.002	0.0508	0.0002	0.00508
30	762.00	3	76.20	0.3	7.62	0.03	0.762	0.003	0.0762	0.0003	0.00762
40	1016.00	4	101.60	0.4	10.16	0.04	1.016	0.004	0.1160	0.0004	0.01016
50	1270.00	5	127.00	0.5	12.70	0.05	1.270	0.005	0.1270	0.0005	0.01270
60	1524.00	6	152.40	0.6	15.24	0.06	1.524	0.006	0.1524	0.0006	0.01524
70	1778.00	7	177.80	0.7	17.78	0.07	1.778	0.007	0.1778	0.0007	0.01778
80	2032.00	8	203.20	0.8	20.32	0.08	2.032	0.008	0.2032	0.0008	0.02032
90	2286.00	9	228.60	0.9	22.86	0.09	2.286	0.009	0.2286	0.0009	0.02286
100	2540.00	10	254.00	1.0	25.40	0.10	2.540	0.010	0.2540	0.0010	0.02540

Millimeters to Inches (1 mm = 0.03937″)

mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
100	3.93701	10	0.39370	1	0.03937	0.1	0.00394	0.01	0.00039	0.001	0.00004
200	7.87402	20	0.78740	2	0.07874	0.2	0.00787	0.02	0.00079	0.002	0.00008
300	11.81102	30	1.18110	3	0.11811	0.3	0.01181	0.03	0.00118	0.003	0.00012
400	15.74803	40	1.57480	4	0.15748	0.4	0.01575	0.04	0.00157	0.004	0.00016
500	19.68504	50	1.96850	5	0.19685	0.5	0.01969	0.05	0.00197	0.005	0.00020
600	23.62205	60	2.36220	6	0.23622	0.6	0.02362	0.06	0.00236	0.006	0.00024
700	27.55906	70	2.75591	7	0.27559	0.7	0.02756	0.07	0.00276	0.007	0.00028
800	31.49606	80	3.14961	8	0.31496	0.8	0.03150	0.08	0.00315	0.008	0.00031
900	35.43307	90	3.54331	9	0.35433	0.9	0.03543	0.09	0.00354	0.009	0.00035
1000	39.37008	100	3.93701	10	0.39370	1.0	0.03937	0.10	0.00394	0.010	0.00039

Decimal Equivalents of Fractions of an Inch

Fraction	Decimal	Fraction	Decimal	Fraction	Decimal
1/64	0.015625	11/32	0.34375	43/64	0.671875
1/32	0.03125	23/64	0.359375	11/16	0.6875
3/64	0.046875	3/8	0.375	45/64	0.703125
1/16	0.0625	25/64	0.390625	23/32	0.71875
5/64	0.078125	13/32	0.40625	47/64	0.734375
3/32	0.09375	27/64	0.421875	3/4	0.750
7/64	0.109375	7/16	0.4375	49/64	0.765625
1/8	0.125	29/64	0.453125	25/32	0.78125
9/64	0.140625	15/32	0.46875	51/64	0.796875
5/32	0.15625	31/64	0.484375	13/16	0.8125
11/641	0.171875	1/2	0.500	53/64	0.828125
3/16	0.1875	33/64	0.515625	27/32	0.84375
13/64	0.203125	17/32	0.53125	55/64	0.859375
7/32	0.21875	35/64	0.546875	7/8	0.875
15/64	0.234375	9/16	0.5625	57/64	0.890625
1/4	0.250	37/64	0.578125	29/32	0.90625
17/64	0.265625	19/32	0.59375	59/64	0.921875
9/32	0.28125	39/64	0.609375	15/16	0.9375
19/64	0.296875	5/8	0.625	61/64	0.953125
5/16	0.3125	41/64	0.640625	31/32	0.96875
21/64	0.328125	21/32	0.65625	63/64	0.984375

Fractions of an Inch to Millimeters Conversion Table

in.	mm	in.	mm	in.	mm	in.	mm
1/64	0.3962	17/64	6.7462	33/64	13.0962	49/64	19.4462
1/32	0.7325	9/32	7.1425	17/32	13.4925	25/32	19.8425
3/64	1.1887	19/64	7.5387	35/64	13.8887	51/64	20.2387
1/16	1.5875	5/16	7.9375	9/16	14.2875	13/16	20.6375
5/64	1.9837	21/64	8.3337	37/64	14.6837	53/64	21.0337
3/32	2.3800	11/32	8.7300	19/32	15.0800	27/32	21.4300
7/64	2.7762	23/64	9.1262	39/64	15.4762	55/64	21.8262
1/8	3.1750	3/8	9.5250	5/8	15.8750	7/8	22.2250
9/64	3.5712	25/64	9.9212	41/64	16.2712	57/64	22.6212
5/32	3.9675	13/32	10.3175	21/32	16.6675	29/32	23.0175
11/64	4.3637	27/64	10.7137	43/64	17.0637	59/64	23.4137
3/16	4.7625	7/16	11.1125	11/16	17.4625	15/16	23.8125
13/64	5.1587	29/64	11.5087	45/64	17.8587	61/64	24.2087
7/32	5.5550	15/32	11.9050	23/32	18.2550	31/32	24.6050
15/64	5.9512	31/64	12.3012	47/64	18.6512	63/64	25.0012
1/4	6.3500	1/2	12.7000	3/4	19.0500	1	25.4000

UNITS OF FORCE CONVERSION

The use of the Newton as a unit of force is of particular interest to engineers. In practical work using the English or traditional metric systems of measurements, it is a common practice to apply weight units as force units. The unit of force in those systems is a force that when applied to unit mass produces an acceleration *g* rather than unit acceleration. The value of gravitational acceleration *g* varies around the earth, so the weight of a given mass also varies. In an effort to account for this minor error, the kilogram-force and pound-force were introduced, which are defined as the forces due to "standard gravity" acting on bodies of one kilogram or one pound mass, respectively. The standard gravitational acceleration is taken as 0.80665 meters per second squared or 0.174 feet per second squared. The Newton is defined as "that force, which when applied to a body having a mass of one kilogram, gives it an acceleration of one meter per second squared." It is independent of *g*. As a result, the factor *g* disappears from a wide range of formulas in dynamics. However, in some formulas in statics, where the weight of a body is important rather than its mass, *g* does appear where it was formerly absent (the weight of a mass of W kilograms is equal to a force of W *g* Newtons, where *g* = approximately 0.81 meters per second squared).

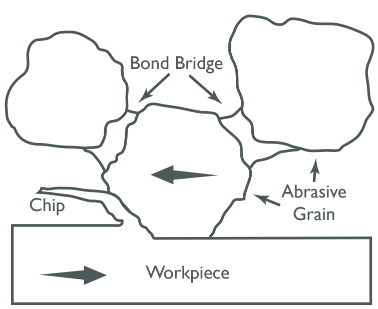
Pound-Force-Inches to Newton-Meters and Newton-Meters to Pound-Force-Inches Conversion Table

Pound-Inches to Newton-Meters (1 lbf-in = 0.1129848 N-m)									
lbf-in	N-m	lbf-in	N-m	lbf-in	N-m	lbf-in	N-m	lbf-in	N-m
100	11.298	10	1.130	1	0.113	0.1	0.011	0.01	0.001
200	22.597	20	2.260	2	0.226	0.2	0.023	0.02	0.002
300	33.895	30	3.390	3	0.339	0.3	0.034	0.03	0.003
400	45.194	40	4.519	4	0.452	0.4	0.045	0.04	0.005
500	56.492	50	5.649	5	0.565	0.5	0.056	0.05	0.006
600	67.791	60	6.779	6	0.678	0.6	0.068	0.06	0.007
700	79.089	70	7.909	7	0.791	0.7	0.079	0.07	0.008
800	90.388	80	9.039	8	0.904	0.8	0.090	0.08	0.009
900	101.686	90	10.169	9	1.017	0.9	0.102	0.09	0.010
1,000	112.985	100	11.298	10	1.130	1.0	0.113	0.10	0.011
Newton-Meters to Pound-Inches (1 N-m = 8.850748 lbf-in)									
N-m	lbf-in	N-m	lbf-in	N-m	lbf-in	N-m	lbf-in	N-m	lbf-in
100	885.07	10	88.51	1	8.85	0.1	0.89	0.01	0.09
200	1770.15	20	177.01	2	17.70	0.2	1.77	0.02	0.18
300	2655.22	30	265.52	3	26.55	0.3	2.66	0.03	0.27
400	3540.30	40	354.03	4	35.40	0.4	3.54	0.04	0.35
500	4425.37	50	442.54	5	44.25	0.5	4.43	0.05	0.44
600	5310.45	60	531.04	6	53.10	0.6	5.31	0.06	0.53
700	6195.52	70	619.55	7	61.96	0.7	6.20	0.07	0.62
800	7080.60	80	708.06	8	70.81	0.8	7.08	0.08	0.71
900	7965.67	90	796.57	9	79.66	0.9	7.97	0.09	0.80
1,000	8850.75	100	885.07	10	88.51	1.0	8.85	0.10	0.89

GLOSSARY

A

Abrasive
Garnet, emery, carborundum, aluminum oxide, silicon carbide, diamond, cubic boron nitride, or other material in various grit sizes used for grinding, lapping, polishing, honing, pressure blasting, and other operations. Each abrasive particle acts like a tiny, single-point tool that cuts a small chip; with hundreds of thousands of points doing so, high metal removal rates are possible while providing a good finish.



ABRASIVE

Abrasive Band
Diamond or other abrasive-coated endless band fitted to a grinding band machine for machining hard-to-cut materials.

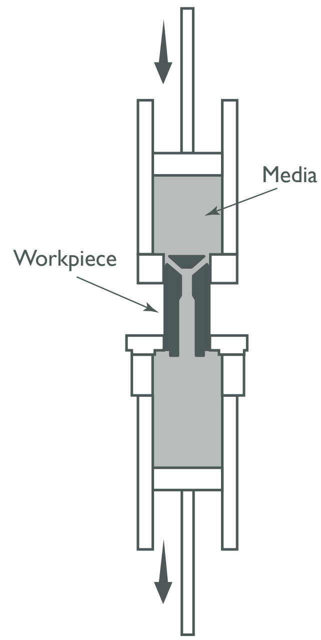
Abrasive Belt
Abrasive-coated belt used for production finishing, deburring, and similar functions. *See coated abrasive.*

Abrasive Cutoff Disc
Blade-like disc with abrasive particles that parts stock in a slicing motion.

Abrasive Cutoff Machine
Machine that uses blade-like discs impregnated with abrasive particles to cut/part stock. *See saw, sawing machine.*

Abrasive Cutoff Saw
See abrasive cutoff machine.

Abrasive Flow Machining
Finishing operation for holes, inaccessible areas, or restricted passages. Done by clamping the part in a fixture, then extruding semisolid abrasive media through the passage. Often, multiple parts are loaded into a single fixture and finished simultaneously.



ABRASIVE FLOW MACHINE

Abrasive Machining
Various grinding, honing, lapping, and polishing operations that utilize abrasive particles to impart new shapes, improve finishes, and part stock by removing metal or other material. *See grinding.*

Abrasive Waterjet (AWJ)
System that uses high-pressure waterjets in combination with a

slurry of fine abrasive grains to machine materials. *See waterjet cutting.*

Abrasive-wire Band Sawing
A variation of band sawing that uses a small-diameter wire with diamond, cubic boron nitride (CBN), or aluminum-oxide abrasives bonded to the surface as the cutting blade. Abrasive-wire band sawing is an alternative to electrical-discharge machining for product dies, stripper plates, electrodes, and cams from difficult-to-machine conductive and nonconductive materials. *See band sawing.*

Additive
Sulfur, chlorine, and other materials added to cutting fluids to improve lubricity, stabilize oil emulsions, and prevent chip welding under high heat and pressure. *See cutting fluid.*

Admixture
Mixture of concentrate and water prepared to restore depleted cutting fluid to its original state.

Age Hardening
Hardening of a heat treated material that occurs slowly at room temperature and more rapidly at higher temperatures. Usually follows rapid cooling or cold-working.

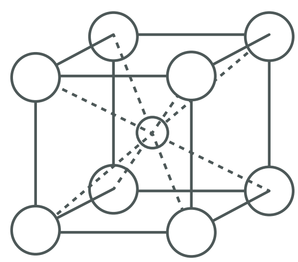
Aging
A change in the properties of certain metals and alloys that occurs at ambient or moderately elevated temperatures after a hot-working operation or a heat treatment (quench aging in ferrous alloys, natural or artificial aging in ferrous and nonferrous alloys) or after a cold-working operation (strain aging). The change in properties is often, but not always, due to a phase change (precipitation), but never involves a change in chemical composition of the metal or alloy.

Aluminum Oxide (Al_2O_{3r})
Abrasive material for grinding tools, Al_2O_{3r} is also the base for ceramics and is used to coat tools.

Alloy
A substance having metallic properties and being composed of two or more chemical elements of which at least one is a metal.

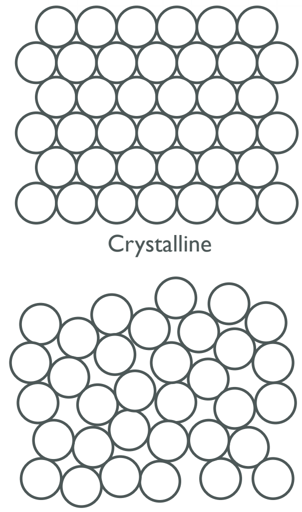
Alloying Element
An element that is added to a metal to change the metal's properties.

Alpha Iron
The body-centered cubic (BCC) form of pure iron, stable below 1,670°F.


BODY-CENTERED CUBIC LATTICE (BCC)

Aluminizing
Formation of an aluminum or aluminum-alloy coating on a metal by hot-dipping, hot-spraying, or diffusion.

Amorphous
Not having a crystal structure; noncrystalline.



GRAIN STRUCTURE OF STEEL

Angle Plate
Solid adjustable or nonadjustable plate that holds work at a precise angle to the spindle during milling and grinding. Also used for other cutting operations and inspection.

Annealing
Softening a metal by heating it to and holding at a controlled temperature, then cooling it at a controlled rate. Also performed to produce simultaneously desired changes in other properties or in microstructure. The purposes of these changes include improvement of machinability, facilitation of cold-working, improvement of mechanical or electrical properties, and/or increase in stability of dimensions. Types of annealing include blue, black, box, bright, full, intermediate, isothermal, quench, and recrystallization.

Arbor
Shaft used for rotary support in machining applications. In grinding, the spindle for mounting the wheel; in milling and other cutting operations, the shaft for mounting the cutter.

Arithmetical Average (AA)
Mathematical expression denoting surface finish or surface texture. Represents the average difference between peaks and valleys on the workpiece surface, measured in microinches.

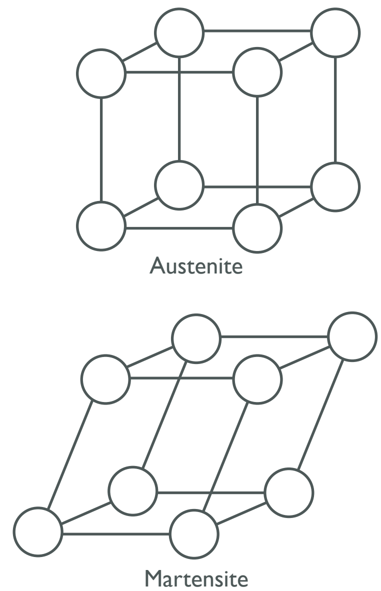
Assembly
Joining together two or more parts to complete a structure.

Atmospheric Corrosion
The gradual degradation or alteration of a material by contact with substances present in the atmosphere; such as oxygen, carbon dioxide, water vapor, sulfur and chlorine compounds.

Ausforming
Hot deformation of metastable austenite within controlled ranges of temperature and time that avoids formation of non-martensitic transformation products.

Austempering
A heat treatment for ferrous alloys in which a part is quenched from the austenitizing temperature at a rate fast enough to avoid formation of ferrite or pearlite, and then held at the appropriate transformation temperature to achieve the desired characteristics. Austempering at lower temperatures (460°F – 518°F) produces a part with maximum strength, while austempering at higher temperatures (680°F – 716°F) yields high ductility and toughness.

Austenite
Metallurgical term for a material that forms when carbon steel is heated above 1,355°F and the iron-carbide compounds within the steel dissolve. Quenching the carbon steel at this point replaces the austenite with martensite, which has an angular molecular structure and high hardness.



PHASE STRUCTURES OF STEEL

Austenitizing
Heating an alloy above its transformation temperature and then quenching it in a salt bath or other medium that extracts the heat at a sufficiently high rate to prevent formation of undesirable high-temperature-transformation qualities on its surface or in its microstructure. *See austenite; martensiting.*

Automatic Bar Machine
Production machine for turning barstock. Similar to an automatic chucking machine except that stock size is limited to through-the-spindle capacity and work is held by push, draw, or stationary collets rather than by chucks. *See automatic chucking machine; turning machine.*

Automatic Chucking Machine
Machine with multiple chucks and tool-holding spindles that permits either processing of several parts simultaneously or multiple machining steps in one pass through the machine. *See automatic bar machine.*

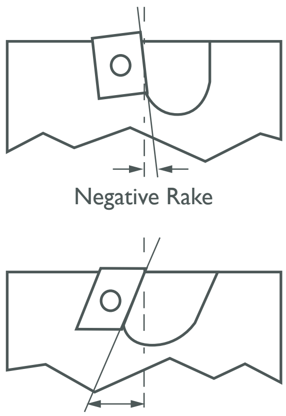
Automatic Screw Machine
Turning machine designed to produce parts automatically from coil or barstock. The two basic types are cam (mechanical) and programmable (computer-controlled). Usually single-spindle, but "Swiss types" often have multiple spindles. *See lathe; turret lathe.*

Automatic Tool Changer
Automatic mechanism typically included in a machining center that, on the appropriate command, will remove one cutting tool from the spindle nose and replace it with another. The changer restores the used tool to the magazine, and selects and withdraws the next desired tool from the storage magazine. The tool changer is controlled by a set of prerecorded/predetermined instructions associated with the part(s) to be produced.

