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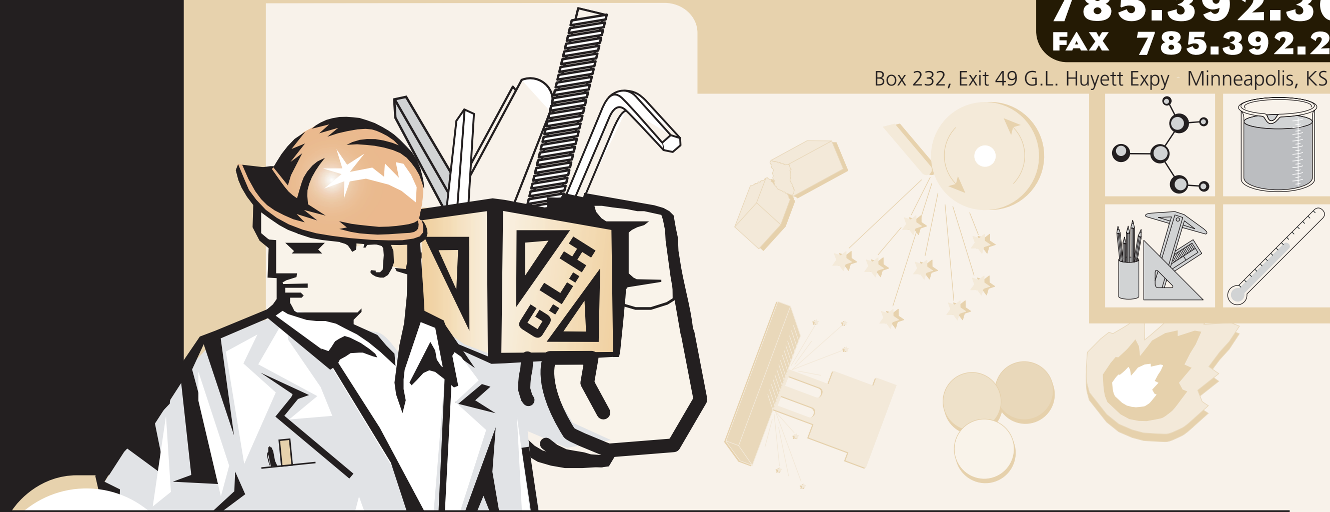

ENGINEERING HANDBOOK

TECHNICAL INFORMATION

ABOUT THIS SECTION...

This document and the information contained herein is not a design standard, design guide or otherwise, but is here solely for the convenience of our customers. For more design assistance contact our plant or consult the Machinery Handbook, published by Industrial Press Inc., New York.

OVER TEN MILLION PARTS IN STOCK !!!

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INTRODUCTION & ACKNOWLEDGMENTS

This document was created based on research and experience of Huyett staff.

Invaluable technical information, including statistical data contained in the tables, is from the 26th Edition Machinery Handbook, copyrighted and published in 2000 by Industrial Press, Inc. of New York, NY.

Steel making information and flowcharts were produced with information from the website of The American Iron and Steel Institute (AISI) 1140 Connecticut Ave., NW, Suite 705 Washington, D.C. 20036.

Many technical definitions are from "Everything You Always Wanted to Know About Steel. . . A Glossary of Terms and Concepts," Summer 1998 Courtesy of Michelle Applebaum, Managing Director. Copyright 2000, Salomon Smith Barney Inc.

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

Much basic and helpful information about steel properties and usage came from Metallurgy FAQ v 1.0 Copyright 1999 Drake H. Damerau, All rights reserved, at Survivalist Books.

STEELMAKING

Steel is the generic term for a large family of iron–carbon alloys, which are malleable, within some temperature range, immediately after solidification from the molten state. 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. A primary reaction in most steelmaking is the combination of carbon with oxygen to form a gas. If dissolved oxygen is not removed from the melt prior to or during 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 deoxidation 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 1 per cent. All steels also contain varying amounts of other elements, principally manganese, which acts 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, but result from the raw materials or steelmaking practice, or as alloying elements added to effect changes in the properties of the steel. When reviewing a steel chemical certification, remember that iron is the element that composes the majority of the chemical values listed. (See Exhibit I attached)

Steels can be cast to shape, or the cast ingot or strand can be reheated and hot worked by rolling, forging, extrusion, or other processes into a wrought mill shape. Wrought steels are the most widely used of engineering materials, offering a multitude of forms, finishes, strengths, and usable temperature ranges. No other material offers comparable versatility for product design.

Following hot working, steel goes through a "pickling" process. Pickling is a chemical process whereby steel is run through a progressive series of tanks. Chemicals in the tanks remove oxidation and impurities from the surface of the product. Hydrochloric acid is a common chemical compound used in pickling.

Finished steel, typical of the grades used in G.L. Huyett's manufacturing, are cold rolled (or cold drawn) after being pickled. Cold finishing, as the process is generally referred to, involves running the hot rolled pickled and oil product through a series of progressive dies or rollers at room temperature. The effect of such work stretches the steel, which creates a permanent increase in the hardness, strength, and finish of the product.

Cold finished steel is typically ready to be used for manufacturing finished goods, but in some cases, additional processes are performed. For G.L. Huyett keystock, bars are bead blasted to create a "bright steel" that is free of surface imperfections that could cause problems when inserted in a keyway.

Other grades such as Blue tempered (also known as "Blue Clock,") which is used to manufacture shims, are heat treated and ground for finer tolerances and hardened finishes.

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, it is important that edges be sharp, straight, and true to ease installation into the keyway.

CERTIFICATE OF ANALYSIS

Control No 26198

Grade 8630

Description. 1/4" SQ +.001 -0

Spec:. AISI 8630

Heat No	Melt Source	Country of Origin	Weight:
231740	CHARTER	USA	6125# N & 6425# G

CHEMISTRY

Specification	0.28 0.33	0.70 0.90	0.035 MAX	0.040 MAX	0.15 0.35	0.40 0.70	0.40 0.60	0.15 0.25							
Heat No	C	Mn	P	S	Si	Ni	Cr	Mo	Cu	O_2	Al	Ti	Sn	V	Pb
231740	.30	.79	.012	.013	.240	.58	.48	.18	.08		.024	.003	.009	.001	