Automation
Approach under which all or part of a machining or manufacturing process is accomplished by setting in motion a sequence that completes the process without further human intervention. May be mechanical (controlled by stops, cams, etc.), electrical (relays, contact switches, etc.), or electronic (computer- or microprocessor-controlled). "Fully

automated" implies computer integrated manufacturing.

Axial Rake
On angular tool flutes, the angle between the tooth face and the axial plane through the tool point.



AXIAL RAKE

B

Backing
Flexible portion of a bandsaw blade; also the support material behind the cutting edges of tools, and the base material for coated abrasives.

Backlash
A reaction in dynamic motion systems where potential energy that was created while the object was in motion is released when the object stops. The release of this potential energy or inertia causes the device to quickly snap backwards relative to the last direction of motion. Backlash can cause a system's final resting position to be different from intended and from where the control system intended to stop the device.

Back-off
Rapid withdrawal of the tool from the workpiece.

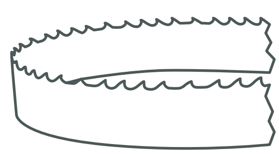
Back Rest
Support that mounts on a cylindrical grinder to prevent deflection when grinding long, small-diameter stock.

Bactericide
Material added to cutting fluids to inhibit bacterial growth. *See fungicide*.

Bainite
A metastable aggregate of ferrite and cementite resulting from the transformation of austenite at temperatures below the pearlite range. Its appearance is feathery if formed in the upper part of the bainite transformation range; acicular, resembling tempered martensite, if formed in the lower part.

Baking
(1) Heating to a low temperature to remove gases. (2) Curing or hardening surface coatings such as paints by exposure to heat. (3) Heating to drive off moisture, as in the baking of sand cores after molding. Often used after plating or welding, or when the presence of hydrogen is suspected, to prevent embrittlement.

Band; Bandsaw Blade
Endless band, normally with serrated teeth, that serves as the cutting tool for cutoff or contour band machines.

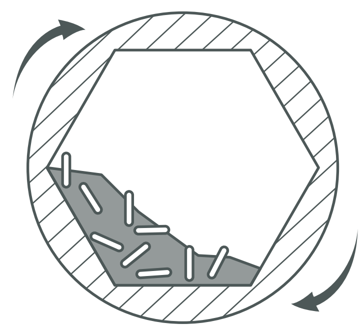


BANDSAW BLADE

Band Polishing
A variation of band sawing that uses an abrasive band to smooth or polish parts previously sawed or filed.

Band Sawing
Power band sawing, often called band machining, uses a long endless band with many small teeth traveling over two or more wheels (one is a driven wheel, and the others are idlers) in one direction. The band, with only a portion exposed, produces a continuous and uniform cutting action with evenly distributed low, individual tooth loads. Band sawing machines are available in a wide variety of types to suit many different applications. *See saw, sawing machine*.

Barrel Finishing
A mass finishing process. It involves low-pressure abrasion resulting from tumbling workpieces in a barrel (usually of hexagonal or octagonal cross section) together with an abrasive slurry. *See finishing*.



BARREL TUMBLER

Bend Test
A test for determining relative ductility of metal that is to be formed (usually sheet, strip, plate or wire) and for determining soundness and toughness of metal (after welding, for example). The specimen is usually bent over a specified diameter through a specified angle for a specified number of cycles.

Black Oxide
A black finish on a metal produced by immersing it in hot oxidizing salts or salt solutions.

Blocks
Work-holding devices used on milling machines. Styles include step, finger-holding, telescoping, and quick-clamp.

Bonded Abrasive
Abrasive grains mixed with a bonding agent. The mixture is pressed to shape and then fired in a kiln or cured. Forms include wheels, segments, cup wheels, etc. Bond types include oxychloride, vitrified, silicate, metal, resin, plastic, rubber, and shellac. Another type of bond is electroplating, wherein the abrasive grains are attached to a backing by a thick layer of electroplated material.

Boring
Enlarging a hole that has already been drilled or cored. Generally, it is an operation of truing the previously drilled hole with a single-point, lathe-type tool. Boring is essentially internal turning, in that usually a single-point cutting tool forms the internal shape. Some tools are available with two cutting edges to balance cutting forces.

Boring Bar
Essentially a cantilever beam that holds one or more cutting tools in position during a boring operation. Can be held stationary and moved axially while the workpiece revolves around it, or revolved and moved axially while the workpiece is held stationary, or a combination of these actions. Boring bars are installed on milling, drilling, and boring machines, as well as lathes and machining centers.

Boring Cutter
Cutting tool mounted in a boring bar (the holder) that enlarges a cored or drilled hole. May be a single-point or multiple-cutting-edge tool. Can be adjustable.

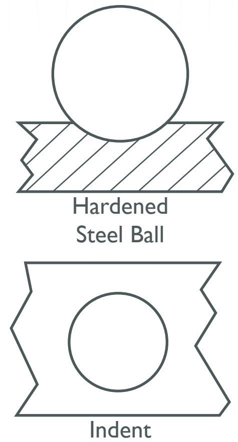
Boring Tool
See boring cutter.

Boring Machine
Similar to a turning machine except that the cutting tool (single-point or multiple cutting-edge), rather than the workpiece, rotates to perform internal cuts. However, boring can be accomplished by holding the tool stationary and turning the workpiece. Takes a variety of vertical, slanted, and horizontal forms, and has one or more spindles. Typically a large, powerful machine, it can readily hold tolerances to ten-thousandths of an inch. *See jig bore; lathe; turning machine.*

Boundary Additives
Sulfur, chlorine, and other materials added to cutting fluids to fill in surface irregularities at the tool/workpiece interface, creating a lubricating film. *See lubricity.*

Brale
A spheroconical-shaped diamond penetrator used with a Rockwell hardness tester. This penetrator is used for the A, C, D, and N scales for testing hard metals. *See hardness tester; Rockwell Hardness Text.*

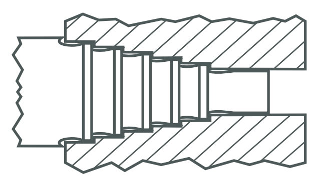
Brinell Hardness Test
Determines the hardness of a material by forcing a hard steel or carbide ball of specified diameter into it under a specified load. The result is expressed as the Brinell Hardness Number, which is the value obtained by dividing the applied load in kilograms by the surface area of the resulting impression in square millimeters.



BRINELL HARDNESS TEST

Broach
Tapered tool, with a series of teeth of increasing length, that is pushed or pulled into a workpiece, successively removing small amounts of metal to enlarge a hole, slot, or other opening to final size.

Broaching
An operation in which a cutter progressively enlarges a slot or hole, or shapes a workpiece exterior. Low teeth start the cut, intermediate teeth remove the majority of the material, and the high teeth finish the task. Broaching can be a one-step operation, as opposed to milling and slotting, which require repeated passes. Typically, however, broaching also involves multiple passes.


BROACHING

Broaching Machine
Machine designed specifically to run broaching tools; typically designated by operating characteristics (pull, push, rotary, continuous, blind spline), type of power used (hydraulic, mechanical), and tonnage ratings. Broaching is also performed on arbor presses (manual and powered).

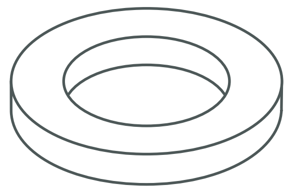
Brushing
Use of rapidly spinning wires or fibers to effectively and economically remove burrs, scratches, and similar mechanical imperfections from precision and highly stressed components. The greatest application has been made in the manufacture of gears and bearing races where the removal of sharp edges and stress risers by power methods has increased the speed of the operation.

Built-up Edge (BUE)
Material from workpiece that adheres to cutting tool during cutting.

Buffing
Smoothing and brightening a surface by pressing an abrasive compound, embedded in a soft wheel or belt, against the workpiece.

Burr
Stringy portions of material formed on workpiece edges during machining. Often sharp; can be removed with hand files, abrasive wheels or belts, wire wheels, abrasive-fiber brushes, waterjet equipment, or vibratory tumbling.

Bushing
A cylindrical sleeve, typically made from high-grade tool steel, inserted into a jig fixture to guide cutting tools. There are three main types: renewable, used in liners that in turn are installed in the jig; press-fit, installed directly in the jig for short production runs; and liner (or master), installed permanently in a jig to receive renewable bushings.



BUSHING

C

Calibration
Checking measuring instruments and devices against a master set to ensure that, over time, they have remained dimensionally stable and nominally accurate.

Cam-cutting Attachment
Device for cutting face, peripheral, or cylindrical cams from flat cam-former stock.

Canned Cycle
Subroutine or full set of programmed numerical control or computer numerical control steps initiated by a single command. Operations are done in a set order; the beginning condition is returned to when the cycle is completed.

Carbide
Compound of carbon and one or more metallic elements. For cutting tools, tungsten carbide, or a combination of these in a cobalt or nickel matrix provides hardness, wear resistance, and heat resistance. Other elements added to carbide include vanadium, niobium, silicon, boron, and hafnium.

Carbon Steel
Steel combined with varying amounts of carbon. Has no specified minimum quantity for any alloying element (other than the commonly accepted amounts of manganese, silicon, and copper) and contains only an incidental amount of any element other than carbon, silicon, manganese, copper, sulfur, and phosphorus.

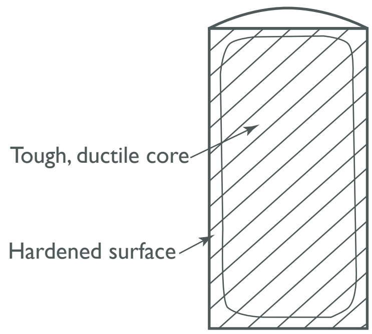
Carbonitriding
Case hardening metal by heating it in a mixture of carbon and nitrogen and by controlling the cooling rate; allows carbon to enter the surface microstructure.

Carburizing
Absorption and diffusion of carbon into solid ferrous alloys by heating, to a temperature usually above the upper transformation temperature, in contact with a suitable carbonaceous material. A form of case hardening that produces a carbon gradient extending inward from the surface, enabling the surface layer to be hardened either by quenching directly from the carburizing temperature or by cooling to room temperature, then reaustenitizing and quenching.

Carriage Stop
Mechanical device placed on the lathe head or ways to prevent over-travel that might damage the machine or workpiece.

Case Hardening
A generic term covering several processes applicable to steel that change the chemical composition of the surface layer by absorption of carbon, nitrogen, or a mixture of the two and, by diffusion, create a concentration gradient. The processes commonly used are

carburizing and quench hardening, cyaniding, nitriding, and carbonitriding. The use of the applicable specific process name is preferred.



CASE HARDENING

Cast Alloy
Alloy cast from the molten state; most high-speed steel is melted in an electric-arc furnace and cast into ingots.

Cast Iron
A generic term for a large family of cast ferrous alloys in which the carbon content exceeds the solubility of carbon in austenite at the eutectic temperature. Most cast irons contain at least 2% carbon, plus silicon and sulfur, and may or may not contain other alloying elements. For the various forms – gray cast iron, white cast iron, malleable cast iron and ductile cast iron – the word "cast" is often left out.

Cavity Cutting
Machining entirely within the body of a workpiece.

Cell Manufacturing
Grouping processes, equipment, and people together to manufacture a specific family of parts. Highly automated and able to change over quickly to produce a different part within the family of parts. *See family of parts; group technology.*

Center Drill
Drill used to make mounting holes for work to be held between centers. Also used to pre-drill holes for subsequent drilling operations.

Center Drilling
Drilling tapered holes for mounting work between centers. Center-drilled holes also serve as preliminary "starter" holes for drilling larger holes in the same location. *See drilling.*

Center Rest
Support provided at the center of the working area of a cylindrical grinder to prevent part deflection during grinding.

Centering
Process of locating the center of a workpiece to be mounted on centers. Also, the process of mounting the workpiece concentric to the machine spindle.

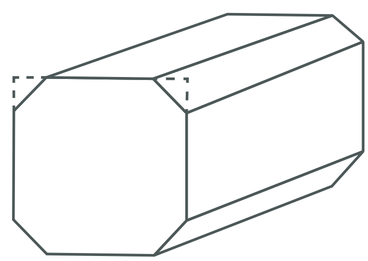
Centerless Grinding
Grinding operation in which the workpiece rests on a knife-edge support, rotates through contact with a regulating or feed wheel, and is ground by a grinding wheel. This method allows grinding long, thin parts without steady rests; also experiences lessened taper problems. Opposite of cylindrical grinding. *See grinding; cylindrical grinding.*

Cementite
Fe_3C, also known as iron carbide.

Centers
Cone-shaped pins that support a workpiece by one or two ends during machining. The centers fit into holes drilled in the workpiece ends. Centers that turn with the work are called "live" centers; those that do not are called "dead" centers.

Ceramic
Made from finely powdered aluminum oxide sintered into the desired form. Ceramics operate at higher speeds than carbides, plus they wear longer, provide smoother finishes, and can machine harder materials. They are, however, less shock-resistant. Typically used for high-speed turning.

Chamfering
Machining a bevel on a workpiece or tool to improve the tool's entrance into the cut.


CHAMFERING

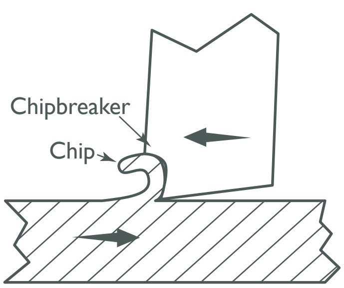
Chamfering Tool
Cutter or wheel that creates a beveled edge on a tool or workpiece.

Charpy Test
A pendulum-type, single-blow impact test in which the specimen, usually notched, is supported at both ends as a simple beam and broken by a falling pendulum. The energy absorbed, as determined by the subsequent rise of the pendulum, is a measure of impact strength or notch toughness. *See impact test; Izod test.*

Chatter
Irregularity in cutting action caused by tool or workpiece vibration, resulting in noise, poor finish, and possible damage to tool and work. May be the result of improper tool geometry, the wrong feed and speed, a loose setup, or worn machinery.

Chip
Small piece of material removed from a workpiece by a cutting tool.

Chipbreaker
Groove or other tool feature that breaks chips into small fragments as they come off the workpiece. Designed to prevent chips from becoming so long that they are difficult to control, catch in turning parts, and cause safety problems.

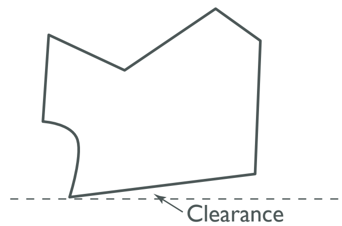


Chuck
Work-holding device that affixes to a mill, lathe, or drill press spindle. It holds a tool or workpiece by one end, allowing it to be rotated. May also be fitted to the machine table to hold a workpiece. Two or more adjustable jaws actually hold the tool or part. May be actuated manually, pneumatically, hydraulically, or electrically. *See collet; magnetic chuck.*

Circular Saw
Cutoff machine utilizing a circular blade with serrated teeth. *See saw; sawing machine.*

Circular Saw Blade
Cutting tool for a cold or circular saw. Round with serrated cutting teeth.

Clearance
Space provided behind a tool's land or relief to prevent rubbing and subsequent premature deterioration of the tool. *See relief.*



Coated Abrasive
Flexible-backed abrasive. Grit is attached to paper, fiber, cloth, or film. Types include sheets, belts, flap wheels, and discs.

Cold-working
Deforming metal plastically under conditions of temperature and strain rate that induce strain hardening. Working below the recrystallization temperature, which is usually, but not necessarily, above room temperature.

Collet
Flexible-sided device that secures a tool or workpiece. Similar in function to a chuck, but can accommodate only a narrow size range. Typically provides greater gripping force and precision than a chuck.

Commercial-grade Tool Steel
Low-grade tool steel; not controlled for hardenability.

Composites
Materials composed of different elements, with one element normally embedded in another, held together by a compatible binder.

Computer-aided Design (CAD)
Product-design functions performed with the help of computers and special software.

Computer-aided Manufacturing (CAM)
Use of computers to control machining and manufacturing.

Computer Numerical Control (CNC)
Microprocessor-based controller dedicated to a machine tool that permits the creation or modification of parts. Programmed numerical control activates the machine's servos and spindle drives, and controls the various machining operations. It can easily hold tolerances to ten-thousandths of an inch. *See DNC, direct numerical control; NC, numerical control.*

Concentrate
Agents and additives that, when added to water, create a cutting fluid.

Continuous Casting
A casting technique in which a cast shape is continuously withdrawn through the bottom of the mold as it solidifies, so that its length is not determined by mold dimensions. Used chiefly to produce semi-finished mill products such as billets, blooms, ingots, slabs, and tubes.