MECHANICAL PROPERTIES

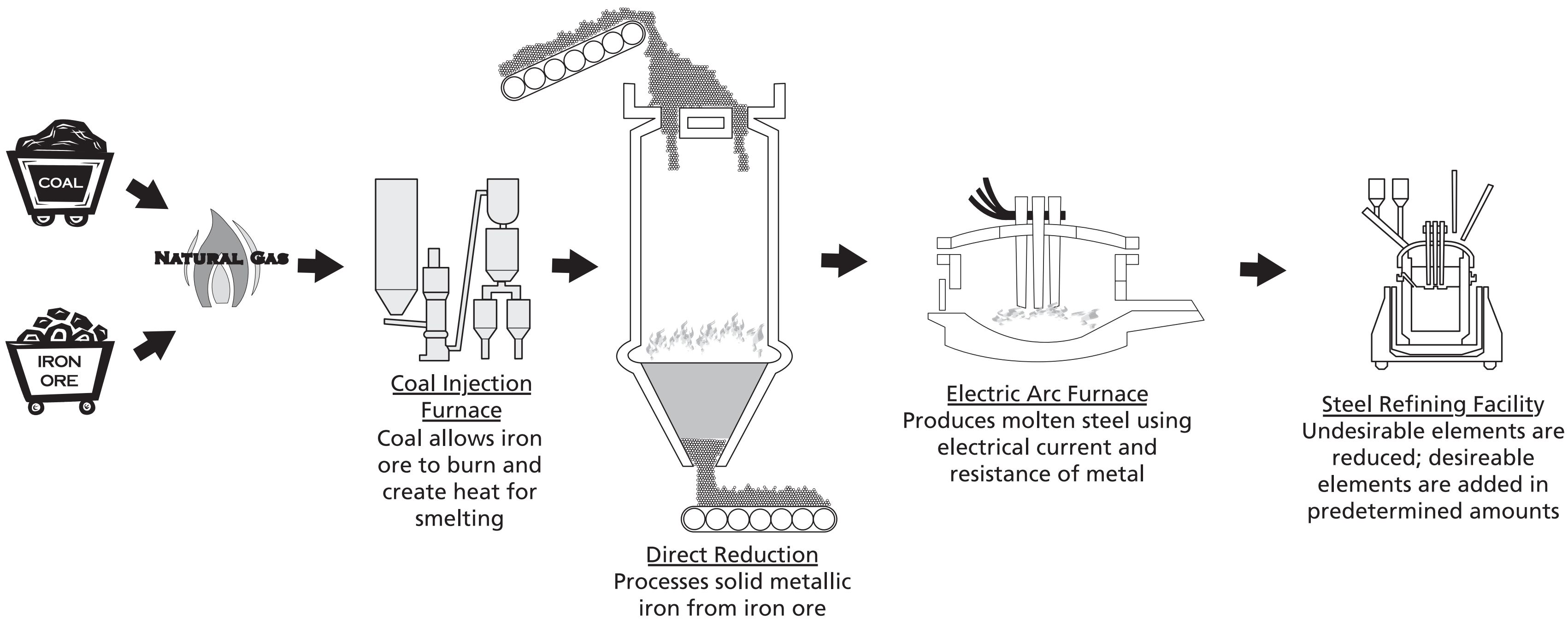
Tensile	Yield	Hardness	R/A	Elong. Over 2"	Grain Size

BY ______________________

- 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** 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. .30 of carbon=.003).
- G **Tensile Strength** Also called ultimate strength, measurement at which steel exhibits strain.
- H **Yield Strength** Related to tensile, yield is the stress level at which steel exhibits strain.
- I **Mechanical Properties** Represents values determined by physically testing the product.
- J **Elongation** Elongation is the increase in gage length or "pull" when steel is tensile tested.

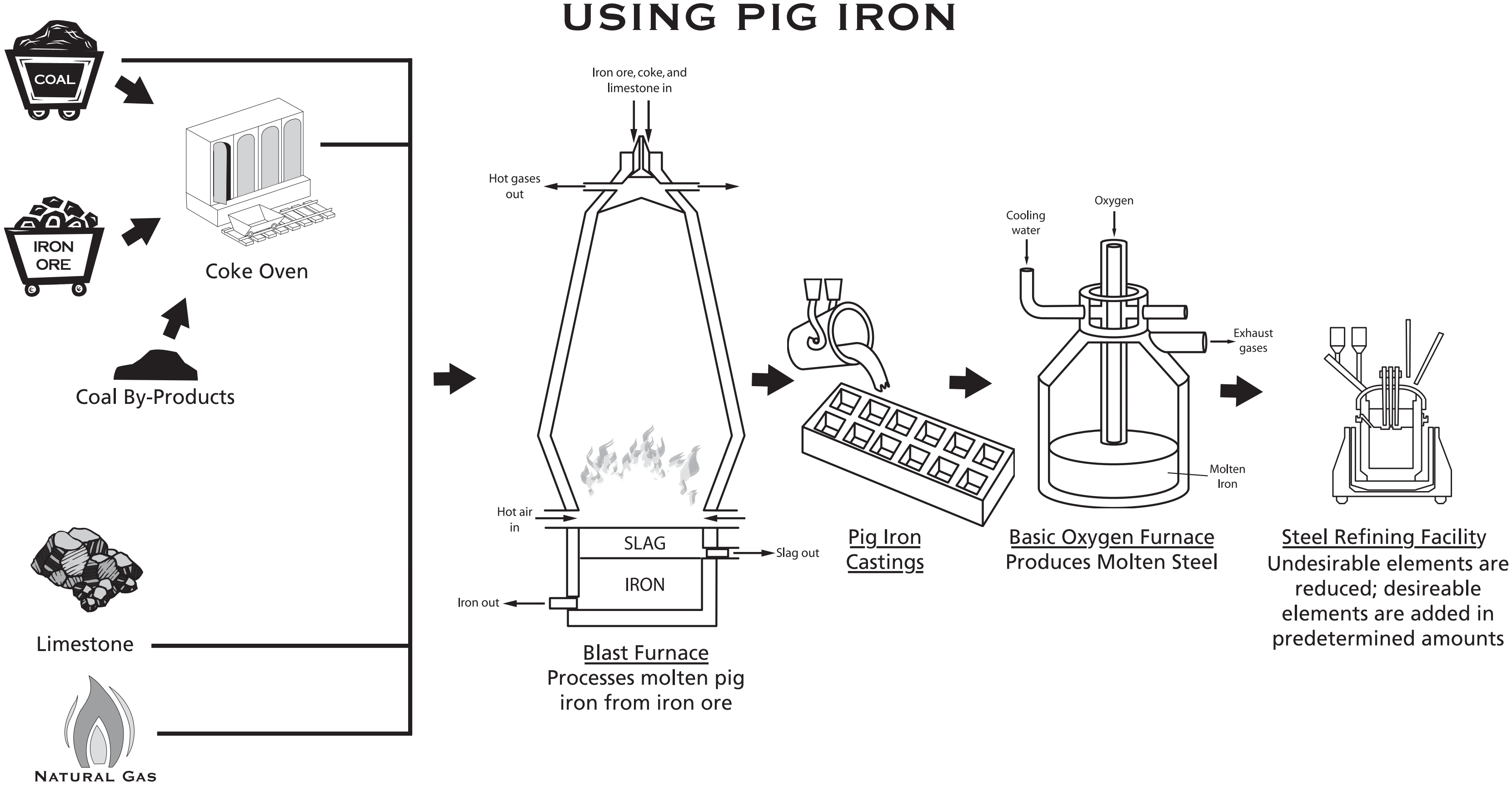
Notice that chemical values do not total 100%. The balance of steel chemistry would consist of iron and trace elements.