Contouring Attachment
Handwheel-operated mechanism for holding and guiding the work while sawing contours on a contour bandsaw.

Coolant
Fluid that reduces temperature buildup at the tool/workpiece interface during machining. Normally takes the form of a liquid such as soluble oil or chemical mixtures (semisynthetic, synthetic), can be pressurized air or other gas. Because of water's ability to absorb great quantities of heat, it is widely used as a coolant and vehicle for various cutting compounds, with the water-to-compound ratio varying with the machining task. *See cutting fluid; semisynthetic cutting fluid; soluble oil cutting fluid; synthetic cutting fluid.*

Cooling
The process of reducing the heat content of a tool, part, assembly, or material. Cooling may be required for a variety of reasons: to improve tool life, increase cutting speeds, and ensure workpiece tolerances by controlling expansion. Electrical and computer equipment requires cooling to maintain a safe operating temperature. When heat treating metal parts, part of the process is cooling, either by air, water, or oil.

Corrosion
The chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties.

Corrosion Fatigue
The process in which a metal fractures prematurely under conditions of simultaneous corrosion and repeated cyclic loading at lower stress levels or fewer cycles than would be required in the absence of the corrosive environment.

Corrosion Resistance
Ability of an alloy or material to withstand rust and corrosion; properties fostered by nickel and chromium in alloys such as stainless steel.

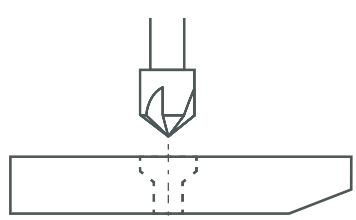
Counterbalancing
Use of weights or mechanisms to balance a workpiece, grinding wheel, rotating tool, or other device. Minimizes machining vibration and maximizes cutting force.

Counterbore
Tool, guided by a pilot, that expands a hole to a certain depth.

Counterboring
The process of enlarging one end of a drilled hole, which is concentric with the original hole and is flat on the bottom. Counterboring is used primarily to set bolt heads and nuts below the workpiece surface.

Countersink
Tool that cuts a sloped depression at the top of a hole to permit a screw head or other object to rest flush with the surface of the workpiece.

Countersinking
Cutting a beveled edge at the entrance of a hole so a screw head sits flush with the workpiece surface. *See counterboring; spotfacing.*



COUNTERSINKING

Cratering
Depressions formed on the face of a cutting tool, caused by heat, pressure, and the motion of chips moving across the tool's surface.

Creep-feed Grinding
Grinding operation in which the grinding wheel is slowly fed into the work at sufficient depth of cut to accomplish in one pass what otherwise would require repeated passes.

Creep-rupture Test
See stress-rupture test.

Curtain Application
Arrangement of multiple nozzles that apply fluid to a broad cutting area, as is found on a horizontal post-type band machine or a large hacksaw.

Cutter Compensation
A feature that allows the operator to compensate for tool diameter, length, deflection, and radius during a programmed machining cycle.

Cutter Path
Path followed by the tool in machining the part.

Cutting Fluid
Liquid used to improve workpiece machinability, enhance tool life, flush out chips and machining debris, and cool the workpiece and tool. Three basic types are: straight oils; soluble oils, which emulsify in water; and synthetic fluids, which are water-based chemical solutions having no oil. *See coolant; soluble oil cutting fluid; synthetic cutting fluid.*

Cutting-velocity Vector
Vector or direction the tool's cutting edge takes as a result of the interplay of forces applied and generated during the chip-making process.

Cutoff
Step that prepares a slug, blank, or other workpiece for machining or other processing by separating it from the original stock. Performed on lathes, chucking machines, automatic screw machines, and other turning machines. Also performed on milling machines, machine centers with slitting saws, and sawing machines, such as cold (circular) saws, hacksaws, bandsaws, or abrasive cutoff saws. *See micro-slicing; sawing; turning.*

Cutoff Blade
Blade mounted on a shank or arbor and held in a milling machine spindle for simple cutoff tasks.

Cutting Tool Materials
Include cast cobalt-base alloys, ceramics, cemented carbides, cubic boron nitride, diamond, high-speed steels, and carbon steels.

Cyaniding
Case hardening method that introduces carbon and nitrogen to the workpiece simultaneously.

Cylindrical Grinding
Grinding operation in which the workpiece is rotated around a fixed axis while the grinding wheel is fed into the outside surface in controlled relation to the axis of rotation. The workpiece is usually cylindrical, but it may be tapered or curvilinear in profile. *See grinding.*

Cylindrical Grinding Attachment
Device that mounts to the table of a surface grinder or lathe, permitting both straight and tapered grinding of round stock.

D

Decarburization
Loss of carbon from the surface layer of a carbon-containing alloy due to reaction with one or more chemical substances in a medium that contacts the surface. Frequently occurs in steel exposed to air at high temperatures, resulting in loss of hardness and strength at the surface.

Deionization
Removal of ions from a water-based solution. *See semisynthetic cutting fluid; soluble oil cutting fluid; synthetic cutting fluid.*

Diamond
Cubic crystalline form of carbon produced under extreme pressures at elevated temperatures. The hardest natural substance, it has approximately five times the indentation hardness of carbide. Its extreme hardness, though makes it susceptible to fracturing.

Diamond Band Sawing
Machine operation in which a band with diamond points is used to machine carbides, ceramics, and other extremely hard materials.

Die-casting
(1) A casting made in a die. (2) A casting process wherein molten metal is forced under high pressure into the cavity of a metal mold.

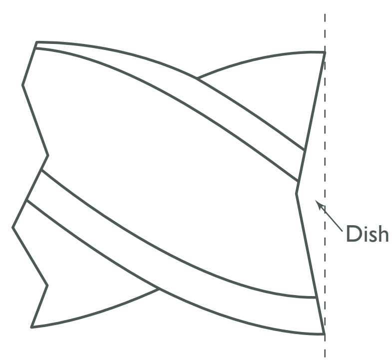
Diffusion
(1) Spreading of a consistent in a gas, liquid, or solid, tending to make the composition of all parts uniform. (2) The spontaneous movement of atoms or molecules to new sites within a material.

Direct Numerical Control (DNC)
Actions of multiple machine tools controlled by a single computer. *See computer numerical control (CNC); numerical control (NC).*

Disc-cutting Attachment
Adjustable device for a contour bandsaw that positions stock to allow the sawing of arcs and circular shapes on a contour bandsaw.

Disc Grinding
Operation in which the workpiece is placed against the side of a wheel rather than the wheel's periphery. *See grinding.*

Dish
Form of relief given to the face of an end-mill to prevent undesirable contact with the work. *See clearance.*



Dividing Head
Attaches to a milling machine table and precisely indexes the workpiece. Allows equally spaced cuts to be made when machining gear and sprocket teeth, spline keys, serrations, etc.

Dovetail Cutter
Cutter for milling dovetail slots. *See milling cutter.*

Dressing
Removal of undesirable materials from "loaded" grinding wheels using a diamond or other tool, single- or multi-point. The process also exposes unused, sharp abrasive points. *See loading; truing.*

Drill; Drill Bit
End-cutting tool for drilling. Tool has shank, body, and angled face with cutting edges that drill the hole. Drills range in size from "micro-drills" a few thousandths of an inch in diameter up to spade drills, which may cut holes several inches in diameter. Drills may have tapered shanks with a driving tang, and fit directly into a spindle or adapter, or they may have straight shanks and be chuck-mounted. The rake angle varies with the material drilled. Styles include twist drills, straight-flute drills, half-round and flat drills, oil-hole drills, and specials.

Drill Jig
Accessory that holds a workpiece securely while guiding a drill or other tool into the workpiece; ensures accurate, repeatable location.

Drill-grinding Gauge
Used to check a drill's entry angle into a workpiece. Also used to check accuracy when grinding drills.

Drilling
Operation in which a rotating tool is used to create a round hole in a workpiece. Drilling is normally the first step in machining operations such as boring, reaming, tapping, counterboring, countersinking, and spotfacing.

Drilling Machine; Drill Press
Machine designed to rotate end-cutting tools. Can also be used for reaming, tapping, countersinking, counterboring, spotfacing, and boring.

Drilling Tool
See drill.

Drive plate
Attaches to a lathe spindle; has a slot or slots that engage a driving dog to turn the work. Usually used in conjunction with centers. *See centers; driving dog.*

Driving Dog
Device having a ring or clamp on one end that slips over the workpiece to be turned; a screw secures the workpiece in place. The dog's opposite end (tail) fits into a drive plate attached to the machine spindle. *See centers; drive plate.*

Ductile Cast Iron
A cast iron that has been treated while molten with an element such as magnesium or cerium to induce the formation of free graphite as nodules or spherulites, which imparts a measurable degree of ductility to the cast metal. Also known as nodular cast iron, spherulitic graphite cast iron, or SG iron.

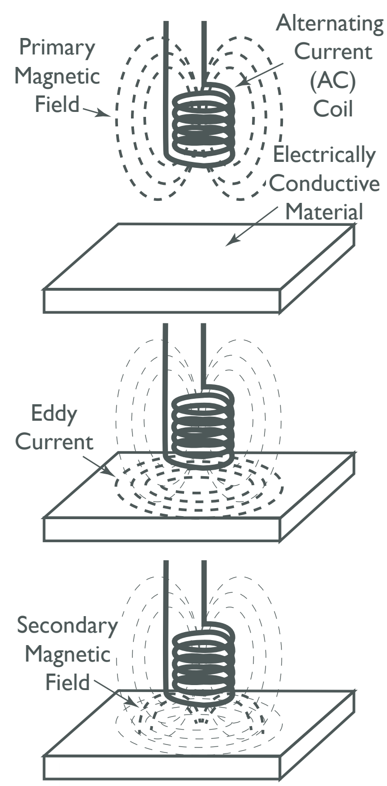
Ductility
The ability of a material to be bent, formed, or stretched without rupturing. Measured by elongation or reduction of area in a tensile test or by other means.

E

Economies of Scale
Achieving low per-unit costs by producing in volume, permitting "fixed costs" to be distributed over a large number of products. Implies inflexible production methods involving interchangeable parts or products. *See economies of scope; interchangeable parts.*

Economies of Scope
Achieving low per-unit costs by computerizing production; allows goods to be manufactured economically in small lot sizes.

Eddy-current Testing
An electromagnetic, nondestructive testing method in which eddy-current flow is induced in the test object. Detects changes in flow caused by variations in the object.



EDDY-CURRENT TESTING

Edge Finder
Gauge mounted in the spindle of a vertical mill and used, while rotating, to find the center of a part relative to the tool-holder.

EDM
Electrical-discharge machining. *See EDM: formed electrode; EDM: standard electrode with CNC; EDM: wire.*

EDM: Formed Electrode
A process using a shaped electrode made from carbon or copper. The electrode is separated by a nonconductive liquid and maintained at a close distance (about 0.001″). A high DC voltage is pulsed to the electrode and jumps to the conductive workpiece. The resulting sparks erode the workpiece and generate a cavity in the reverse shape of the electrode, or a through hole in the case of a plain electrode. Permits machining shapes to tight accuracies without the internal stresses conventional machining often generates. Also known as "die-sinker" or "sinker" electrical-discharge machining.

EDM: Standard Electrode with CNC
Similar to the standard electrical-discharge-machining process, but uses a CNC to generate shapes with standard electrodes. The conventional electrical-discharge machining process must have an electrode that conforms to the required shape.

EDM: Wire
A process similar to conventional electrical-discharge machining except a small-diameter copper or brass wire is usually used in conjunction with a CNC and will only work when a part is to be cut completely through. A common analogy is to describe wire electrical-discharge machining as an ultra-precise, electrical, contour-sawing operation.

Elastic Limit
The maximum stress that a material can sustain without deforming.

Elasticity
The property of a material to deform under stress and recover its original shape and dimensions after release of stress.

Electrical-discharge Grinding (EDG)
A process similar to conventional EDM except a grinding wheel type of electrode is used.

Electrochemical Deburring
A variation on electrochemical machining designed to remove burrs and impart small radii to corners. The process normally uses a specially shaped electrode to carefully control the process to a specific area. The process will work on material regardless of hardness.

Electrochemical Grinding
A variation on electrochemical machining that uses a conductive, rotating abrasive wheel. The chemical solution is forced between the wheel and the workpiece. The shape of the wheel determines the final shape.

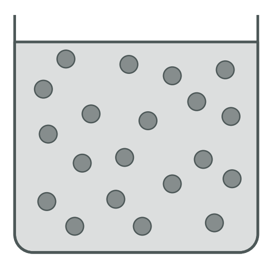
Electrochemical Machining (ECM)
Operation in which electrical current flows between a workpiece and conductive tool through an electrolyte. Initiates a chemical reaction that dissolves metal from the workpiece at a controlled rate. Unlike traditional cutting methods, workpiece hardness is not a factor, making ECM suitable for machining tough materials. Takes forms such as electrochemical grinding, electrochemical honing, and electrochemical turning.

Electrochemical-discharge Grinding
A combination of electrochemical grinding and electrical discharge machining. Material is removed by both processes. The workpiece and the grinding wheel never come into contact as in any other electrical-discharge machining process.

Elongation
In tensile testing, the increase in the gauge length, measured after fracture of the specimen within the gauge length, usually expressed as a percentage of the original gauge length.

Embrittlement
Reduction in the normal ductility of a metal due to a physical or chemical change. Examples include blue brittleness, hydrogen embrittlement, and temper brittleness.

Emulsion
Suspension of one liquid in another, such as oil in water.



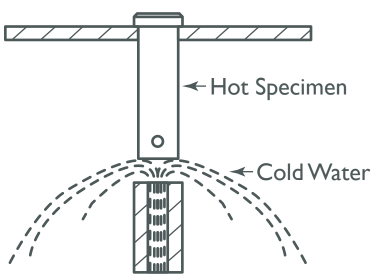
EMULSION

End-mill
Milling cutter held by its shank that cuts on its periphery and, if so configured, on its free end. Takes

a variety of shapes (single- and double-end, roughing, ballnose, and cup-end) and sizes (stub, medium, long, and extra-long). Also comes with differing numbers of flutes. *See milling cutter.*

End-milling
Operation in which the cutter is mounted on the machine's spindle rather than on an arbor. Commonly associated with facing operations on a milling machine. *See milling.*

End-quench Hardenability Test
A laboratory procedure for determining the hardenability of a steel or other ferrous alloy; widely referred to as the Jominy test. Hardenability is determined by heating a standard specimen above the upper critical temperature, placing the hot specimen in a fixture so that a stream of cold water impinges on one end, and, after cooling to room temperature, measuring the hardness near the surface of the specimen at regularly spaced intervals along its length. The data is normally plotted as hardness vs. distance from the quenched end.



END-QUENCH
HARDENABILITY TEST

Endurance Limit
The maximum stress below which a material can presumably endure an infinite number of stress cycles.

Extreme Pressure (EP) Additives
Cutting-fluid additives (chlorine, sulfur, or phosphorous compounds) that chemically react with the workpiece material to minimize chip-welding; good for high-speed machining.

Extrusion
Conversion of an ingot or billet into lengths of uniform cross sections by forcing metal to flow plastically through a die or orifice.

F

Face
A flat surface, usually at right angles and adjacent to the ground hole.

Face-mill
Milling cutter for cutting flat surfaces. *See milling cutter.*

Face-milling
A form of milling that produces a flat surface generally at right angles to the rotating axis of a cutter having teeth or inserts both on its periphery and on its end face. *See milling.*

Facing
Preliminary "cleanup" operation that provides a true reference surface before beginning another operation.

Face Plate
Flat, round work-holder with slots used to hold regular- or irregular-shaped stock. If stock is markedly asymmetrical, counterbalances may be needed to prevent vibration. *See drive plate.*

Family of Parts
Parts grouped by shape and size for efficient manufacturing.

Fatigue
The phenomenon leading to fracture under repeated or fluctuating stresses having a maximum value less than the tensile strength of the material. Fatigue fractures are progressive, beginning as minute cracks that grow under the action of the fluctuating stress.

Fatigue Life
The number of cycles of stress that can be sustained prior to failure under a stated test condition.

Fatigue Resistance
Ability of a tool or component to be flexed repeatedly without cracking; important for bandsaw-blade backing.

Fatigue Strength
The maximum stress that can be sustained for a specified number of cycles without failure, the stress being completely reversed within each cycle unless otherwise stated.

Feather Burr
A very fine or thin burr. *See burr.*

Feather Edge
The same as a feather burr except that feather edge can also refer to a very thin machined ridge located at the ends of a lead-in or lead-out thread. It is sometimes called a wire edge or whisker-type burr.

Ferrite
A solid solution of one or more elements in body-centered cubic iron. Unless otherwise designated (for instance, as chromium ferrite), the solute is generally assumed to be carbon. On some equilibrium diagrams, there are two ferrite regions separated by an austenite area. The lower area is alpha ferrite; the upper, delta ferrite. If there

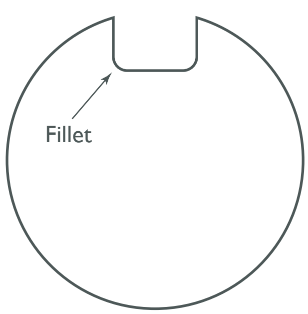
is no designation, alpha ferrite is assumed.

Filing
Operation in which a tool with numerous small teeth is used manually to round off sharp corners and shoulders and remove burrs and nicks. Although often a manual operation, filing on a power filer or contour band machine with a special filing attachment can be an intermediate step in machining low-volume or one-of-a-kind parts.

Filing Attachment
Mounts on a contour bandsaw for power-filing operations.

File Bands
Segmented files mounted on an endless band for use on a powered band-type filing machine or on a contour band machine with filing attachment.

Fillet
Rounded corner or arc that blends together two intersecting curves or lines. In three dimensions, a fillet surface is a transition surface that blends together two surfaces.



KEYWAY WITH FILLET

Film Strength
Relative ability of a fluid to form a film between workpiece and tool, under the influence of temperature and pressure, to prevent metal-to-metal contact. *See boundary additives; lubricity.*

Finish Cut
Final cut made on a workpiece to generate final dimensions or specified finish. Often made using reduced feeds and higher speeds. Generally, the better the surface finish required, the longer the finish cut takes. Also, the final cut taken on an electrical-discharge-machined part.

Finish Feed
Feeding in small increments for finishing the part.

Finishing Tool
Tool, belt, wheel, or other cutting implement that completes the final, precision machining step/cut on a workpiece. Often takes the form of a grinding, honing, lapping, or polishing tool. *See roughing cutter, roughing tool.*

Finishing
Any of many different processes employed for surface, edge, and corner preparation, as well as conditioning, cleaning, and coating. In machining, usually constitutes a final operation. In recent years, there has been dynamic growth in the development and improvement of these processes, as well as the equipment, tooling, media, and compounds used.

Fixed Cycle
See canned cycle.

Fixture
Device, usually made in-house, that holds a specific workpiece. *See jig; modular fixturing.*

Flame Hardening
Hardening process in which an intense flame is applied to the surfaces of hardenable ferrous alloys, heating the surface layers above the upper transformation temperature, whereupon the workpiece is immediately quenched.

Flank Wear
Reduction in clearance on the tool's flank caused by contact with the work. Ultimately causes tool failure.

Flat
Flat surface machined into the shank of a cutting tool for enhanced holding of the tool.

Flexible Manufacturing System (FMS)
Automated manufacturing system designed to machine a variety of similar parts. System is designed to minimize production changeover time. Computers link machine tools with the work-handling system and peripherals. Also associated with the machine tools grouped in "cells" for efficient production. *See cell manufacturing.*

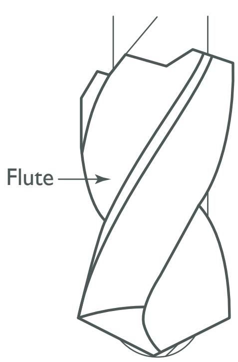
Flood application
Fluid applied in volume by means of a recirculating system comprised of a reservoir, filters, chip-removal components, pump, hoses, and positionable application nozzles, along with movable splash shields, valves for adjusting flow, and other controls. Normally permits the highest metal-removal rates possible with fluids. It requires careful setup and adjustment, as the stream and attendant splashing may obscure the cut point from the operator's view.

Fluorescent Magnetic-particle Inspection
Inspecting ferrous materials for cracks or flaws with either dry magnetic particles or those in a liquid suspension, the particles being coated with a fluorescent substance to increase the visibility of the indications. *See magnetic-particle inspection.*

Fluorescent Penetrant Inspection
Inspection using a fluorescent liquid that will penetrate any surface opening; after the surface has been wiped clean, the location of any surface flaws may be detected by the fluorescence – under ultraviolet light – of back-seepage of the fluid.

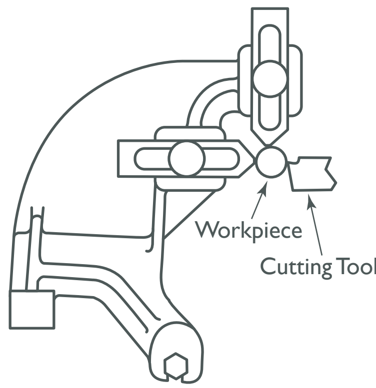
Flushing Hose
Hand-operated hose and nozzle added to machine's cutting-fluid-application system to permit manual flushing of table and workpiece areas.

Flutes
Grooves and spaces in the body of a tool that permit chip removal from, and cutting-fluid application to, the point of cut.



Fluting
Cutting straight or spiral grooves in drills, end-mills, reamers, and taps to improve cutting action and chip removal.

Follower Rest
A work rest or supporting device attached to the carriage that "follows" the cutting tool, keeping support near the point of cut. *See back rest; steady rest.*



FOLLOWER REST

Form Cutter
Cutter shaped to cut stepped, angular, or irregular forms in the workpiece. The cutting-edge contour corresponds to the workpiece shape required. The cutter can often be reground repeatedly without changing the cutting-edge shape. Two general classes: straight and circular.

Form-rolling Machine
Used to roll splines, gears, worms, and threads. A cold-forming machine for production processing of previously machined parts. *See broaching machine.*

Fracture Stress
(1) The maximum principal true stress at fracture. Usually refers to un-notched tensile specimens. (2) The (hypothetical) true stress that will cause fracture without further deformation at any given strain.

Free-machining Steels
Carbon and alloy steels that contain lead, sulfur, or other elements that improve machinability.

Friction Sawing
Sawing with a special band machine capable of achieving band velocities of 15,000 surface feet per minute (sfm) or more. Metal removal is accomplished in two steps: Frictional heat softens the metal, then the teeth scoop out the molten material. Carbon-steel bands are used for flexibility and to maximize band life. Excellent for cutting extremely hard alloys, but cannot be used on most aluminum alloys or other materials that load the teeth of conventional blades. *See sawing.*

Full Annealing
An imprecise term that denotes an annealing cycle designed to produce minimum strength and hardness. For the term to be meaningful, the composition and starting condition of the material and the time-temperature cycle used must be stated.

Fungicide
Material added to chemical or soluble oil cutting fluids to inhibit the growth of fungi and bacteria. *See bactericide.*

G

Galling
A condition whereby excessive friction between high spots results in localized welding with subsequent spalling and further roughening of the rubbing surface(s) of one or both of two mating parts.

Gang Cutting
Machining with several cutters mounted on a single arbor, generally for simultaneous cutting.

Gang Milling
See gang cutting.

Gang Slitting
See gang cutting.

Gear Cutter
Cutters (mills, broaches, hobs, etc.) designed for machining gears.

Gear Shaper
Machine that, in contrast to mills and hobbing machines, reciprocates the tool to cut the gear.

Gray Cast Iron
A cast iron that gives a gray fracture die to the presence of flake graphite. Often called gray iron.

Grinding
Machining operation in which material is removed from the workpiece by a powered abrasive wheel, stone, belt, paste, sheet, compound, slurry, etc. Takes various forms: precision surface grinding (creates flat and/or squared surfaces); cylindrical grinding (for external cylindrical and tapered shapes, fillets, undercuts, etc.); centerless grinding; chamfering; thread and form grinding; tool-and-cutter grinding; offhand grinding; lapping and polishing (grinding with extremely fine grits to create ultra smooth surfaces); honing; and disc grinding.

Grinding Machine
Powers a grinding wheel or other abrasive tool for the purpose of removing metal and finishing workpieces to close tolerances. Provides smooth, square, parallel, and accurate workpiece surfaces. When ultra-smooth surfaces and finishes on the order of microns are required, lapping and honing machines (precision grinders that run abrasives with extremely fine, uniform grits) are used. In its "finishing" role, the grinder is perhaps the most widely used machine tool.

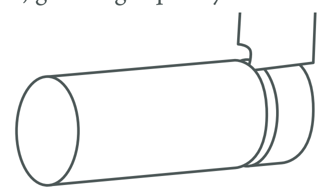
Various styles are available: bench and pedestal grinders for sharpening lathe bits and drills; surface grinders for producing square, parallel, smooth, and accurate workpieces; cylindrical and centerless grinders; center-hole grinders; form grinders; face-mill and end-mill grinders; gear-cutting grinders; jig grinders; abrasive belt (backstand, swing-frame, belt roll) grinders; tool-and-cutter grinders for sharpening and resharpening cutting tools; carbide grinders; hand-held die grinders; and abrasive cutoff saws.

Grinding Ratio
Ratio of work material removed to grinding wheel material lost.

Grinding Wheel
Wheel formed from abrasive material mixed in a suitable matrix. Takes a variety of shapes, but falls into two basic categories: those that cut on their periphery, as in reciprocating grinding, and those that cut on their side or face, as in tool-and-cutter grinding.

Grit Size
Specified size of the abrasive particles in grinding wheels and other abrasive tools. Determines metal-removal capability and quality of finish.

Grooving
Machining grooves and shallow channels. Example: grooving ball-bearing raceways. Typically performed by tools that are capable of light cuts at high feed rates; gives high-quality finish.



GROOVING

Group Technology
Classifying large numbers of different parts by characteristics (shape, configuration, holes, threads, size, etc.) before creating families of parts, with special consideration given to size. Also involves clustering machines into cells for efficient flow of parts between machines and operations. May involve automated work handling.

Gun Drill
Self-guided drill for producing deep, long holes with good accuracy and fine surface finish; has coolant passages that deliver coolant to the tool/workpiece interface at high pressure.

Gun Drilling
Drilling process using a self-guiding tool to produce deep, precise holes. High-pressure coolant is fed to the cutting area, usually through the gun drill's shank.

H

Hacksaw Blade
Serrated blade for a manual or power hacksaw that cuts on the forward or return stroke.

Hard Chromium
Chromium electro-deposited for engineering purposes (to increase the wear resistance of sliding metal surfaces) rather than as a decorative coating. It is usually applied directly to basis metal and is customarily thicker than a decorative deposit, but not necessarily harder.

Hardenability
The ability of a ferrous alloy to form martensite when quenched from a temperature above the upper transformation temperature. Hardenability is commonly measured as the distance below a quenched surface at which the metal exhibits a specific hardness (RC 50 for example) or a specific percentage of martensite in the microstructure.

Hardening
The process of increasing the surface hardness of a part. It is accomplished by heating a piece of steel to a temperature within or above its critical range and then cooling (or quenching) it rapidly. In any heat treatment operation, the rate of heating is important. Heat flows from the exterior to the interior of steel at a definite rate. If the steel is heated too quickly, the outside becomes hotter than the inside, and the desired uniform structure cannot be obtained. If a piece is irregular in shape, a slow heating rate is essential to prevent warping and cracking. The heavier the section, the longer the heating time must be to achieve uniform results. Even after the correct temperature has been reached, the piece should be held at the temperature for a sufficient period of time to permit its thickest section to attain a uniform temperature.

Hardness
Resistance of metal to plastic deformation, usually by indentation. However, the term may also refer to stiffness or temper, or to resistance to scratching, abrasion, or cutting. Indentation hardness may be measured by various hardness tests, such as Brinell, Rockwell, and Vickers.

Hardness Tester
Tool designed to record the amount of pressure required to form an indentation in a material. A variety of scales are used to measure hardness, with the Rockwell C and the Brinell hardness scales being the most frequently encountered in the shop or plant.

Head-changing Machine
Like machining centers, this is a relatively new class of multifunction, numerical control machine tool. It differs from machining centers in that single- or multi-spindle heads, rather than tools, are transferred to a single workstation in proper sequence to perform the required series of operations. The single workstation is equipped with a spindle drive and slide feed unit; the workpiece remains in a fixed or indexable position. Additional workstations can be added on some machines if required.

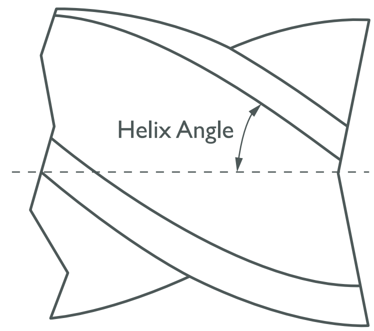
Heat Treating
A process that combines controlled heating and cooling of metals or alloys in their solid state to derive desired properties. Heat treatment can be applied to a variety of commercially used metals, including iron, steel, aluminum, and copper.

Heel Drag
See heeling.

Heeling
Rubbing that occurs on the cutter's heel, the area just behind the tooth's cutting edge.

Helical Cutter
End-mill or other cutter with spiral or helical flutes. May be right- or left-hand.

Helix Angle
Angle that the tool's leading edge makes with the plane of its centerline.



High-speed Milling Attachment
Device, typically combined with a universal milling attachment, that has gearing to turn small end-mills at high speeds. *See universal milling attachment.*

High-speed Steel (HSS)
Tool steel alloyed with tungsten and molybdenum. Permits cutting at higher speeds and feeds than carbon-steel tools because HSS tool cutting edges do not soften at temperatures that soften carbon steel.

Hob
A rotating tool with teeth arranged along a helical path, used for cutting (hobbing) worm, spur, and helical gears; splines; etc.

Hobbing
A gear-tooth-generating process consisting of rotating and advancing a fluted steel worm cutter past a revolving blank. In the actual process of cutting, the gear and hob rotate together. The speed ratio of the two depends on the number of teeth to be generated on the gear, and on whether the hob is single or multi-threaded. The hob cutting speed is controlled by change gears that vary the speed of the hobbing machine's main drive shaft.

Hobbing Machine
Machine in which a hob and a blank rotate in precise relation to each other to create worm, spur, and helical gears and splines. *See gear shaper.*

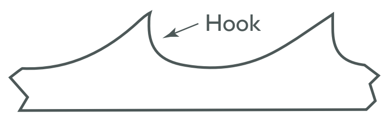
Hole Making
Using a consumable tool such as a drill, reamer, punch, liquid medium, or electrode to produce holes in the workpiece. Often a preliminary step to subsequent machining and finishing operations.

Hold-down
T-slot bolt, strap clamp, or other device for securing the workpiece to the machine tool.

Honing
A low-velocity abrading process. Material removal is accomplished at lower cutting speeds than in grinding. Therefore, heat and pressure are minimized, resulting in excellent size and geometry control. The most common application of honing is on internal cylindrical surfaces. The cutting action is obtained using abrasive sticks (aluminum oxide and silicon carbide) mounted on a metal mandrel. Since the work is fixtured in a way as to allow floating and no clamping or chucking, there is no distortion. Also used to give cutting tools ultra-fine edges.

Honing Tool
Abrasive segments affixed to the periphery of a tool head and used to bring internal bores to an accurate, fine finish. Most often used for precision sizing and finishing of bores, but can be used to hone other shapes and to impart thin, ultra-sharp cutting edges. For certain applications, may be hand-held.

Hook
Concave shape on the face of a cutting edge or blade tooth that tends to pull the cutter or blade into the work.



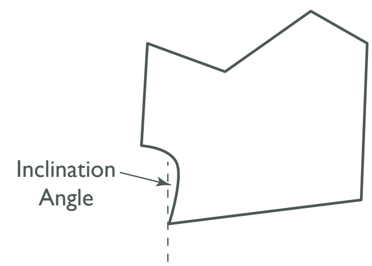
Hot-working
Deforming a metal plastically at a temperature and strain rate so that the recrystallization temperature is exceeded and recrystallization takes place simultaneously with the deformation, thus avoiding any strain hardening.

Hydrodynamic Machining
General term for various forms of waterjet and abrasive waterjet machining. In all cases, a fine, highly pressurized jet of water cuts and removes the material. *See abrasive waterjet; waterjet cutting.*

I

Impact Test
A test to determine the behavior of materials when subjected to high rates of loading, usually in bending, tension, or torsion. The quantity measured is the energy absorbed in breaking the specimen by a single blow, as in Charpy and Izod tests.

Inclination Angle
Angle that the cutter edge makes with a plane that is perpendicular to the direction of tool travel. Determines the direction the chip curls.



Indexable Insert
Replaceable tool that clamps into a tool-holder, drill, mill, or other cutter body designed to accommodate inserts. Most inserts are made of cemented carbide; often they are coated with titanium nitride or other hard material. Other insert materials are high-speed steels, ceramics, cermets, polycrystalline cubic boron nitride, and polycrystalline diamond. The insert is used until dull, then indexed, or turned, to expose a fresh cutting edge. When the entire insert is dull, it is usually discarded; some inserts can be resharpened.

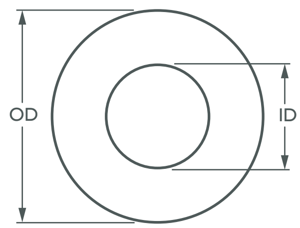
Indicator Drop Measurement
Method of determining if the primary and secondary reliefs on an end-mill or other cutter have been properly ground. *See clearance; relief.*

Induction Hardening
A surface-hardening process in which only the surface layer of a suitable ferrous workpiece is heated

by electromagnetic induction to above the upper transformation temperature and immediately quenched.

Inhibitor
A chemical substance or combination of substances that, when present in the environment, prevents or reduces corrosion without significant reaction with the components of the environment.

Inner Diameter (ID)
Dimensions that define the inside of a part. *See outer diameter (OD).*



INNER AND OUTER DIAMETERS

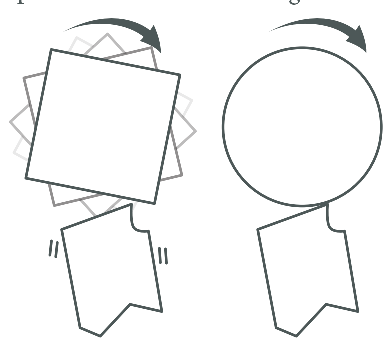
In-process Gauging and Inspection
Quality control approach that monitors work in progress, rather than inspecting parts after the run has been completed. May be done manually on a spot-check basis, but often involves automatic sensors that provide 100% inspection.