STEELMAKING
DIRECT REDUCTION METHOD



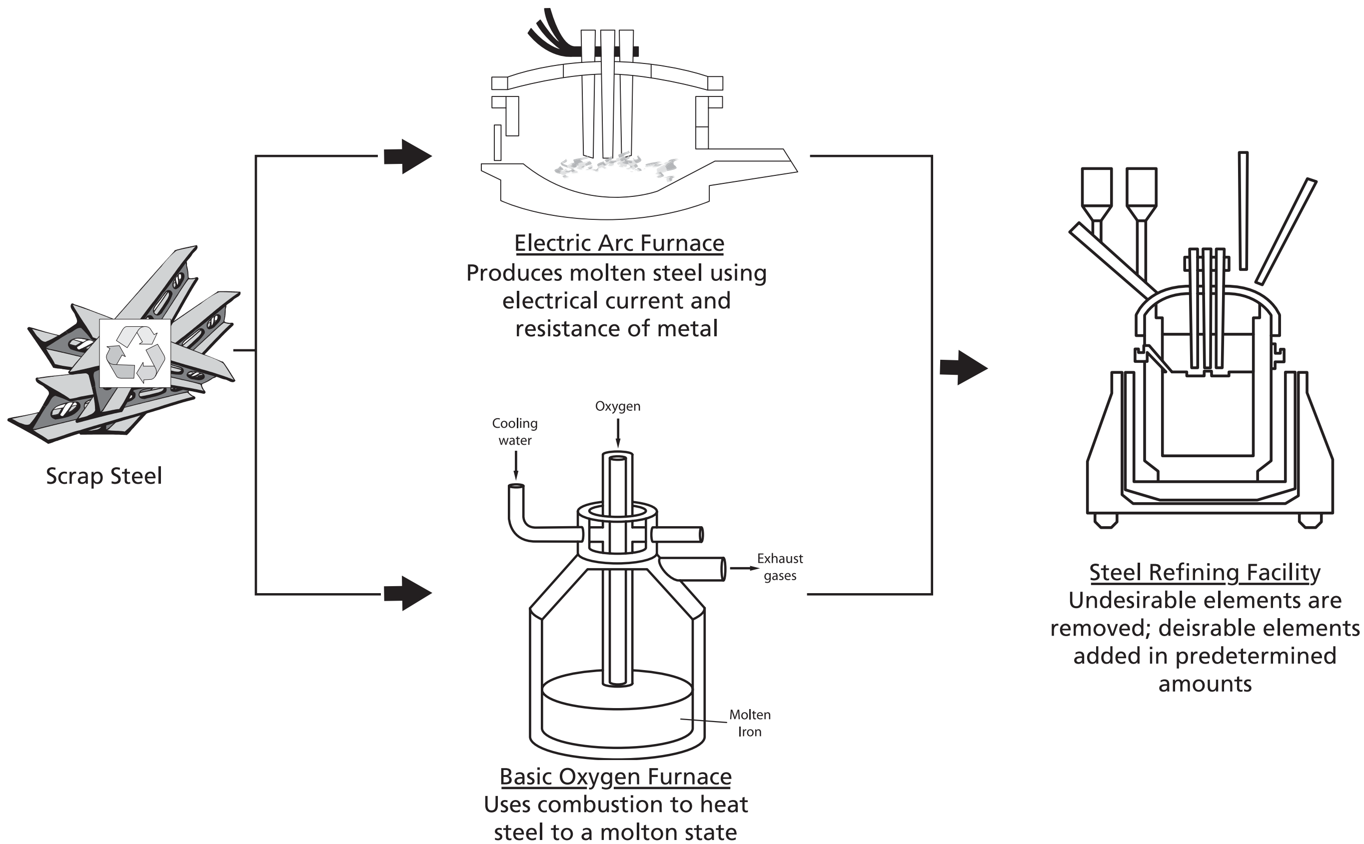
Iron is not a free element on earth, but is trapped in the Earth's crust in its oxide state. Iron ore is a mineral containing enough iron to be a commercially viable source of the element to be used in steelmaking.

STEELMAKING
USING PIG IRON



Coke is a processed form of coal that is used as the fuel in a blast furnace because it burns evenly inside and out and is not crushed by the weight of the iron ore.

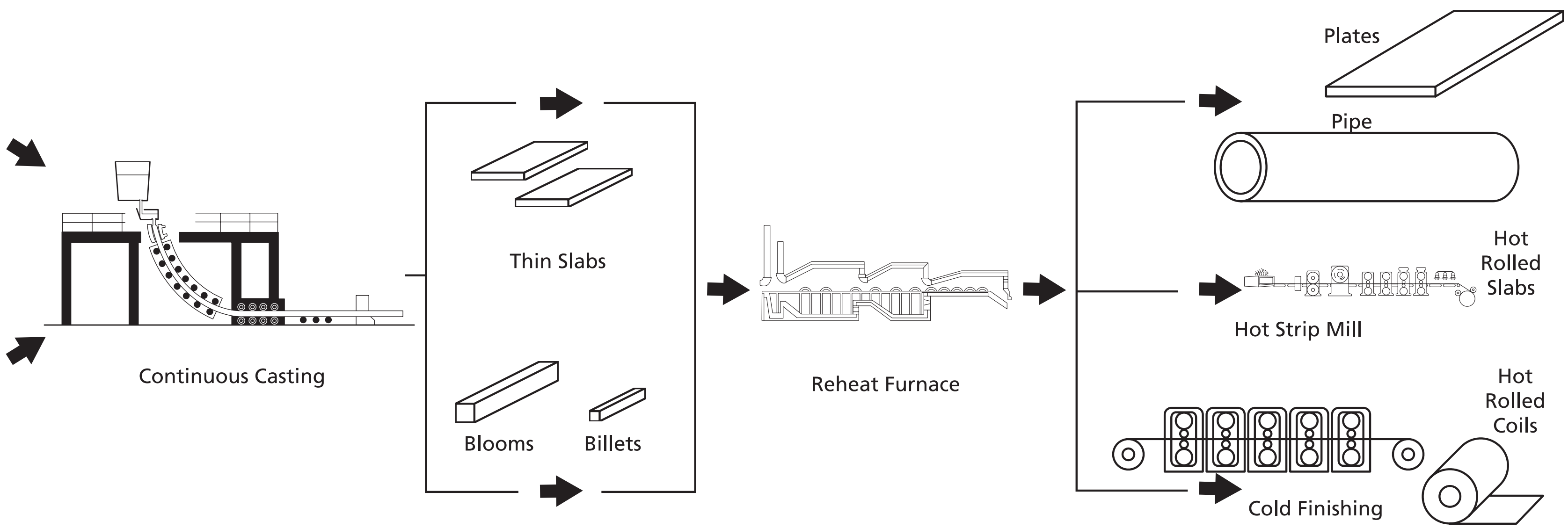
STEELMAKING
USING SCRAP



Scrap steel is ferrous, or iron-containing material, that is remelted and recast into new steel. Recycling scrap steel accounts for up to 25% of oxygen furnace charge and up to 100% of the raw material for electric furnaces.

STEEL FINISHING

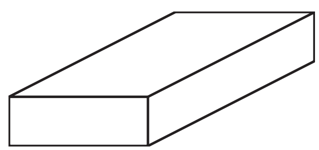
HOT WORKING



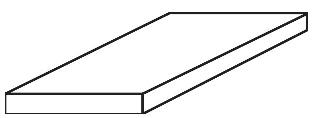
The hot mill squeezes slabs which are the most common type of semi-finished steel. Traditional slabs measure 10 inches thick and 30-85 inches wide (and average about 20 feet long), while the output of the recently developed "thin slab" casters is approximately two inches thick. Subsequent to casting, slabs are sent to the hot-strip mill to be rolled into coiled sheet and plate products.

STEEL FINISHING

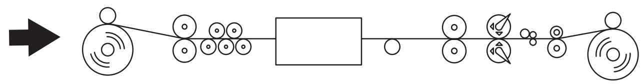
COLD WORKING



Slabs



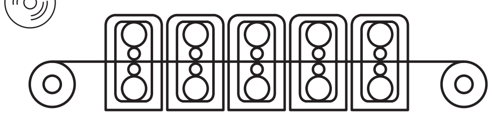
Thin Slabs



Pickle Line

- Cleans steel of rust, dirt, and oil

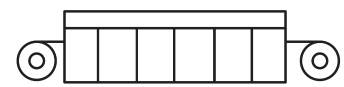
- Uses hydrochloric acid baths and water cleaning to make useable for further working



Cold Rolling

- Changes in the structure and shape of steel achieved through rolling, hammering, or stretching the steel at a low temperature (often room temperature)

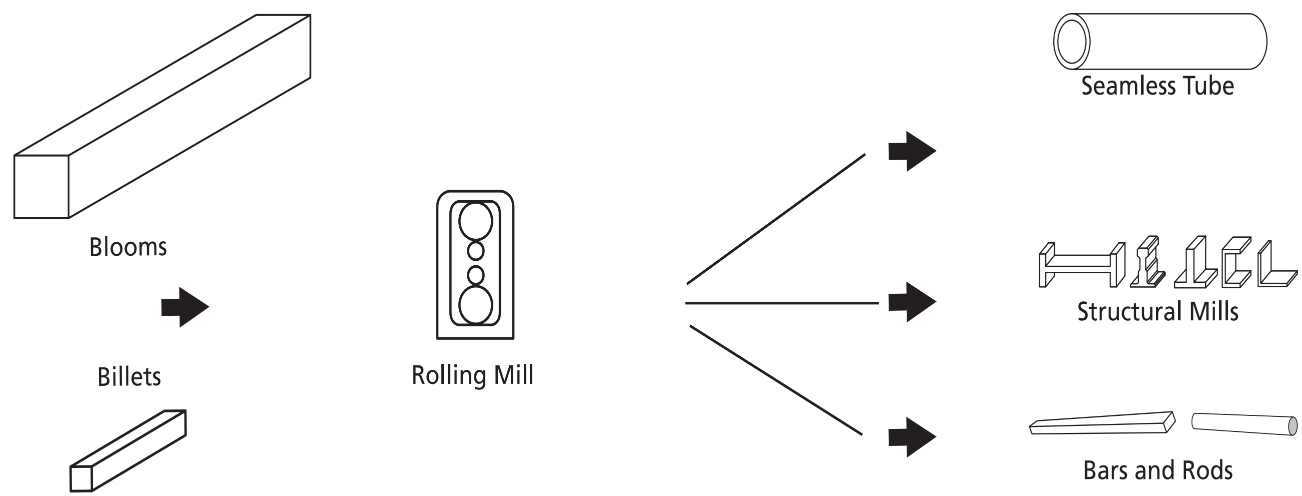
- Cold working creates a permanent increase in the hardness, strength, and finish to enhance and improve the steel's properites.



Heat Treating, Coating, or Finishing Line

Typically, used when steel is a finished good (i.e. galvanized sheets for buildings)

STEEL FINISHING



The rolling mill uses dies, or progressive sets of dies to create shapes or final-dimensioned sizes. Keystock steel, or bright steel, possesses the finest shapes and sizes. Bars are typically bead blasted following rolling to increase brightness and surface perfection.

METALS AND ALLOYS

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, 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).

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, 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 which relies upon carbon content for its structure. The most perfect carbon structure in the world is a diamond, which is 100% carbon. Carbon is present in all steel and is the principal hardening element, determining the level of hardness or strength attainable by quenching. It raises tensile strength, hardness, resistance to wear and abrasion as the carbon content of steel is increased. It lowers 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 100%). For example, C1018 has 0.18% carbon, while C1045 has 0.45%.

Generally carbon adds hardness to the material which improves wearability. For carbon contents above 0.30%, the product may be direct hardened ("through hardened"). Carbon steel beneath this level typically require carburizing when heat treated in which carbon molecules are introduced so that a hardened "skin" is able to be developed on the surface, or "case". This is where the concept of case hardening is found.

Carbon is maximized at under 1.00% of steel because for levels above this percentage material can become brittle. Generally, the higher the carbon content, the more difficult carbon steel is to machine.

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 temperature of all the phase changes are altered. This is why salt is a common ice melt compound. Salt will lower the transition temperature of the liquid to gas, and lowers the temperature of liquid to solid as well. 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 of the phase change will occur. Carbon also creates new phases that don't exist in iron by itself. Pearlite is a mixture of cementite (Fe3C) 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 element that can be dissolved into the parent material.

The more carbon you add to steel (above 0.20%), the more pearlite you get, up to the 0.80%. Above 0.80% you get carbides. If a steel has less that 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.

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.

Common Carbon Steels and Steel Alloys

The following information should be considered only as a guideline. 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 (see the hardness comparison chart). For example, a typical steel spring has a Rockwell hardness of 110 on the B scale and 38 on the C scale. Note: Yield strength is the amount of pressure a material will accept before becoming permanently deformed.

1018 - Heat treating in contact with carbon (carburizing) hardens the surface of this low-carbon steel. It's easy to cold form, bend, braze, and weld. Max. attainable Rockwell hardness is B72. Melting point is 2800° F. Yield strength is 77,000 psi.

1045 - This medium-carbon steel is stronger than 1018 and is more difficult to machine and weld. Max. attainable Rockwell hardness is B90. Melting point is 2800° F. Yield strength is 77,000 psi

A36 - General purpose carbon steel is suitable for welding and mechanical fastening. Max. attainable Rockwell hardness is B68. Melting point is 2000° F. Yield strength is 36,000 psi.

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. Max. attainable Rockwell hardness is B75-B90. Melting point is 2800° F. Yield strength is 60,000-80,000 psi.

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. Max. attainable Rockwell hardness is B97. Melting point is 2750° F. Yield strength is 95,000 psi.

4140 Alloy - Also called "chrome-moly" steel. Ideal for forging and heat treating, 4140 alloy is tough, ductile, and wear resistant. Max. attainable Rockwell hardness is C20-C25. Melting point is 2750° F. Yield strength is 60,000-105,000 psi.

4140 ASTM A193 Grade B7 Alloy - Similar to 4140 alloy, but it's already quenched, tempered, and stress relieved. Rockwell hardness is C35 max.

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. Max. attainable Rockwell hardness is B85-B97. Melting point is 2800° F. Yield strength is 55,000-90,000 psi.

One of the more common alloys is 1144, a carbon steel in which alloying elements enhance machining. 1144 stress-proof, a product of LaSalle Steel, is an example of an alloy with good machining 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%), and is the primary alloying element. As one can see, chrome alloy steels begin with "40" prefix and end in two numbers that account for the nominal percentage of carbon. For example, 4140 has 0.40% of carbon and 0.1% chromium.

Nickel alloy steels substitute nickel in place of roughly half of standard chromium contents for chrome alloys. For example, whereas 4140 has 0.0% nickel and 0.1% chromium, 8630 has 0.60% nickel and 0.50% chromium. These alloys are normally prefixed with "80" numbers. 8630 compare to 4140 as follows:

	C	Mn	Si	P	S	Cr	Ni	Mo	Other
8630	0.25-0.35	0.65-0.85	0.70	0.04	0.04	0.40-0.70	0.40-0.70	0.20-0.30	---
4140	0.38-0.43	0.75-1.00	0.035	0.04	0.15-0.35	0.8-1.10	---	---	---

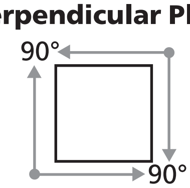
It is difficult to make mechanical comparisons between chrome alloys and nickel alloys as they are similar but unique to a grade. Generally nickel alloys can be drawn to a more precise finish size and therefore are more common in end use steels such as keystock.