Inspection
Process of physically checking a part or product to ensure that it meets specific, predetermined dimensions. Since errors can be caused by out-of-tolerance measuring instruments as well as out-of-spec parts, it is important to periodically check the measuring tools for accuracy. *See calibration.*

Interchangeable Parts
Parts and components produced to specified tolerances, permitting them to be substituted for one another. Essential to mass production, permitting the high-volume output that results in "economies of scale." Less critical to operating costs in computer-integrated manufacturing operations, but facilitates maintenance and repair.

Interpolation
Process of generating a sufficient number of positioning commands for the servomotors driving the machine tool so the path of the tool will closely approximate the ideal path.

Interrupted Cut
Cutting tool repeatedly enters and exits the work; subjects tool to shock loading, making tool toughness, impact strength, and flexibility vital. Closely associated with milling operations. *See shock loading.*



INTERRUPTED VS. SMOOTH CUT

Investment Casting
(1) Casting metal into a mold produced by surrounding (investing) an expendable pattern with a refractory slurry that sets at room temperature, after which the wax, plastic, or frozen mercury pattern is removed through the use of heat. Also called precision casting or lost-wax process. (2) A part made by the investment-casting process.

Izod test
A pendulum-type, single-blow impact test in which the specimen, usually notched, is fixed at one end and broken by a falling pendulum. The energy absorbed, as measured by the subsequent rise of the pendulum, is a measure of impact strength or notch toughness. *See Charpy test; impact test.*

J

Jig
Tooling usually considered to be a stationary apparatus. A jig assists in the assembly or manufacture of a part or device. It holds the workpiece while guiding the cutting tool with a bushing. A jig used in subassembly or final assembly can provide assembly aids such as alignments and adjustments. *See fixture.*

Jig Bore
Precision boring machine that resembles a milling machine. Originally designed to make precision jigs, fixtures, dies, and other tooling, this machine is now used for production machining of precision parts, extremely accurate hole location, and similar tasks. Employs a precision spindle that drives the cutting tool and an accurate, stable work-holding table. Basic types include fixed-bridge, open-side or "C-frame," and adjustable-rail machines. Often used under climate-controlled conditions. *See boring machine; mill; milling machine.*

Jig Boring
High-precision machining (a sophisticated form of milling) that originally pertained to jig and fixture manufacturing. Basic jig-

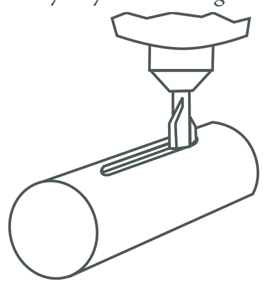
boring processes include centering, drilling, reaming, through and step boring, counterboring, and contouring. The continually increasing demands for accuracy within many branches of metalworking have extended the application possibilities for jig-boring machines.

Just in Time (JIT)
Philosophy based on identifying and removing impediments to productivity. Applies to machining processes, inventory control, rejects, changeover time, and other elements affecting production.

K

Kerf
Width of cut left after a blade or tool makes a pass.

Key-seating
Milling or grinding an internal keyway. *See slotting.*



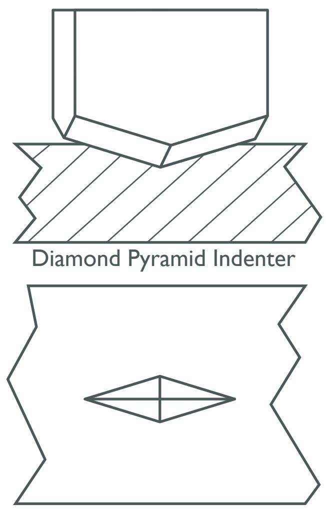
KEYSEATING

Killed Steel
Steel treated with a strong deoxidizing agent such as silicon or aluminum to reduce the oxygen content so that no reaction occurs between carbon and oxygen during solidification.

Knockout
A mechanism for releasing workpieces from a die; it is also called ejector, kickout, liftout, or shedder.

Knoop Hardness
Hardness rating for very thin materials and plated surfaces.

Knoop Hardness Test
Determines microhardness from the resistance of metal to indentation by a pyramidal diamond indenter, having edge angles of 172° and 130°, making a rhombohedral impression with one long and one short diagonal. *See Brinell Hardness Text; Vickers Hardness Text.*



KNOOP HARDNESS TEST

Knurling
Rolling depressions into the surface of a handle or similar part to provide a better gripping surface. In automotive machining, this process is used to enhance clearances and help pistons and valve guides retain oil.

Knurling Tool
Normally a lathe tool for impressing a design on a rod or handle to improve gripping. May be either a cutting or forming operation.

L

Lapping
Finishing operation in which a loose, fine-grain abrasive in a liquid medium abrades material. Extremely accurate process that corrects minor shape imperfections, refines surface finishes, and produces a close fit between mating surfaces.

Lapping Compound
Light, abrasive material used for finishing a surface.

Lapping Powder
See lapping compound.

Laser-beam Machining: Cavity Type
A process that removes material by focusing a concentrated laser beam onto the workpiece. The material is melted and vaporized. In the cavity process, the beam is carefully controlled to prevent burning through the workpiece.

Laser Machining
Intensified, pulsed beams of light generated by lasers – typically carbon dioxide or neodymium-doped yttrium aluminum garnet (Nd:YAG) – that drill, weld, engrave, mark, slit, case harden, etc. Usually under computer numerical control, often at both high cutting rates (100 linear inches/second) and high power (5 kW or more). Lasers also are used in conjunction with in-process quality control monitoring systems allowing measuring accuracies of 0.00001″.

Lathe
Turning machine capable of sawing, milling, grinding, gear-cutting, drilling, reaming, boring, threading, facing, chamfering,

grooving, knurling, spinning, parting, necking, taper-cutting, and cam- and eccentric-cutting, as well as step- and straight-turning. Comes in a variety of forms, ranging from manual to semiautomatic to fully automatic, with major types being engine lathes, turning and contouring lathes, turret lathes, and numerical control lathes. The engine lathe consists of a headstock and spindle, tailstock, bed, carriage (complete with apron), and cross slides. Features include gear- (speed) and feed-selector levers, tool post, compound rest, lead screw and reversing lead screw, threading dial, and rapid-traverse lever. Special lathe types include through-the-spindle, camshaft and crankshaft, brake drum and rotor, spinning, and gun-barrel machines. Tool-room and bench lathes are used for precision work; the former for tool-and-die work and similar tasks, the latter for small workpieces (instruments, watches), normally without a power feed. Models are typically designated according to their "swing," or the largest-diameter workpiece that can be rotated; bed length, or the distance between centers; and horsepower generated. Modern lathes often are equipped with digital readouts and computer numerical controls.

Lathe Bit
Cutting tool for lathes and other turning machines. Normally a single-point cutting tool, square in cross section and ground to a shape suitable for the material and task. Intended for simple metal removal, threading, slotting, or other internal or external cutting jobs. Clearance to prevent rubbing is provided by grinding back rake, side rake, end relief, and side relief, as well as side- and end-cutting edges.

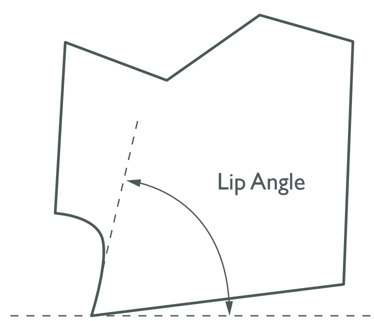
Lathe Tool
See lathe bit.

Lathe Turning
Machining operation in which a workpiece is rotated, while a cutting tool removes material, either externally or internally.

Layout
Use of scribers, ink, and prick punches to create a part outline that machinists use to visually check part shape during machining of prototypes or during tool-and-die work.

Linear Elastic Fracture Mechanics
A method of fracture analysis relating load (stress); the size, shape, and orientation of a crack; the shape of the cracked object; and the stress-intensity factor (KI). The critical value of KI is a material property known as fracture toughness. This method of analysis is commonly used to determine the load (stress) or crack size at the onset of sudden brittle fracture.

Lip Angle
Included angle between a cutter's tooth and relieved land.



Loading
In grinding, the wheel's tendency to accumulate workpiece material between its abrasive points.
In milling, drilling, and other operations, excessive packing of chips in cutter flutes or at cutter edge.

Lubricant
Substance that reduces friction between moving machine parts. Can be liquid (hydrocarbon oil), solid (grease), or gaseous (air). Important characteristics are to prevent metal-to-metal contact between moving surfaces, be a cooling medium, and protect surfaces from rust and corrosion.

Lubricity
Measure of the relative efficiency with which a cutting fluid or lubricant reduces friction between surfaces.

M

Machinability
Determines acceptability of a tool for the workpiece to be machined. Indicates workpiece's hardness, chemical composition and qualities, microstructure, propensity to work-harden, elasticity, and propensity to be worked cold. In general, the harder a material, the higher its machinability rating. A material's machinability also is impacted by the type and age of machine, its power and rigidity, and the cutting tool used.

Machinability Rating
See machinability.

Machining
Process of giving a workpiece a new configuration by cutting or shaping it. Typically performed on a machine tool or machining center. Includes cutting and shaping all kinds of materials, not just metals.

Generally associated with precision and high-quality fit.

Machining Center
A computer-controlled machine tool capable of drilling, reaming, tapping, milling, and boring. Normally comes with an automatic tool changer. *See automatic tool changer.*

Magnetic Chuck
Work-holding device used on surface grinders and milling machines for holding ferrous parts with large, flat sides. Holding power may be provided by permanent magnets or by an electromagnetic system. *See chuck.*

Magnetic-particle Inspection
A nondestructive method of inspecting for determining the existence and extent of surface cracks and similar imperfections in ferromagnetic materials. Finely divided magnetic particles, applied to the magnetized part, are attracted to and outline the pattern of any magnetic-leakage fields created by discontinuities. *See fluorescent magnetic-particle inspection.*

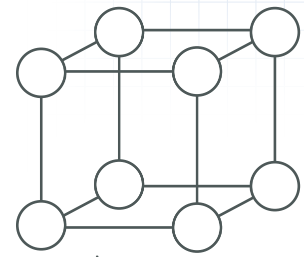
Malleable Cast Iron
A cast iron made by prolonged annealing of white cast iron in which decarburization or graphitization, or both, take place to eliminate some or all of the cementite. The graphite is in the form of temper carbon.

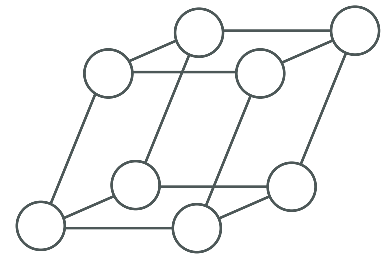
Mandrel
Work-holder for turning that fits inside hollow workpieces. Types available include expanding, pin, and threaded.

Manufacturing Resources Planning
See materials requirements planning.

Martempering
(1) A hardening procedure in which an austenitized ferrous workpiece is quenched into a medium whose temperature is maintained at the temperature at which martensite starts to form austenite in the workpiece. It is held in the medium until its temperature is uniform throughout – but not long enough to permit bainite to form – and then cooled in air. The treatment is frequently followed by tempering. (2) When the process is applied to carburized (case hardened) material, the controlling temperature is that of the case. This variation of the process is frequently called marquenching.

Martensite
A generic term for micro-structures formed by diffusionless phase transformation in which the parent and product phases have a specific crystallographic relationship. Martensite is characterized by an acicular pattern in the microstructure in both ferrous and nonferrous alloys. In alloys where the solute atoms occupy interstitial positions in the martensitic lattice (such as carbon in iron), the structure is hard and highly strained; but where the solute atoms occupy substitutional positions (such as nickel in iron), the martensite is soft and ductile. The amount of high-temperature phase that transforms to martensite on cooling depends to a large extent on the lowest temperature attained, there being a rather distinct beginning temperature and a temperature at which the transformation is essentially complete.


Austenite


Martensite

PHASE STRUCTURES OF STEEL

Martensiting
Rapid quenching of carbon steel in the austenite state causes a new structure – martensite – to form. Martensite is extremely hard.

Mass Production
Large-scale manufacturing with high-volume production and output; implies precomputer-era methods, with departmentalized operation and reliance on "economies of scale" to achieve low per-unit costs.

Materials Handling
Methods, equipment, and systems for conveying materials to various machines and processing areas and for transferring finished parts to assembly, packaging, and shipping areas.

Materials Requirements Planning (MRP, MRP-II)
Management method, normally computer-aided, for cost-effective control of manufacturing support functions, such as inventory, production equipment, and

personnel. MRP was the initial, somewhat limited method; MRP-II implies a more sophisticated system.

Mechanical Properties
The properties of a material that reveal its elastic and inelastic behavior when force is applied, thereby indicating its suitability for mechanical applications; for example, modulus of elasticity, tensile strength, elongation, hardness, and fatigue limit. *See physical properties*.

Metal Cutting
Any machining process used to part metal or a material or give a workpiece a new configuration. Conventionally applies to machining operations in which a cutting tool mechanically removes material in the form of chips; applies to any process in which metal or material is removed to create new shapes.

Metal-cutting Dynamometer
Device for measuring cutting forces developed during machining.

Metal Forming
Manufacturing processes in which products are given new shapes either by casting or by some form of mechanical deformation, such as forging, stamping, bending, spinning, etc. Some processes, such as stamping, may use dies or tools with cutting edges to cut as well as form parts.

Metal Working
Any manufacturing process in which metal is processed or machined giving workpiece a new shape. Broadly defined, the term includes processes such as design and layout, heat treating, material handling, inspection, etc.

Metal-removal Factor
The volume of metal removed per unit of power in a given period of time (reciprocal of the specific power-consumption factor). Also known as the "K-factor," it is primarily dependent on the properties of the metal being cut, is only slightly dependent on feed, and has virtually no dependence on depth of cut.

Metrology
Science of measurement; the principles on which precision machining, quality control, and inspection are based. *See precision machining, measurement*.

Microhardness
The hardness of a material as determined by forcing an indenter such as a Vickers or Knoop indenter into the surface of the material under very light load; usually, the indentations are so small that they must be measured with a microscope. Capable of determining hardness of different micro-constituents within a structure, or measuring steep hardness gradients such as those encountered in case hardening.

Micro-slicing
Cutting very small or thin parts from a larger base part. Uses a special machine with a thin, tensioned blade that takes a minimum kerf. Process for cutting expensive materials such as silicon, germanium, and other computer-chip materials.

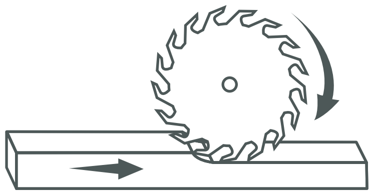
Microstructure
The structure of a metal as revealed by microscopic examination of the etched surface of a polished specimen.

Mild Steel
Carbon steel with a maximum of about 0.25% carbon.

Mill
Runs end-mills and arbor-mounted milling cutters. Features include a head with a spindle that drives the cutters; a column, knee, and table that provide motion in the three Cartesian axes; and a base that supports the components and houses the cutting-fluid pump and reservoir. The work is mounted on the table and fed into the rotating cutter or end-mill to accomplish the milling steps; vertical milling machines also feed end-mills into the work by means of a spindle-mounted quill. Models range from small manual machines to big bed-type and duplex mills. All take one of three basic forms: vertical, horizontal, or convertible horizontal/vertical. Vertical machines may be knee-type (the table is mounted on a knee that can be elevated) or bed-type (the table is securely supported and only moves horizontally). In general, horizontal machines are bigger and more powerful, while vertical machines are lighter but more versatile and easier to set up and operate. Modern mills often are equipped with digital readouts and computer numerical controls.

Milling
Machining operation in which metal or other material is removed by applying power to a rotating cutter. Takes two general forms: vertical and horizontal. In vertical milling, the cutting tool is mounted vertically on the spindle. In horizontal milling, the cutting tool is mounted horizontally, either directly on the spindle or on an arbor. Horizontal milling

is further broken down into conventional milling, where the cutter rotates opposite the direction of feed, or "up" into the workpiece. Milling operations include plane or surface-milling, end-milling, face-milling, angle milling, form milling, and profiling.



MILLING

Milling Arbor
Shaft or tool-holder that inserts in the machine spindle and holds a peripheral milling or face-milling cutter.

Milling Cutter
Loosely, any milling tool. Horizontal cutters take the form of plain milling cutters, plain spiral-tooth cutters, helical cutters, side-milling cutters, staggered-tooth side-milling cutters, face-milling cutters, angular cutters, double-angle cutters, convex and concave form-milling cutters, straddle-sprocket cutters, spur-gear cutters, corner-rounding cutters, and slitting saws. Vertical mills use shank-mounted cutting tools, including end-mills, t-slot cutters, woodruff keyseat cutters, and dovetail; these may also be used on horizontal mills.

Milling Machine
See mill.

Miscibility
Ability of a liquid to mix with another liquid. *See emulsion.*

Mist Application
Atomized fluid generally applied when a clear view of the cut point is needed, as in contour band sawing or manual milling. The airborne mist can be directed precisely to the point of cut, sometimes reaching areas flood-applied coolant will not penetrate. The water evaporates on contact, providing further cooling, and leaves oils and additives on the work. *See flood application.*

Mixture Ratio
Ratio of water to concentrate in certain cutting fluids. *See semisynthetic cutting fluid; soluble oil cutting fluid; synthetic cutting fluid.*

Modular Construction
See modular design.

Modular Design
Manufacturing of a product in subassemblies that permit fast and simple replacement of defective assemblies and tailoring of the product for different purposes.

Modular Fixturing
System in which fixtures are constructed from standardized, reusable components. Fixtures are assembled and disassembled quickly. Basic styles are subplate, dowel-pin, and t-slot. *See jig.*

Modular Tooling
Tooling system comprised of standardized tools and tool-holders. Devices that allow rapid mounting and replacement of tools. Commonly used with carousel tool-changers and other computerized machining operations.

Modulus of Elasticity
A measure of the rigidity of metal. Ratio of stress, below the proportional limit, to corresponding strain.

Multifunction Machines
Machines and machining/turning centers capable of performing a variety of tasks, including milling, drilling, boring, turning, and cutoff, usually in just one setup.

N

Nitriding
Introducing nitrogen into the surface layer of a solid ferrous alloy by holding at a suitable temperature (below the lower transformation temperature for ferritic steels) in contact with a nitrogenous material, usually ammonia or molten cyanide of appropriate composition.

Nitrocarburizing
Any of several processes in which both nitrogen and carbon are absorbed into the surface layers of a ferrous material and, by diffusion, create a concentration gradient. Nitrocarburizing is done mainly to provide an anti-scuffing surface layer and to improve fatigue resistance. *See carbonitriding.*

Nondestructive Examination
Inspection by methods that do not destroy the part or impair its serviceability.

Nondestructive Inspection
See nondestructive examination.

Nondestructive Testing (NDT)
Same as nondestructive inspection, but implying use of a method in which the part is stimulated and its response measured quantitatively or semi-quantitatively.

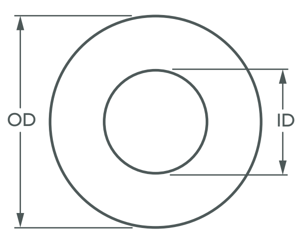
Normalizing
Heating a ferrous alloy to a temperature above the transformation range and then cooling in air to a temperature below the transformation range.

Numerical Control (NC)
Any controlled equipment that allows an operator to program its movement by entering a series of coded numbers, symbols, etc. *See computer numerical control (CNC); direct numerical control (DNC).*

Nontraditional Machining
Variety of chemical, electrical, mechanical, and thermal processes for machining workpieces. Originally applied to new or emerging processes, it designates any process developed since 1945.

O

Outer Diameter (OD)
Dimensions that define the exterior of a part. *See inner diameter (ID).*



INNER AND OUTER DIAMETERS

Offhand Grinding
Hand-feeding a workpiece into a bench grinder. Usually utilized in the shop to resharpen tools. Attachments or other mechanical devices are required for increased efficiency and accuracy. *See grinding.*

Orthogonal Chip Formation
Concentrated shear action at the point of cut that results in the formation of a continuous chip. *See shear plane.*

Overshoot
Deviation from nominal path caused by momentum carried over from the previous step, as when a tool is rapidly traversed a considerable distance to begin a cut. Usually applies to numerical control (NC)/computer numerical control (CNC) machining. *See undershoot.*

Oxidation
(1) A reaction in which there is an increase in valence resulting from a loss of electrons. Contrast with reduction. (2) A corrosion reaction in which the corroded metal forms an oxide; usually applied to a reaction with a gas containing elemental oxygen, such as air.

P

Parallel
Strip or block of precision-ground stock used to elevate a workpiece, while keeping it parallel to the worktable, to prevent cutter/table contact.

Parting
When used in lathe or screw-machine operations, this process separates a completed part from chuck-held or collet-fed stock by means of a very narrow, flat-end cutting tool (parting tool).

Pearlite
A lamellar aggregate of ferrite and cementite. Softer than most other micro-structures. Formed from austenite during air cooling from austenite.

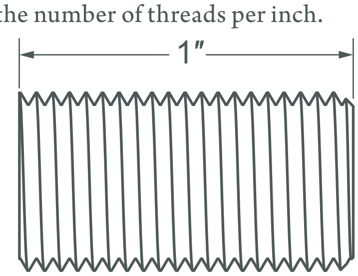
Peening
Mechanical working of a metal by hammer blows or shot impingement.

Peripheral Milling
A form of milling that produces a finished surface generally in a plane parallel to the rotating axis of a cutter having teeth or inserts on the periphery of the cutter body. *See milling.*

Photochemical Machining
A variation on chemical machining that uses a chemically resistant mask that is sensitive to light. Light activates the mask only in the areas to be protected. The remaining mask is washed away. The process is typically used to produce parts such as circuit boards and other delicate items.

Physical Properties
Properties of a metal or alloy that are relatively insensitive to structure and can be measured without the application of force; for example, density, electrical conductivity, coefficient of thermal expansion, magnetic permeability, and lattice parameter. Does not include chemical reactivity. *See mechanical properties.*

Pitch
On a saw blade, the number of teeth per inch. In threading, the number of threads per inch.



THREAD PITCH

Pitting
Localized corrosion of a metal surface, confined to a point or small area, that takes the form of cavities.

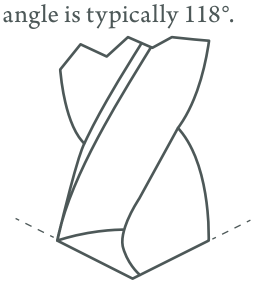
Planer
See planing machine.

Planing
Machining operation that creates flat surfaces. The workpiece is reciprocated in a linear motion against one or more single-point tools. Also used to create contours or irregular configurations.

Planing bit
Cutting tool similar in appearance to a turning tool, but with a longer shank.

Planing machine
Machines flat surfaces. Planers take a variety of forms: double-housing, open-side, convertible and adjustable open-side, double-cut, and milling. Large multi-head (milling, boring, drilling, etc.) planers and planer-type milling machines handle most planing work.

Point Angle
The included angle at the point of a twist drill or similar tool; for general-purpose tools, the point angle is typically 118°.



POINT ANGLE

Point-to-point System
Numerical control (NC) system normally used for drilling and other operations where center-point location is readily determined. Tool is rapidly moved to a position, then drills, taps, reams, bores, counter-bores, countersinks, or performs some other task.

Polar Additives
Animal, vegetable, or synthetic oils that, when added to a mineral oil, improve its ability to penetrate the tool/workpiece interface.

Polishing
Abrasive process that improves surface finish and blends contours. Abrasive particles attached to a flexible backing abrade the workpiece.

Polishing Attachment
Abrasive grinding device that mounts on a contour bandsaw and uses fine-grit belts to grind and polish.

Powder Metallurgy (PM)
Processes in which metallic particles are fused under various combinations of heat and pressure to create solid metals.

Power Brushing
Any process that uses a power-driven, rotating industrial brush to deburr, clean, or finish a metal part. Depending on the application, the brush fibers, collectively known as brush fill material, may be metal wires; fiberglass-coated, abrasive-filled plastics; synthetics such as nylon and polypropylene; natural animal hairs such as horsehair; or vegetable fibers such as tampico and bahia.

Power Hacksaw
Machine fitted with serrated blade held taut in a reciprocating frame that cuts in one direction, either on the forward or return stroke. *See saw, sawing machine.*

Power Hacksawing
A sawing process that uses the back-and-forth motion of a short, straight toothed blade to cut the workpiece. Hacksawing machines are generally electrically driven, and may not provide for application of cutting fluid to the saw blade or workpiece.

Precision Machining
Machining and measuring to exacting standards. Four basic considerations are: dimensions, or geometrical characteristics such as lengths, angles, and diameters of which the sizes are numerically specified; limits, or the maximum and minimum sizes permissible for a specified dimension; tolerances, or the total permissible variations in size; and allowances, or the prescribed differences in dimensions between mating parts.

Precision Measurement
See precision machining.

Preheating
Heating before some further thermal or mechanical treatment.

Probability Theory
Discipline based on the likelihood of any given event happening; mathematical techniques built around sampling methods, combinations, and permutations. Key to understanding statistical-process-control systems. *See statistical process control (CPC).*

Process Annealing
An imprecise term denoting various treatments used to improve workability. For the term to be meaningful, the condition of the

material and the time/temperature cycle used must be stated.

Process Control
Method of monitoring a process. Relates to electronic hardware and instrumentation used in automated process control. *See in-process gaging, inspection; statistical process control (SPC).*

Productivity
Measure of the efficiency with which human and material resources are used to produce goods and services. Output per man-hour has traditionally been the most stable measure, but since direct labor is sharply reduced by computer-aided design (CAD), computer-aided manufacturing (CAM), and computer-integrated manufacturing (CIM), alternative methods of measuring may be more accurate. Software and other support/service functions must be factored into the equation.

Profiling
Machining vertical edges of workpieces having irregular contours; normally performed with an end-mill in a vertical spindle on a milling machine or with a profiler, following a pattern.

Q

Quality Assurance (QA) or Quality Control (QC)
Terms denoting a formal program for monitoring product quality. The denotations are the same, but QC typically connotes a more traditional post-machining inspection system, while QA implies a more comprehensive approach, with emphasis on “total quality,” broad quality principles, statistical process control, and other statistical methods.

Quality Circles
Teams or groups within a plant or organization dedicated to improving product quality.

Quench Cracking
Fracture of a metal during quenching. Most frequently observed in hardened carbon-steel, alloy-steel, or tool-steel parts of high hardness and low toughness. Cracks often emanate from fillets, holes, corners, or other stress raisers and result from high stresses due to volume changes accompanying transformation to martensite.

Quench Hardening
(1) Hardening alpha-beta alloys (most often copper or titanium alloys) by solution-treating and quenching to develop a martensite-like structure. (2) In ferrous alloys, hardening by austenitizing and then cooling so that austenite transforms to martensite.

Quenching
Rapid cooling of the workpiece with an air, gas, liquid, or solid medium. When applicable, more specific terms should be used to identify the quenching medium, the process, and the cooling rate.

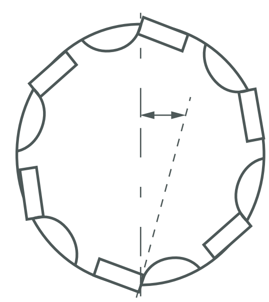
Quick-change Tool Holder
Cutter holder that permits rapid tool changes. Generally associated with automatic or semiautomatic machining operations. *See Tool Holder.*

R

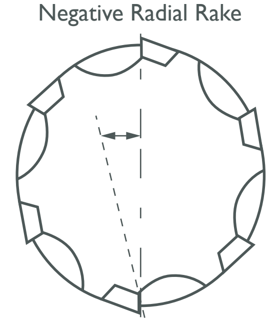
Rack-milling Attachment
Attachment for cutting gear teeth, usually in a straight line, but when used in conjunction with universal spiral-index centers on a universal mill, it allows the machining of worm gears.

Radial Drill
Large drill with an arm that pivots about a column to provide positioning flexibility and great reach and stability. *See drilling machine, drill press.*

Radial Rake
Also known as the tool back rake, the angle between the tooth face and the radial plane through the tool point.



Negative Radial Rake



Positive Radial Rake

Rake
Angle formed between a tooth face and a line perpendicular to the cutter centerline.

Rancidity
Bacterial and fungal growths in water-miscible fluids that cause unpleasant odors, stained workpieces, and diminished fluid life.

Reaction Injection Molding (RIM)
A molding process that allows the rapid molding of liquid materials. The injection-molding process consists of heating and homogenizing plastic granules in a cylinder until they are sufficiently fluid to allow for pressure injection into a relatively cold mold, where they solidify and take the shape of the mold cavity. For thermoplastics, no chemical changes occur within the plastic, and consequently the process is repeatable. The major advantages of the injection molding process are the speed of production; minimal requirements for post-molding operations; and simultaneous, multi-part molding.

Reamer
Rotating cutting tool used to enlarge a drilled hole to size. Normally removes only a small amount of stock. The workpiece supports the multiple-edge cutting tool. Also for contouring an existing hole.

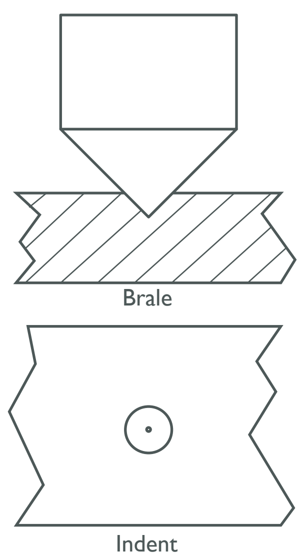
Reaming
A machining process that uses a multi-edge, fluted cutting tool to smooth, enlarge, or accurately size an existing hole. Reaming is performed using the same types of machines as drilling. Reaming is simpler to perform than boring, but it is not as precise. *See drilling.*

Recarburizing
(1) Increasing the carbon content of molten cast iron or steel by adding a carbonaceous material, a high-carbon pig iron, or a high-carbon alloy. (2) Carburizing a metal part to return surface carbon lost in processing; also known as carbon restoration.

Relief
Space provided behind the cutting edges to prevent rubbing. Sometimes called primary relief. Secondary relief provides additional space behind primary relief. Relief on end teeth is axial relief; relief on side teeth is peripheral relief.

Rockwell Hardness
Various scales for determining material hardness. Rockwell C, A, and D scales measure metal hardness. The Rockwell C, or RC, scale and the Brinell hardness (BHN) scale are used most often in connection with cutting tools and machining.

Rockwell Hardness Test
An indentation hardness test based on the depth of penetration of a specified penetrator into the specimen under certain arbitrarily fixed conditions. *See brale.*



ROCKWELL HARDNESS TEST

Rotary Attachment
Bolts to a milling machine to permit machining shapes such as circular t-slots and cams.

Roughing Cutter
See roughing tool.

Roughing Tool
Tool for high-volume metal removal; normally followed by finishing passes. *See finishing tool.*

S

Salt Fog Test
An accelerated corrosion test in which specimens are exposed to a fine mist of a solution usually containing sodium chloride but sometimes modified with other chemicals. Used to determine resistance to, and rates of, corrosion exhibited by various materials.

Salt Spray Test
See salt fog test.

Saw
Machine designed to use a serrated-tooth blade to cut metal or other material. Comes in a wide variety of styles, but takes one of four basic forms: A) hacksaw (a simple, rugged machine that uses a reciprocating motion to part metal or other material); B) cold or circular saw (powers a circular blade that cuts structural materials); C) bandsaw (runs an endless band; the two basic types are cutoff and contour band machines, which cut intricate contours and shapes); and D) abrasive cutoff saw (similar in appearance to the cold-saw, but uses an abrasive disc that rotates at high speeds rather than a blade with serrated teeth).

Sawing
Machining operation in which a powered machine, usually equipped with a blade having milled or ground teeth, is used to part material (cutoff) or give it a new shape (contour band sawing, band machining). *See Saw.*

Scalloping
Wavy surface condition caused by deflection, unbalanced tool, loose workpiece or tooling, worn machine, etc.

Screw Flat
See flat.

Semisynthetic Cutting Fluid
Water-based chemical solution that contains some oil. *See synthetic cutting fluid.*

Shank
Main body of a tool; the portion of a drill or similar end-held tool that fits into a collet, chuck, or similar mounting device.

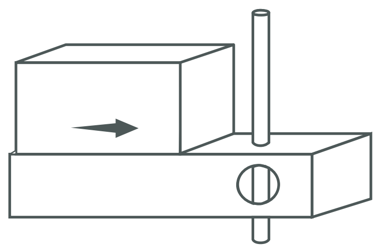
Shaper
See slotting machine.

Shaper Tool
Single-point tool that traverses the workpiece in a reciprocating fashion to machine a desired shape.

Shaping
Using a shaper primarily to produce flat surfaces in horizontal, vertical, or angular planes. It can also include the matching of curved surfaces, helixes, serrations, and special work involving odd and irregular shapes. Often used for prototype or short-run manufacturing to eliminate the need for expensive special tooling or processes.

Shear Plane
Plane along which the chip parts from the workpiece. In orthogonal cutting, most of the energy is used to create the shear plane.

Shear Strength
The stress required to produce fracture in the plane of cross section, the conditions of loading being that the directions of force and of resistance are parallel and opposite although their path are offset a specified minimum amount. The maximum load divided by the original cross sectional area of a section separated by shear.



SINGLE SHEAR TEST

Shock Loading
Tool is subjected to sudden, heavy loads and/or impacts, as in interrupted cutting. *See interrupted cut.*

Shop Air
Pressurized air system that cools the workpiece and tool when machining dry. Also refers to central pneumatic system.

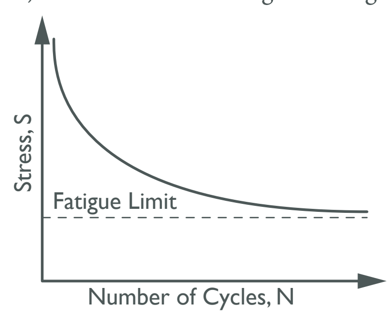
Sintering
The bonding of adjacent surfaces in a mass of particles by molecular or atomic attraction on heating at high temperatures below the melting temperature of any constituent in the material. Sintering strengthens and increases the density of a powder mass and recrystallizes powder metals.

Slotting
Machining, normally milling, that creates slots, grooves, and similar recesses in workpieces, including t-slots and dovetails.