Bright Steels

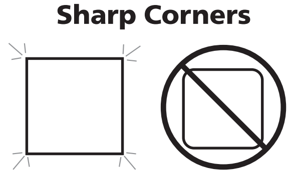
Because of the relevance of these grades to the G.L. Huyett product line, we are giving separate coverage here. Bright steels typically refer to a class of cold finished square and rectangle bars that are drawn to more exacting tolerances; they possess sharp corners, perpendicular and parallel sides, and my be bead blasted to make them "bright." Bright steels are also known as keystock.

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.

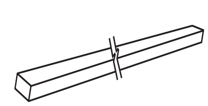
Perpendicular Planes



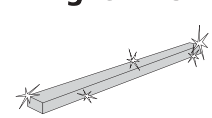
Sharp Corners



Straight



Bright Finish



The definition of keystock has been elusive because no single standard exists. Most technicians refer to "barstock" or "key barstock" as cold finished material drawn from market-ready grades to market-ready tolerances. "Keystock" refers to barstock carefully drawn to ANSI Class 2 fits.

ANSI sets forth two types with the following tolerance specifications:

ANSI *B17.1-1967(R1998)*	**Type of Key**	**Key Width**		**Tolerance**
		OVER	**TO** (incl.)	
Class 1: "A clearance or metal-to-metal side fit obtained by using bar stock 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

Many users of keystock have used the above 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. 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.

G.L. Huyett has pioneered the development of new cold drawing technologies. Working in concert with steel mills in both the United States and abroad Huyett has put together the most complete line of keystock steel anywhere in the world.

Stainless Steels

Stainless steel is the term used for grades of steel that contain more than 0.10% chromium, with or without other alloying elements. Stainless steel resists corrosion, maintains its strength at high tolerances and is easily maintained. The most common grades are:

TYPE 304 - 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. Type 304 is available in virtually all product forms and finishes.

TYPE 316 - Austenitic (chromium-nickel stainless class) stainless steel containing 0.2%-0.3% molybdenum (whereas 304 has none). The inclusion of molybdenum gives 316 greater resistance to various forms of deterioration.

TYPE 409 - Ferritic (plain chromium stainless category) stainless steel suitable for high temperatures. This grade has the lowest chromium content of all stainless steels and thus is the least expensive.

TYPE 410 - The most widely used martensitic (plain chromium stainless class with exceptional strength) stainless steel, featuring the high level of strength conferred by the martensitics. It is a low-cost, heat-treatable grade suitable for non-severe corrosion applications.

TYPE 430 - The most widely used ferritic (plain chromium stainless category) stainless steel, offering general-purpose corrosion resistance, often in decorative applications. 430 stainless is a martensitic stainless with higher levels of carbon (.15%) that allow it to be heat treated. 430 is also highly magnetic.

Tool Steels

Tool steels serve primarily for making tools used in manufacturing and in the trades for the working and forming of metals, wood, plastics, and other industrial materials. Tools must withstand high specific loads, often concentrated at exposed areas, may have to operate at elevated or rapidly changing temperatures and in continual contact with abrasive types of work materials, and are often subjected to shocks, or may have to 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 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, generally hardened and tempered, to provide the properties needed for the particular application. The adaptability to heat treatment with a minimum of harmful effects, which dependably results in the intended beneficial changes in material properties, is still another requirement that tool steels must satisfy.

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 the steel mills, which generally are made available with proprietary designations, it is rather 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.

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.

Type	Comparative Properties for the Selection of Drill Rod and Ground Flat Stock	Use
O-1	Dimensionally stable during hardening with high hardness response in low temperatures. Heat treatable up to HRC 65.	Tool and Die
W-1	Also known as commercial carbon for use in general metal working. Used where simple heat treatment is desirable. Max HRC 68.	General Purpose
A-2	Used in place of O-1 in applications requiring safer heat treatment, less distortion, and greater wear resistance. Max HRC 63.	Machining to finish job.
D-2	Offers better wear resistance and higher compressive strength than A-2. Good for long duration runs. Max HRC 63.	Shock resistant . Machine to finish.
S-7	Used in cold work tools needing high shock resistance. Good toughness with ease of heat treat and machinability. Max HRC 58.	Mold dies.
M-2	High speed steel with good abrasion resistance and good toughness. Resists softening at high temperatures. Max HRC 65	High heat environments.
H-13	Air hardening material that resists thermal fatigue cracking. Better hardenability and wear resistance than 4140. Max HRC 54.	Hot work die steel.
V44	Free machining version of H-13 that is prehardened to HRC 42-46.	Prehardened for machine to finish.
A-8	Air hardening grade that has higher toughness than D-2, and better wear resistance than S-7. Max HRC 60.	Pneumatic tools.
1018	Very common cold forming steel for bending, brazing, welding, and forming. Must be carburized during heat treatment.	Weldable.
O-6	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. Max HRC 22.	Free Machining

Grade W1 (Water-Hardening Steel) - This water-quenching 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. Max. attainable Rockwell hardness is C57-C60. Melting point is 2800° F. Yield strength is 55,000-100,000 psi.

Grade O1 (Oil-Hardening 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. Max. attainable Rockwell hardness is C57-C62. Melting point is 2800° F. Yield strength is 50,000-99,000 psi.

Grade 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. Max. attainable Rockwell hardness is C65. Melting point is 2580° F. Yield strength is 105,000 psi.

Grade A2 (Air-Hardening 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. Max. attainable Rockwell hardness is C62-C65. Melting point is 2620° F. Yield strength is 108,000 psi.

Grade D2 (High-Chrome Air-Hardening 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. Max. attainable Rockwell hardness is C62-C65. Melting point is 2525° F. Yield strength is 111,000 psi.

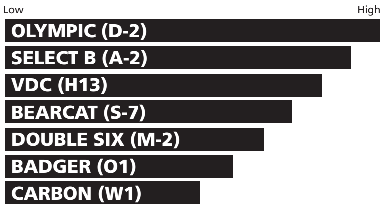
Grade S7 (Shock-Resistant Air-Hardening Steel) - Strong and ductile, this steel is known for its ability to resist failure from shock. It combines high-impact strength with average wear and abrasion resistance. Max. attainable Rockwell hardness is C59-C61. Melting point is 2640° F. Yield strength is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

Grade A6 (Low-Temperature Air-Hardening Steel) - Heat treat this steel at low temperatures (1525° to 1575° F). It experiences almost no dimensional changes after heat treating. Max. attainable Rockwell hardness is C61-C62. Melting point is 2600° F. Yield strength is 110,000 psi.

Grade 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.

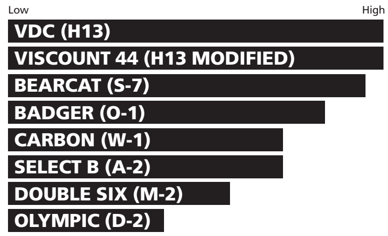
Grade P20 - This hardened, general purpose mold steel is suitable for production of machined or EDM plastic mold and zinc die casting components. Supplied prehardened to a Rockwell hardness of C32. Melting point is 2790° F. Yield strength is 130,000 psi.