Slotting Attachment
Converts a milling machine's rotary spindle motion into a reciprocating motion for machining keyways and slots.

Slotting Machine
Vertical or horizontal machine that accommodates single-point, reciprocating cutting tools to shape or slot a workpiece. Normally used for special (unusual/intricate shapes), low-volume runs typically performed by broaching or milling machines. *See broaching machine; mill, milling machine.*

Stress/Number (S-N) Diagram
A plot showing the relationship of stress, S, and the number of cycles, N, before fracture in fatigue testing.

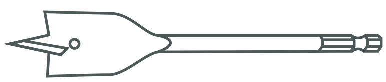


STRESS/NUMBER DIAGRAM

Soluble Oil Cutting Fluid
Fluid in which oil is suspended in water. Since water is a superior heat removal agent, this fluid is primarily used when lubrication is desirable, but cooling is the key consideration. The ratio of oils and other additives to water varies with the application. For milling, the ratio of water to oil/additives runs 20:1 to 25:1. For sawing and other work, where a

more confined tool/chip/workpiece condition is normal, a 10:1 ratio is used to improve lubricity. Additives include emulsifying agents that help keep the oil in suspension and substances that promote wetting, enhance lubricity, prevent chip welding, and inhibit rusting. Also known as emulsified oil. *See cutting fluid*.

Spade Drill
A flat end-cutting tool, used to produce holes ranging from about 1″ – 6″ in diameter. Spade drills consist of an interchangeable cutting blade and a tool holder that has a slot into which the blade fits. In horizontal applications, a spade drill can achieve extreme depth-to-diameter ratios, but in vertical applications the tools are limited by poor chip evacuation.



SPADE DRILL

Spade Drilling
Drilling operation in which a machine powers a cutting tool consisting of a holder and flat, interchangeable end-cutting blades. Spade drilling takes over where twist drilling leaves off; requires more power and a larger machine, but offers lower cost and greater rigidity. Large diameter spade drills are used when trepanning is impractical or impossible. Spade drills are not, however, precision tools. *See drilling; trepanning.*

Specific Cutting Energy
Measure of the total energy required to make the cut, including the energy needed to part the stock and overcome frictional forces generated during cutting.

Spheroidizing
Heating and cooling to produce a spheroidal or globular form of carbide in steel. Spheroidizing methods frequently used are: A) prolonged holding at a temperature just below the lower eutectoid transformation temperature; B) heating and cooling alternately between temperatures that are just above and below the lower eutectoid transformation temperature; C) heating to a temperature above the lower eutectoid transformation temperature or the upper eutectoid transformation temperature, and then cooling very slowly in the furnace or holding at a temperature just below the lower eutectoid transformation temperature; and D) cooling at a suitable rate from the minimum temperature at which all carbide is dissolved, to prevent the reformation of a carbide network, and then reheating in accordance with method A or B above; applicable to hypereutectoid steel containing a carbide network.

Spindle Adapters
Bushings of tool holders that permit affixing a variety of taper- and straight-shank tools to a machine spindle.

Spindle Finishing
A mass finishing process in which workpieces are individually mounted on spindles, then lowered into a rotating tub containing the finishing media. In most applications, the spindles rotate at 10 – 3000 rpm, but in some cases the spindles oscillate up and down instead of rotating. The process is sometimes automated for robotic loading and unloading. *See finishing.*

Spiral Milling
Milling while simultaneously rotating and feeding the workpiece to create a spiral form. Often used to mill flutes on end-mill and twist-drill blanks.

Spot-facer
Tool, guided by a pilot, used to machine a recess around a hole.

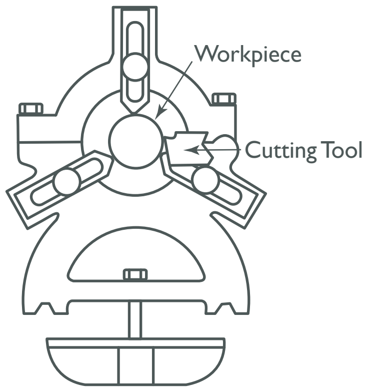
Spot-facing
Similar to counterboring except that, in spot-facing, material around the original hole is cut. Application example: the recessed area that a washer fits into. *See counterboring; countersinking.*

Stabilizing Treatment
(1) Before finishing to final dimensions, repeatedly heating a ferrous or nonferrous part to its normal operating temperature, or slightly hotter, and then cooling it to room temperature, ensuring dimensional stability in service. (2) Transforming retained austenite in quenched hardenable steels, usually by cold-treatment. (3) Heating a solution-treated stabilized grade of austenitic stainless steel to 1600°F – 1650°F to precipitate all carbon as titanium carbide.

Statistical Process Control (SPC)
Statistical techniques to measure and analyze the extent to which a process deviates from a set standard.

Statistical Quality Control (SQC)
Statistical techniques to measure and improve the quality of a given process.

Steady Rest
Supports long, thin, or flexible work being turned on a lathe. Mounts on the bed's ways and, unlike a follower rest, remains at the point where mounted. *See follower rest*.



STEADY REST

Steel
Pure iron in combination with carbon and other elements. There are two types of steel: carbon steel – a combination of iron and carbon – and alloy steel – carbon steel plus manganese, molybdenum, chromium, nickel, or other alloying elements. A steel's quality depends on how it is refined and produced. *See alloy; alloy steel; alloying element; carbon steel*.

Steel Specification Number
A system of numbers developed by the American Iron and Steel Institute (AISI) and Society of Automotive Engineers (SAE) to identify steel. The first two digits in the code indicate the family and basic alloying elements. The final two digits indicate the approximate carbon content in hundredths of a percent. For steels with a carbon content above 1.00%, five digits are used. Numbers with L or S added indicate alloys incorporating lead or sulfur for improved machinability. A number of steels and alloys are identified under different codes, including tool steel, carbon tool steel, high-speed steel, die steel, stainless steel, strain-hardenable or work hardening steel, and nickel-based super-alloys.

Stereo Lithography: Metal
A process similar to plastic stereo lithography, but uses powder metal to build up the part. *See stereo lithography: plastic*.

Stereo Lithography: Plastic
A process that uses a combination of lasers and photosensitive, liquid plastics to generate models. The desired workpiece is electronically "sliced" into thin sections. The laser beam scans over a bath of uncured polymer and only turns on where material should exist, duplicating the sliced section. The polymer partially hardens in these areas. By lowering the workpiece into the polymer bath and scanning successive layers, the part is developed. When the part is completely built up, it is removed from the bath and finish-cured with intense ultraviolet light. Can be used to generate complex models.

Straight-cut System
Numerical-control (NC) system wherein tools move at either 45° or 90° angles to the coordinate axes. Used in turning shoulders or milling rectangular shapes; normally is combined with point-to-point system for greater efficiency and flexibility.

Straight Oil
Cutting fluid that contains no water. Produced from mineral, vegetable, marine, or petroleum oils, or combinations of these oils.

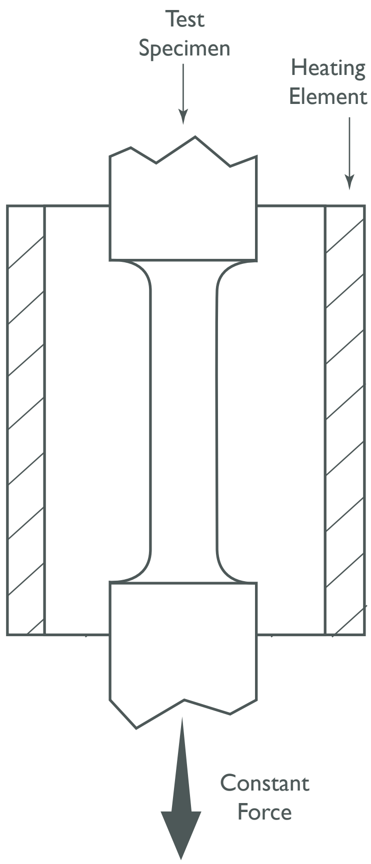
Strain
A measure of the relative change in the size or shape of a body. Linear strain is the change per unit length of a linear dimension. True strain (or natural strain) is the natural logarithm of the ratio of the length at the moment of observation to the original gauge length. Conventional strain is the linear strain over the original gauge length. Shearing strain (or shear strain) is the change in angle (expressed in radians) between two lines originally at right angles. When the term "strain" is used alone it usually refers to the linear strain in the direction of applied stress.

Stress
Force per unit area, often thought of as force acting through a small area within a plane. It can be divided into components, normal and parallel to the plane, called normal stress and shear stress, respectively. True stress denotes the stress where force and area are measured at the same time. Conventional stress, as applied to tension and compression tests, is force divided by original area. Nominal stress is the stress computed by simple elasticity formulas, ignoring stress raisers and disregarding plastic flow; in a notch bend test, for example, it is bending moment divided by minimum section modulus.

Stress Relieving
Annealing designed to relieve internal stresses caused by machining, welding, casting, cold-working, quenching, or normalizing.

Stress-rupture Test
A method of evaluating elevated-temperature durability in which a tension-test specimen is stressed

under constant load until it breaks. Data recorded commonly include initial stress, time to rupture, initial extension, creep extension, and reduction of area at fracture.



STRESS-RUPTURE TEST

Super-abrasive Tools
Abrasive tools made from diamond or cubic boron nitride (CBN), the hardest materials known.

Super-cooling
Cooling below the temperature at which an equilibrium phase transformation can take place, without actually obtaining the transformation.

Superficial Rockwell Hardness Test
Form of Rockwell Hardness Test using relatively light loads that produce minimum penetration by the indenter. Used for determining surface hardness or hardness of thin sections or small parts, or where a large hardness impression might be harmful. *See brale; Rockwell Hardness Test.*

Super-heating
Heating above the temperature at which an equilibrium phase transformation should occur, without actually obtaining the transformation.

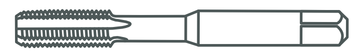
Surface Grinding
The machining of a flat, angled, or contoured surface by passing a workpiece beneath a grinding wheel in a plane parallel to the grinding wheel spindle. *See grinding.*

T

Tailstock Drill and Tap Holder
Accessory that mounts in a turning machine's tailstock for center drilling chucked work and tapping. *See chuck.*

Tang
Extended flat portion of tapered drill shank, end-mill, or other tool that allows maximum power transmission and proper positioning of the tool. Reverse shape of the machine-spindle slot it fits into.

Tap
Cylindrical tool that cuts internal threads and has flutes to remove chips and carry tapping fluid to the point of cut. Normally used on a drill press or tapping machine, but also may be operated manually.



TAP

Tap Reamer
Reamer designed to produce a reamed hole with a specified taper. Principles of standard reamers apply. *See reamer.*

Taper-turning Attachment
Guide to which a cross slide is attached that permits the turning of tapers without disturbing the alignment of the tailstock. Also permits taper boring.

Tapping
Machining operation in which a tap, with teeth on its periphery, cuts internal threads in a pre-drilled hole having a smaller diameter than the tap diameter. Threads are formed by a combined rotary and axial-relative motion between tap and workpiece.

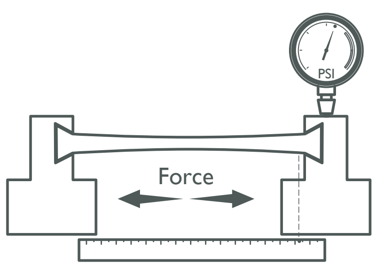
Tapping Attachment
Fits in a drill press spindle and automatically reverses the tap when the thread is completed, ensuring proper retraction of the tool.

Tapping Machine
Production machine used for high-volume tapping. Offers repeatability, high production rates, and reduced tap breakage. Comes in a variety of configurations, including indexing units with multiple tapping spindles. Precise stroke-depth settings and automatic features generally make tapping machines very cost-effective.

Technical Office Protocol (TOP)
Standardized computer communications for the office; combines with manufacturing automation protocol to permit office/machine computer integration of multi-vendor systems and software. *See Manufacturing Automation Protocol.*

Tempering
(1) In heat treatment, reheating hardened steel or hardened cast iron to a given temperature below the eutectoid temperature to decrease hardness and increase toughness. The process is sometimes applied to normalized steel as well. (2) In nonferrous alloys and in some ferrous alloys (steels that cannot be hardened by heat treatment), the hardness and strength produced by mechanical or thermal treatment, or both, and characterized by a certain structure, mechanical properties, or reduction in area during cold-working.

Tensile Strength
In tensile testing, the ratio of maximum load to original cross sectional area. Also called ultimate strength. *See yield strength.*



TENSILE STRENGTH TEST

Thread Chaser
Die-type external threading tool. Makes final threading pass.

Thread Grinder
Typically a form grinder as well as a thread grinder, this machine differs from other grinders in that precision gears and lead screws ensure a precise traverse to impart the correct lead to a thread.

Threading
A process of both external and internal (tapping) cutting, turning, and rolling of threads into particular material. Standardized specifications are available to determine the desired results of the threading process. Numerous thread-series designations are written for specific applications. Threading is often performed on a lathe. Specifications such as thread height are critical in determining the strength of the threads. The material used is taken into consideration in determining the expected results of any particular application for that threaded piece. In external threading, a calculated depth is required as well as a particular angle to the cut. To perform internal threading, the exact diameter to bore the hole is critical before threading. The threads are distinguished from one another by the amount of tolerance and/or allowance that is specified. *See turning.*

Threading Machine
Typically takes the form of multi-spindle, universal threading machines that use die heads and thread chasers to cut threads, often automatically or semi-automatically. Threading also is performed on lathes and automatic screw machines.

Tolerance
Minimum and maximum amount a workpiece dimension is allowed to vary from a set standard and still be acceptable.

Tool Path
See cutter path.

Tool Steel
Any of a class of carbon and alloy steels commonly used to make tools. Tool steels are characterized by high hardness and resistance to abrasion, often accompanied by high toughness and resistance to softening at elevated temperatures. These attributes are generally attained with high-carbon and alloy contents.

Tool Changer
Carriage or drum attached to a machining center that holds tools until needed; when a tool is needed, the tool changer inserts the tool into the machine spindle.

Tool Holder
Secures a cutting tool during a machining operation. Basic types include block, cartridge, chuck, collet, fixed, modular, quick-change, and rotating.

Tool-room Lathe
High-precision lathe built to hold tighter tolerances than regular, general purpose lathes. *See lathe; turning machine.*

Tooth Rest
Finger of metal that contacts a cutter edge during resharpening on a tool-and-cutter grinder, ensuring accurate location of edges so they are properly ground.

Total Indicator Run-out (TIR)
Combined variations of all dimensions of a workpiece, measured with an indicator, determined by rotating the part 360°.

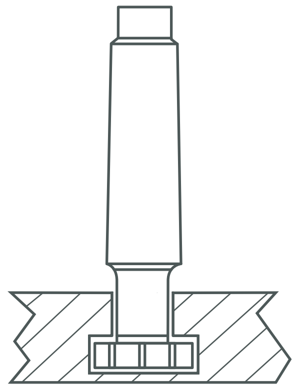
Tracer Attachment
Used to duplicate a workpiece. A stylus connected to a servo traces a template or sample workpiece. The attachment directs the movements of a machine tool that cuts a duplicate workpiece. For machining complex parts.

Transformation Range
Temperature range at which austenite forms as steel is heated and disappears as steel cools. This range is critical and must be known in order to heat treat steel.

Trepanning
Drilling deep holes that are too large to be drilled by high-pressure coolant drills or gun drills. Trepanning normally requires a big, powerful machine. Shallow trepanning operations can be performed on modified engine or turret lathes, or on boring machines. *See boring; drilling; spade drilling.*

Truing
Using a diamond or other dressing tool to ensure that a grinding wheel is round and concentric and will not vibrate at required speeds. Weights also are used to balance the wheel. Also performed to impart a contour to the wheel's face. *See dressing.*

T-slot Cutter
Milling cutter for machining t-slots. Desired t-slot shape is reverse of cutter shape.



T-SLOT CUTTER

Turning
A workpiece is held in a chuck, mounted on a faceplate, or secured between centers and rotated while a cutting tool – normally a single-point tool – is fed into it along its periphery or across its end or face. Takes the form of straight turning (cutting along the periphery of the workpiece); taper turning (creating a taper); step turning (turning different-size diameters on the same work); chamfering (beveling an edge or shoulder); facing (cutting on an end); turning threads (usually external but can be internal); roughing (volume metal removal); and finishing (final light cuts). Performed on lathes, turning centers, chucking machines, automatic screw machines, and similar units.

Turning Machine
Any machine that rotates a workpiece while feeding a cutting tool into it. *See lathe.*

Turret Lathe
Differs from engine lathe in that the normal compound rest is replaced by pivoting, multi-tool turrets mounted on the cross slide and tailstock. *See lathe.*

Turret Ram Mill
Variation of the vertical milling machine; has a movable ram mounted on a swivel base atop the column, providing positioning flexibility. *See mill, milling machine.*

Twist Drill
The most common type of drill, having one or more helical cutting edges with adjacent grooves for the passage of chips and for admitting coolant to the cutting edges. Twist drills are used either for originating holes or for enlarging existing holes. Standard twist drills come in fractional sizes 1/16″ – 1 1/2″, wire-gauge sizes 1 – 80, letter sizes A – Z, and metric sizes.

U

Ultimate Strength
The maximum conventional stress (tensile, compressive, or shear) that a material can withstand.

Ultrasonic Machining
Material removal operation in which an abrasive slurry, vibrating at a high frequency, flows between a tool and a workpiece.

Ultrasonic Testing
A nonconductive test applied to sound-conductive materials having elastic properties for the purpose of locating inhomogeneities or structural discontinuities within a material by means of an ultrasonic beam.

Undercut
In numerical control (NC) applications, a cut shorter than the programmed cut resulting after a command change in direction. Also a condition in generated gear teeth when any part of the fillet curve

lies inside of a line drawn tangent to the working profile at its point of juncture with the fillet. Undercut may be deliberately introduced to facilitate finishing operations, as in pre-shaving.

Undershoot
Tendency of a numerical control (NC)/computer numerical control (CNC) machine to round off the corners of a programmed path because of servo lag or backlash, or because mechanical systems cannot react quickly to programmed instructions, especially when the machine is cold.

Universal Milling Machine
A horizontal mill equipped with a table that swivels, with respect to the saddle, allowing angular surfaces to be cut without changing the workpiece's position.

Universal Head
Facilitates setups on a tool-and-cutter grinder by allowing the grinding head to rotate away from the work area, leaving table alignment undisturbed. Also called a swivel attachment.

Universal Milling Attachment
Mounts on a horizontal mill, permitting the spindle to be set at almost any angle.

Universal Spiral-milling Attachment
On a universal mill, permits milling helixes with a 45° or greater helix angle. Mills gears, screw threads, worms, twist drills, spiral-milling cutters, and other helical shapes. Mounted to a plain milling machine equipped with a dividing head, it permits the mill to handle work that otherwise would require a universal mill.

V

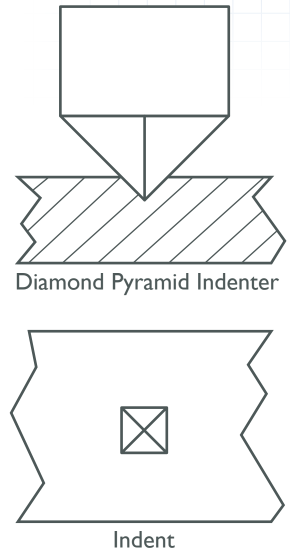
Vacuum Bag Molding
A process for molding reinforced plastics in which a sheet of flexible, transparent material is placed over the lay-up on the mold and sealed. A vacuum is created between the sheet and the lay-up. The entrapped air is next mechanically worked out of the lay-up and removed by the vacuum; finally, the part is cured.

Vacuum Melting
Melting in a vacuum to prevent contamination from air, as well as to remove gases already dissolved in the metal; solidification may also be carried out in a vacuum or at low pressure.

V-block
Work-holding device with V-shaped slot for holding pipe and other round stock during machining or inspection.

Vertical Milling Attachment
Permits a horizontal mill to perform vertical and angled milling.

Vickers Hardness Test
An indentation hardness test employing a 136° diamond pyramid indenter (Vickers) and variable loads enabling the use of one hardness scale for all ranges of hardness from very soft lead to tungsten carbide. *See Brinell Hardness Test; Rockwell Hardness Test.*



VICKERS HARDNESS TEST

Viscosity
Measure of a fluid's tendency to flow; varies with temperature.

Vise
Work-holding device that mounts on various machining tables. Designs vary from plain to flanged to swiveling. Multi-angle vises, such as the toolmaker's universal vise, accurately hold work to allow machining at virtually any angle.

W

Warm-working
Plastically deforming metal above room temperature but below the temperature at which the material undergoes recrystallization.

Waterjet Cutting
A fine, high-pressure (up to 50,000 psi or greater), high-velocity jet of water directed by a small nozzle to cut material. The pressure of the waterjet is usually thousands of psi and the velocity of the stream

can exceed twice the speed of sound. The small nozzle opening ranges 0.004″ – 0.016″ (0.10 mm – 0.41 mm), producing a very narrow kerf. *See abrasive waterjet (AWJ).*

Wear Resistance
Ability of the tool to withstand stresses that cause it to wear during cutting; an attribute linked to alloy composition, base material, thermal conditions, type of tooling and operation, and other variables.

Web
On a rotating tool, the portion of the tool body that joins the lands. Web is thicker at the shank end, relative to the point end, providing maximum torsional strength.

Wheel-balancing Stand
Used to ensure that a grinding wheel is balanced before mounting it on the machine.

Wheel Flange
Metal plate inside the grinding-wheel hole that allows the wheel to be mounted on a spindle.

Woodruff Cutter
Milling cutter used for cutting keyways.

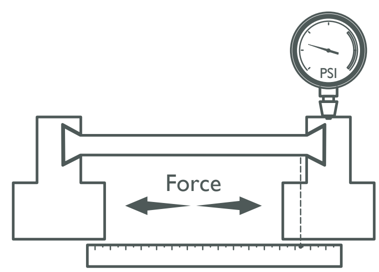
Work Hardening
Tendency of all metals to become harder when they are machined or subjected to other stresses and strains. This trait is particularly pronounced in soft, low-carbon steel or alloys containing nickel and manganese, nonmagnetic stainless steel, high-manganese steel, and the super-alloys Inconel and Monel.

Work-squaring Bar
Mounts to the table of a contour band machine and automatically squares the work to the blade.

Y

Yield Point
The first stress in a material, usually less than the maximum attainable stress, at which an increase in strain occurs without an increase in stress. Only certain metals exhibit a yield point. If there is a decrease in stress after yielding, a distinction may be made between upper and lower yield points.

Yield Strength
The stress at which a material exhibits a specified deviation from proportionality of stress and strain. An offset of 0.2% is used for many metals. Compare with tensile strength.



YIELD STRENGTH TEST

LINKS & RELATED SITES

Industrial Fasteners Institute (IFI)
http://www.indfast.org/

National Fastener Distributors Association (NFDA)
http://www.nfda-fastener.org/

American National Standards Institute (ANSI)
http://www.ansi.org/

International Organization for Standardization (ISO)
http://www.iso.org/

American Society for Testing & Materials (ASTM)
http://www.astm.org/

National Institute of Standards and Technology (NIST)
http://www.nist.gov/

American Society of Mechanical Engineers (ASME)
http://www.asme.org/

National Society of Professional Engineers (NSPE)
http://www.nspe.org/

Society of Automotive Engineers (SAE)
http://www.sae.org/

Society of Manufacturing Engineers (SME)
http://www.sme.org/

INDEX

A

Abrasive . . . . 96, 97, 100, 103, ... 113, 121, 127
Abrasive band 96
Abrasive belt 96
Abrasive cutoff disc 96
Abrasive flow machining 96
Abrasive machining 96
Abrasive-wire bandsawing . . . 96, 97
Admixture 97
Age hardening 96
Aging 96
Allotropic transformation 48
Alloy 23, 24, 28, 97, 102
Alloying element 97
Alloy Numbering System 23
Alloy steels 24
Alpha iron 97
Aluminizing 97
Amorphous 97
Annealing 50, 97, 126
Anodizing 78
Atmospheric corrosion 97
Ausforming 109
Austempering 98, 109
Austenite 98
Austenitizing 109
Automatic screw machine 98
Automatic tool changer 98

B

Backlash 99
Backoff 99
Back rest 99
Bainite 98
Baking 86, 109
Band 54, 99
Band polishing 99
Band sawing 54
Barrel finishing 99
Barstock 26
Black oxide 86, 99
Bonded abrasive 100
Boring 100
Boring bar 100
Boring cutter 100
Boring machine 100
Boundary additives 100
Bright steels 25
Brinell Hardness Test 68
Broaching 100, 101
Broaching machine 101
Brushing 101
Buffing 101
Burr 101
Bushing 101

C

Carbide 101, 102
Carbonitriding 109
Carbon steel 23, 26, 101, 118
Carburization 23
Carburizing 109, 123
Case 51, 101, 105
Case hardening 101, 105
Cast alloy 102
Cast iron 102
Cementite 102
Center drill 102
Center drilling 102
Centering 102
Centerless grinding 102
Center rest 102
Centers 102
Ceramic 102
Chamfering 102
Chamfering tool 102
Charpy test 114
Chip breaker 103
Chuck 103
Circular saw 103
Circular saw blade 103
Clearance 103, 116
Cold-drawing 55
Cold-sawing 55
Cold-working 102
Composites 103
Contact fatigue 39
Continuous casting 103
Cooling 104, 125, 127
Corrosion 39, 87, 103, 104
Corrosion fatigue 39, 104
Corrosion resistance 87, 104
Counterbore 104
Counterboring 104
Countersink 104
Countersinking 104
Creep 39
Creep-feed grinding 104

Cutoff 103, 104, 105
Cutoff blade 105
Cutter compensation 104
Cutter path .104
Cutting fluid 126
Cutting tool materials 105
Cutting-velocity vector 104
Cyaniding 109
Cylindrical-grinding attachment 105

D

Decarburization 109
Deionization 105
Diamond 96, 105
Diamond bandsawing 105
Die-casting .105
Diffusion 105
Disc grinding 105
Dish 105
Dividing head 105
Dressing 106
Drill 102
Drilling 102, 106, 111, 125, 129
Drilling machine 106
Driving dog 106
Ductile cast iron 105
Ductility 38, 106

E

Economies of scope 106
Edge finder .107
Elasticity 107
Elastic limit 37, 106
Elongation .107
Embrittlement 107
Endmill 112
Endurance limit 108
Extrusion 108

F

Face 108, 109
Face-mill 108
Face-milling 108
Face plate 108
Facing 108
Family of parts 108
Fatigue 38, 39, 108
Fatigue failure 38
Fatigue life .108
Fatigue resistance 108
Fatigue strength 108
Feather burr 109
Feather edge 108
Ferrite 108
File bands 109
Filing 109
Filing attachment 109
Fillet 109
Film strength 109
Finish cut 109
Finish feed .109
Finishing 109, 115
Finishing tool 109
Fixture 109
Flame hardening 109
Flank wear 113
Flat 108, 109
Flood application 113
Fluorescent penetrant inspection 110
Flushing hose 113
Flutes 110
Follower rest 110
Form cutter .110
Form-rolling machine 110
Fracture stress 109
Free-machining steels 110
Friction sawing 113
Fungicide 113

G

Galling 110
Gang cutting 113
Gear cutter .111
Gear shaper .111
Gray cast iron 111
Grinding . . . . 16, 56, 102, ... 104, 105, 111, 113
Grinding machine 111
Grinding ratio 113
Grinding wheel 111
Grit size 111
Grooving 111
Group technology 111
Gun drill 111
Gun drilling .111

H

Hacksaw blade 113
Hard chromium 111
Hardenability 48, 108, 112
Hardening 30, 97, 109, 122
Hardness . . . . 48, 68, 69, ... 70, 71, 74, 112, 115
Head-changing machine 113
Heat treating .28
Heeling 113
Helical cutter 112
Helix angle .112
High-carbon .51
High-speed milling attachment . .112
Hob 113
Hobbing 113
Hobbing machine 113
Hold-down .113
Holemaking 113
Honing 113
Honing tool 113
Hook 113
Hot-working 112
Hydrodynamic machining 113

I

Inclination angle 113
Indexable insert 113
Indicator drop measurement 113
Induction hardening 113
Inhibitor 114
Inspection 110, 114, 119
Interchangeable parts 114
Interpolation 114
Interrupted cut 114
Investment casting 114
Izod test 102

J

Jig 114
Jig bore 114
Jig boring 114

K

Key-seating 115
Keystock 26
Killed steel 114
Knoop hardness 115
Knurling 115
Knurling tool 115

L

Lapping 115
Lapping compound 115
Laser 56, 115
Laser machining 115
Lathe 116
Lathe bit 116
Layout 116
Loading 116
Low-carbon 131
Lubricant 116
Lubricity 116

M

Machinability 115
Machining 56, 60, 102, 111,
.............116, 117, 118, 121,
..................122, 124, 127
Machining center 117
Malleable cast iron 117
Martensite 117
Mechanical properties 38, 117
Metal working 118
Metrology 118
Microhardness 118
Microstructure 118
Mild steel 118
Milling 56, 107, 108,
.........115, 119, 125, 129, 131
Milling arbor 119
Milling cutter 107, 108,
..................119, 129, 131
Mixture ratio 119
Modular fixturing 119
Modular tooling 119

N

Nitrocarburizing 119
Nontraditional machining 120
Normalizing 119

O

Offhand grinding 120
Orthogonal chip formation 120
Overshoot 120
Oxidation 78, 119

P

Parting 120
Pearlite 24, 120
Peening 120
Physical properties 120
Pitch 120
Pitting 121
Planing 121
Planing bit 121
Point-to-point system 121
Polar additives 121
Polishing 121
Polishing attachment 121
Power hacksaw 121
Power hacksawing 121
Process annealing 121
Profiling 122
Proportional limit 37

Q

Quality circles 122
Quench hardening 122
Quenching 48, 49, 98, 122

R

Rack-milling attachment 127
Radial drill 122
Radial rake 122
Rake 122
Rancidity 123
Reamer 123, 127
Reaming 123, 127
Relief 123, 127
Rockwell Hardness Test 69
Rotary attachment 127
Roughing cutter 123

S

Saw 127
Sawing 54, 110, 127
Scalloping 127
Semisynthetic cutting fluid 127
Shank 127
Shaper 127
Shaper tool 127
Shaping 124
Shear plane 127
Shear properties 37
Shear strength 38, 123
Shock loading 127
Shop air 124
Sintering 124
Slotting 124, 127
Slotting attachment 124
Soluble oil cutting fluid 127
Spade drill 127
Spade drilling 125
Specific cutting energy 125
Spheroidizing 125
Spindle adapters 127
Spindle finishing 125
Spiral milling 125
Sponge iron 6
Spot-facer 127
Spot-facing 125
Stabilizing treatment 125
Stainless steel 26, 29
Stamping 58
Steady rest 127
Steel .... ii, 2, 3, 22, 24, 27,
.... 30, 48, 50, 101,
.... 115, 124, 126, 128
Steel specification number 126
Straight-cut system 127
Straight oil 126
Strain 36
Stress 28, 36, 50, 87, 126
Stress relieving 50
Super-abrasive tools 127
Super-cooling 126
Super-heating 127
Surface grinding 127

T

Tailstock 127
Tap 127
Taper-turning attachment 127
Tapping 127
Tapping attachment 127
Tapping machine 127
Tap reamer 127
Tempering 50, 127
Tensile strength 71, 126
Thermal fatigue 39
Thermal modification 50
Thread grinder 128
Threading 128
Tool holder 128
Tool-room lathe 128
Tool steel 128
Tooth rest 128
Trepanning 129
Truing 129
T-slot cutter 127
Turning 59, 98, 115, 129
Turning machine 98, 115, 129
Turret lathe 129
Turret ram mill 129
Twist drill 129

U

Ultrasonic testing 129
Undercut 130
Undershoot 130
Unit strain 36
Universal head 130
Universal milling attachment 130
Universal milling machine 130
Universal
spiral-milling attachment 130

V

Vacuum melting 130
Vickers Hardness Test 70

W

Warm-working 130
Wear resistance 129
Web 131
Wheel flange 131

Y

Yield 28, 30, 37, 38, 131
Yield point 37, 131
Yield strength 28, 30, 37, 38, 131

FROM THE OLD TIN SHED

The Old Tin Shed houses the story of G.L. Huyett. According to newspaper accounts, a German immigrant named Guy Lamson Huyett bought the hardware stock of the Globe Department Store in 1899 and moved it to a location on Main Street in Minneapolis, Kansas. He incorporated the business in 1906 which is the date that we trace to our founding over 100 years ago.

From 1906 until 1994, the shed sheltered our entire company. The shed was originally an old hotel that was hitched to a team of horses and dragged a quarter mile down South Concord Street so G.L. Huyett could be closer to the local rail spur.

Our story isn't unique…and that is exactly what we love about it. It is a story you have heard a hundred times before…a story that is filled with human drama, pain, struggle, and triumph. It is a story lived by millions of lucky people. It is the American Dream.

During the Great Depression, Henry Hahn, successor to Guy Huyett, sold alfalfa seed to supplement lost hardware sales so that he could stay in business. Henry turned the business over to his son, Louis, who was already a successful entrepreneur. Later, Louis allowed his son, Bob, to join the firm, which at the time centered on machinery bushings. A group of residents was known to gather on Sunday afternoons under a big tree and count machinery bushings into 10's and 25's and wire them up while sipping whiskey. The group was affectionately known as the "South Side Sunday Sipper's Society," or "SSSSS."

Soon Bob took to the road and expanded G.L. Huyett's product lines to include pins, keystock, grease fittings, snap rings, and more. Bob worked days packing, shipping orders, and answering the phone while his wife, Dolly, worked at nights pounding out invoices on a Smith Corona typewriter. Sometimes, when going to bed, Bob would meet Dolly just as she was arising to start typing. Some customers were known to "appreciate" Dolly's penny-pinching ways and would mail coins taped to postcards so that Dolly would stop calling to collect for small billing differences.

Today, G.L. Huyett has grown into a highly entrepreneurial business with an interest in personal improvement and commitment to community that is inherent to the spirit of the pioneers who made the Great American Desert into America's Breadbasket. We now manufacture a large part of our products and are committed to improving our community and the life of our customers by upholding the principles of our humble past.

We call this our "Way of Life™" and we are proud to have you as part of our lives. Our job is to make your job easier, and we thank you for the opportunity. ■

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