DIMENSIONAL STABILITY IN HEAT TREATMENT

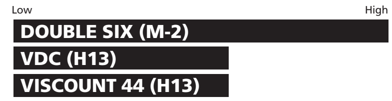


Viscount 44 is pre-hardened.

TOUGHNESS

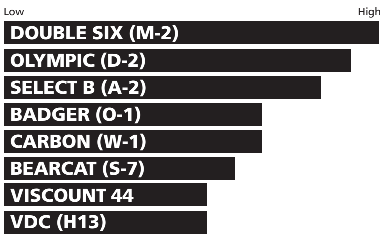


HOT HARDNESS

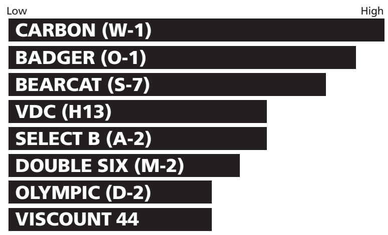


Hot hardness not applicable to cold work steels such as Olympic, Select b, Badger, Carbon and Bearcat.

WEAR RESISTANCE AT ROOM TEMPERATURE



MACHINABILITY



This Chart summarizes metallurgical properties of the various grades of tool steel available. The first step is applying data from the chart is to examine the specific application for the important properties involved. For example, an ejector pin for die-casting requires top toughness with good wear resistance and hot hardness — the chart indicates VDC as a logical start. If the VDC part wears too rapidly, the next move would be to Bearcat. Another application might involve a part for a short run cold forming die setup. Considering die life and steel cost, carbon would be first source — if wear or size change in heat treatment becomes a problem, the next step would be to use Select B but if size change in heat treat was the only problem, then Badger should be tried.

Chemical Composition Limits (%) of Steel— Iron makes up the remaining percentage.

Grade	Carbon	Manganese	Silicon	Phosphorus	Sulfur	Chromium	Molybdenum	Vanadium	Other
1018	0.15-0.2%	0.6-0.9%	None	0.04%	0.05%	None	None	None	None
1045	0.43-0.5%	0.6-0.9%	None	0.04%	0.05%	None	None	None	None
A36	0.26%	1.0%	0.40%	0.04%	0.05%	None	None	None	None
12L14	0.15%	0.85-1.15%	None	0.04-0.09%	0.26-.35%	None	None	None	0.15-0.35% Lead
1144	0.4-.48%	1.35-1.65%	None	0.04%	0.24-.33%	None	None	None	None
4140	0.42%	0.90%	0.15-0.35%	0.035%	0.04%	1.00%	0.20%	None	None
8620	0.17-.23%	0.6-0.9%	0.15-0.35%	0.035%	0.04%	0.35-0.6%	0.15-0.25%	None	None
W1	0.95-1.05%	0.3-0.4%	0.1-0.25%	0.025%	0.025%	0.15%	0.1%	0.1%	0.15% Tungsten
O1	0.94%	1.0-1.4%	0.3%	0.03%	0.03%	0.5%	None	0.3%	0.4-0.6% Tungsten
M2	0.85%	0.3%	0.3%	None	None	4%	5%	2%	6% Tungsten
A2	0.95-1.05%	1%	0.3%	0.03%	0.03%	4.75-5.5%	0.9-1.4%	0.25%	None
D2	1.4-1.6%	0.6%	0.3%	0.03%	0.03%	11-13%	0.75%	0.9%	None
S7	0.45-0.55%	0.2-0.8%	0.2-1%	0.03%	0.03%	3-3.5%	1.3-1.8%	0.2-0.3%	None
A6	0.7%	2%	0.3%	None	None	1%	1%	None	None
4142	0.42%	0.9%	None	None	None	1%	0.2%	None	None
P20	0.33%	0.75%	0.5%	None	None	1.7%	0.4%	None	None

Alloying Elements and the Effect on Steel

Element	Effect
Aluminum	Deoxidizes and restricts grain growth.
Boron	Increases hardenability.
Carbon	Increases hardenability and strength.
Chromium	Increases corrosion resistance, hardenability and wear resistance.
Lead	Increases machinability.
Manganese	Increases hardenability and counteracts brittleness from sulfur.
Molybdenum	Deepens hardening, raises creep strength and hot-hardness, enhances corrosion resistance and increases wear resistance.
Nickel	Increases strength and toughness.
Phosphorus	Increases strength, machinability, and corrosion resistance.
Silicon	Deoxidizes, helps electrical and magnetic properties, improves hardness and oxidation resistance.
Sulfur	Increases machinability, but damages hot forming characteristics.
Titanium	Forms carbides, reduces hardness in stainless steels.
Tungsten	Increases wear resistance and raises hot strength and hot-hardness.
Vanadium	Increases hardenability.

Four Digit 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
5xxxx	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

Metals and Alloys Glossary

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.

$Al_2 0_{3r}$ - aluminum oxide - Abrasive material for grinding tools, $Al_2 0_{3r}$ also is 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 form of pure iron, stable below 910° C.

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.

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, and sulfur and chlorine compounds.

Austenite - Metallurgical term for a material that forms when carbon steel is heated above 735° C 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.

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.

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

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.

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.

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.

Cementite - Fe3C also known as Iron Carbide.

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.

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.

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 semifinished mill products such as billets, blooms, ingots, slabs, and tubes.

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.

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

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.

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.

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.

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.

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

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

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

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.

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.

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.

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.

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

Hard chromium - Chromium electrodeposited for engineering purposes (such as 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 critical temperature. Hardenability is commonly measured as the distance below a quenched surface at which the metal exhibits a specific hardness (R_c 50, for example) or a specific percentage of martensite in the microstructure.

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.

Hot working - Deforming a metal plastically at a temperature and strain rate such that the recrystallization temperature is exceeded and recrystallization takes place simultaneously with the deformation, thus avoiding any strain hardening.

HSS, high-speed steel - Tool steel alloyed with tungsten and molybdenum. Permits cutting at higher speeds and feeds than carbon-steel tools because an HSS tool's cutting edges don't soften at temperatures that soften carbon steel.

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 critical 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.

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.

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.

Knoop hardness - Hardness rating for very thin materials and plated surfaces.

Machinability, machinability rating - Determines acceptability of a tool for the workpiece to be machined. Indicates workpiece's hardness, chemical composition and qualities, microstructure, propensity to workharden, 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.

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.

Martensite - A generic term for microstructures 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 (Ms) and a temperature at which the transformation is essentially complete (Mf).

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. Compare with physical properties.

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 microconstituents within a structure, or measuring steep hardness gradients such as those encountered in casehardening.

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.

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.

Peening - Mechanical working of a metal by hammer blows or shot impingement.

Pearlite - A lamellar aggregate of ferrite and cementite. Softer than most other microstructures. Formed from austenite during air cooling from austenite.

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. Compare with mechanical properties.

Pitting - Localized corrosion of a metal surface, confined to a point or small area, that takes the form of cavities.

PM, powder metallurgy - Processes in which metallic particles are fused under various combinations of heat and pressure to create solid metals.

Rockwell hardness - Various scales for determining material hardness. Rockwell C, A, and D scales measure metal hardness. The Rockwell C, or R_C, scale, and the Brinell hardness (Bhn) scale are used most often in connection with cutting tools and machining.

Shear strength - The stress required to produce fracture in the plane of cross section, the conditions of loading being such 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.

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.

Steel - Basically pure iron in combination with carbon and other elements. There are two types of steel: carbon steel, or a combination of iron and carbon; and alloy steel, which is 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 AISI (American Iron and Steel Institute) and SAE (Society of Automotive Engineers) 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 workhardening steel, and nickel-base superalloys.

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.

Tensile strength - In tensile testing, the ratio of maximum load to original cross-sectional area. Also called ultimate strength. Compare with yield strength.

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.

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.

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 percent is used for many metals. Compare with tensile strength.

DESIGNATIONS FOR CHEMICAL CONTENT

This section sets forth specifications for the chemical content and physical properties for materials manufactured and sold by G.L. Huyett. The nomenclature used is in large part based on American Iron and Steel Institute (AISI) Standards.

Periodic Table of the Elements

Key: 6 — Atomic number; C — Symbol; Carbon — Name; 12.0107 — Average atomic mass

Period	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12	Group 13	Group 14	Group 15	Group 16	Group 17	Group 18
1	1 H Hydrogen 1.007 94																	2 He Helium 4.002 602
2	3 Li Lithium 6.941	4 Be Beryllium 9.012 182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.006 74	8 O Oxygen 15.9994	9 F Fluorine 18.998 4032	10 Ne Neon 20.1797
3	11 Na Sodium 22.989 770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981 538	14 Si Silicon 28.0855	15 P Phosphorus 30.973 761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
4	19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955 910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938 049	26 Fe Iron 55.845	27 Co Cobalt 58.933 200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.61	33 As Arsenic 74.921 60	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
5	37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.905 85	40 Zr Zirconium 91.224	41 Nb Niobium 92.906 38	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.905 50	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.904 47	54 Xe Xenon 131.29
6	55 Cs Cesium 132.905 45	56 Ba Barium 137.327	57 La Lanthanum 138.9055	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.966 55	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.980 38	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
7	87 Fr Francium (223)	88 Ra Radium (226)	89 Ac Actinium (227)	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (263)	107 Bh Bohrium (264)	108 Hs Hassium (265)†	109 Mt Meitnerium (268)†	110 Uun* Ununnilium (269)†	111 Uuu* Unununium (272)†	112 Uub* Ununbium (277)†		114 Uuq* Ununquadium (285)†				

A team at Lawrence Berkeley National reported the discovery of elements 116 and 118 in June 1999. The same team retracted the discovery in July 2001. The discovery of element 114 has been reported but not confirmed.

58 Ce Cerium 140.116	59 Pr Praseodymium 140.907 65	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.925 34	66 Dy Dysprosium 162.50	67 Ho Holmium 164.930 32	68 Er Erbium 167.26	69 Tm Thulium 168.934 21	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
90 Th Thorium 232.0381	91 Pa Protactinium 231.035 88	92 U Uranium 238.0289	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

† Estimated from currently available IUPAC data.

* The systematic names and symbols for elements greater than 109 will be used until the approval of trivial names by IUPAC.

The atomic masses listed in this table reflect the precision of current measurements. (Values listed in parentheses are those of the element's most stable or most common isotope.) In calculations throughout the text, however, atomic masses have been rounded to two places to the right of the decimal.

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. 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, for instance, sparks are produced that appear to split into several bright tracers. Patterns produced by several other elements, including small amounts of aluminum and titanium, for instance, can be identified with the aid of Data Sheet 13, issued by the American Society for Metals (ASM), Metals Park, OH.

A Simple Way of Differentiating Carbon Steel from Stainless Steel

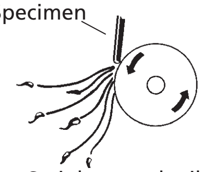
1. Place a drop of 20% nitric acid solution on a cleaned portion of the specimen

Stainless steel will remain unstained.

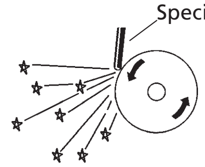
Carbon steel will turn dark.

or

2. Hold the specimen with a pliers and place it on a grinding wheel.



Stainless steel will make curved tails.



Carbon steel will look like fireworks.

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 a steel. The equipment used should be a grinder with a no-load speed of 9000 rpm and a wheel size of around 2.5 inches. 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) is 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 that is detached from the end of the carrier line identifies *phosphorus*.

The higher the phosphorous 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 presents of *silicon* and *aluminum* have a tendency to depress the carbon bursts.

The safest and most reliable method to check chemical content is to use an Eddy Current test or similar technique performed by a certified laboratory with technicians certified and trained in such matters.

Composition of AISI-SAE Standard Carbon Steels

AISI-SAE No.	UNS No	Composition(%)			
		C.	Mn	P(max)	S(max)
Nonresulferized Grades — 1 per cent 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
1065c	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
12L14d	G12144	0.15 max	0.85–1.15	0.04–0.09	0.26–0.35

Compositions 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
E4340c	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
E52100c	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

a) Small quantities of certain elements are present that are not specified or required. These incidental elements may be present to the following maximum amounts: Cu, 0.35 per cent; Ni, 0.25 per cent; Cr, 0.20 per cent; and Mo, 0.06 per cent.
b) Standard alloy steels can also be produced with a lead range of 0.15–0.35 per cent. Such 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.
d) 0.0005–0.003 per cent
Source: American Iron and Steel Institute: Steel Products Manual.

Compositions of AISI-SAE Standard Stainless Steels

AISI Type (UNS)	Typical Composition (%)								
	Cr	**Ni**	**C**	**Mn**	**Si**	**P**	**S**	**Mo**	**N**
316 (S31600) Austenitic	16–18	10–14	0.08	2.0	0.75	0.045	0.030	2.0–3.0	0.10
302 (S30200) Austenitic	17–19	8–10	0.15	2.0	0.75	0.045	0.030	---	0.10
316L (S31603) Austenitic	16–18	10–14	0.03	2.0	0.75	0.045	0.030	2.0–3.0	0.10
303 (S30300) Austenitic	17–19	8–10	0.15	2.0	1.0	0.20	0.015 min	0.60 optional	---
304 (S30400) Austenitic	18–20	8–10.50	0.08	2.0	0.75	0.045	0.030	---	0.10
304L (S30403) Austenitic	18–20	8–12	0.03	2.0	0.75	0.045	0.030	---	0.10
321 (S32100) Austenitic	17–19	9–12	0.08	2.0	0.75	0.045	0.030 [Ti, 5(C + N) min, 0.70 max]	---	0.10 max
430 (S43000) Ferritic	16–18	0.75 Ni	0.12	1.0	1.0	0.040	030	---	---
416 (S41600) Martensitic	12–14		0.15	1.25	1.0	0.060	0.15min	0.060 optional	---

DESIGNATIONS FOR HEAT TREATMENT

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 as such or with 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 realized only 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 certain 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.

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 between 1300 and 1600 degrees 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 certain of the other alloying elements. Depending primarily on cooling rate, the 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 (needlelike) 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).

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 a required structure and properties.

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 are the size and shape changes that result from quenching and the greater is the risk of quench cracking. Consequently, although water quenching is less costly than oil quenching, and water quenching 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.

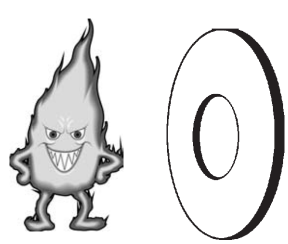
Oil, salt, and synthetic water-polymer quenchants are also used, but they often require steels of higher alloy content and hardenability. A general rule for the selection of steel and quenchant for a particular part is that the steel should have a hardenability not exceeding that required by the severity of the quenchant selected. The carbon content of the steel should also not exceed that 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 is the quench. Listed below are some terms commonly associated with the quenching process:

Quenching (rapid cooling) When applicable, the following more specific terms should be used: Direct Quenching, Fog Quenching, Hot Quenching, Interrupted Quenching, Selective Quenching, Slack Quenching, Spray Quenching, and Time Quenching.

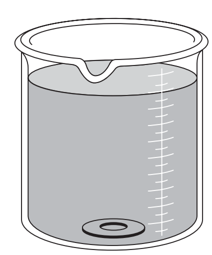
> ***Direct Quenching:*** Quenching carburized parts directly from the carburizing operation.
>
> ***Fog Quenching:*** Quenching in a mist.
>
> ***Hot Quenching:*** An imprecise term used to cover a variety of quenching procedures in which a quenching medium is maintained at a prescribed temperature above 160 degrees F (71 degrees C).
>
> ***Interrupted Quenching:*** A quenching procedure in which the workpiece is removed from the first quench at a temperature substantially higher than that of the quenchant and is then subjected to a second quenching system having a different cooling rate than the first.
>
> ***Selective Quenching:*** Quenching only certain portions of a workpiece.
>
> ***Slack Quenching:*** The incomplete hardening of steel due to quenching from the austenitizing temperature at a rate slower than the critical cooling rate for the particular steel, resulting in the formation of one or more transformation products in addition to martensite.
>
> ***Spray Quenching:*** Quenching in a spray of liquid.
>
> ***Time Quenching:*** Interrupted quenching in which the duration of holding in the quenching medium is controlled.

Direct 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 parts are heated and quenched (cooled) to fix the structure of the part in a hardened state. The best recognized through hardened part in the world is a diamond!

Heat



Quench



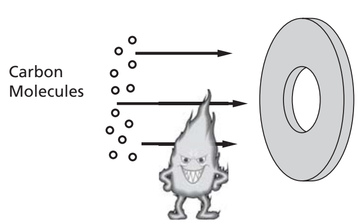
Typical Heat Treatments for SAE Carbon Steels (Direct Hardening)

SAE Number	Normalize Deg. F	Anneal, Deg. F	Harden Deg. F	Quench	Temper Deg.F
1025 & 1030	---	---	1575–1650	A	
1033 to 1035	---	---	1525–1575	B	
1036	1600–1700	---	1525–1575	B	
	---	---	1525–1575	B	
1038 to 1040	1600–1700	---	1525–1575	B	
	---	---	1525–1575	B	
1041	1600–1700 and/or	1400–1500	1475–1550	E	
1042 to 1050	1600–1700	---	1475–1550	B	
1052 & 1055	1550–1650 and/or	1400–1500	1475–1550	E	To Desired Hardness
1060 to 1074	1550–1650 and/or	1400–1500	1475–1550	E	
1078	---	1400–1500[a]	1450–1500	A	
1080 to 1090	1550–1650 and/or	1400–1500[a]	1450–1500	E[b]	
1095	---	1400–1500[a]	1450–1500	F	
	---	1400–1500[a]	1500–1600	E	
1132 & 1137	1600–1700 and/or	1400–1500	1525–1575	B	
1138 & 1140	---	---	1500–1550	B	
	1600–1700	---	1500–1550	B	
1141 & 1144	---	1400–1500	1475–1550	E	
	1600–1700	1400–1500	1475–1550	E	
1145 to 1151	---	---	1475–1550	B	
	1600–1700	---	1475–1550	B	

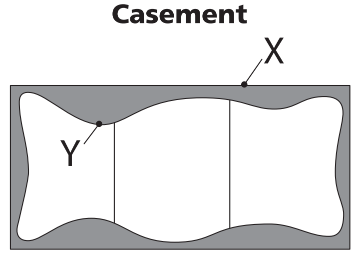
a) Slow cooling produces a spheroidal structure in these high-carbon steels that is sometimes required for machining purposes.
b) May be water- or brine-quenched by special techniques such as partial immersion or time quenched; otherwise they are subject to quench cracking.

Indirect Hardening Case hardening (or indirect hardening) is applied to low-carbon content steel parts to increase surface hardness. During case hardening, 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). More exacting specifications will identify an effective case (z) 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.

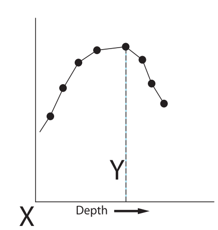
Heat



Casement



Effective Hardness



Listed below are some terms and processes typically associated with case hardening (also known as indirect hardening):

Carburizing: A process in which carbon is introduced into a solid iron-base alloy by heating above the transformation temperature range while in contact with a carbonaceous material that may be a solid, liquid, or gas. Carburizing is frequently followed by quenching to produce a hardened case.

Case: 1) The surface layer of an iron-base alloy that has been suitably altered in composition and can be made substantially harder than the interior or core by a process of case hardening; and 2) the term case is also used to designate the hardened surface layer of a piece of steel that is large enough to have a distinctly softer core or center.

Typical Heat Treatments for SAE Carbon Steels (Indirect hardening)

SAE No.	Normalize Deg. F	Carburize Deg. F	Cool[a]	Reheat Deg. F	Cool[a]	2nd Reheat Deg. F	Cool[a]	Temper[b] Deg. F
	---	1650 - 1700	A	---	---	---	---	250-400
1010	---	1650 - 1700	B	1400 - 1450	A	---	---	250-400
to	---	1650–1700	C	1400–1450	A	---	---	250–400
1022	---	1650–1700	C	1650–1700	B	1400–1450	A	250–400
	---	1500–1650[cd]	B	---	---	---	---	Optional
	---	1350–1575[ed]	D	---	---	---	---	Optional
	1650–1750[f]	1650–1700	E	---	---	---	---	250–400
1024	---	1350–1575[ed]	D	---	---	---	---	Optional
1025	---	1650–1700	A	---	---	---	---	250–400
1026	---	1500–1650[cd]	B	---	---	---	---	Optional
1027	---	1350–1575[ed]	D	---	---	---	---	Optional
1030	---	1500–1650[cd]	B	---	---	---	---	Optional
	---	1350–1575[ed]	D	---	---	---	---	Optional
1111								
1112	---	1500–1650[cd]	B	---	---	---	---	Optional
1113	---	1350-1575[ed]	D	---	---	---	---	Optional
	---	1650–1700	A	---	---	---	---	250–400
1109	---	1650–1700	B	1400–1450	A	---	---	250–400
to	---	1650–1700	C	1400–1450	A	---	---	250–400
1120	---	1650–1700	C	1650–1700	B	1400–1450	A	250–400
	---	1500–1650[cd]	B	---	---	---	---	Optional
	---	1350–1575[ed]	D	---	---	---	---	Optional
1126	---	1500–1650[cd]	B	---	---	---	---	Optional
	---	1350–1575[ed]	D	---	---	---	---	Optional

a) Symbols: A = water or brine; B = water or oil; C = cool slowly; D = air or oil; E = oil; F = water, brine, or 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) Activated or cyanide baths.
d) May be given refining heat as in other processes.
e) Carbonitriding atmospheres
f) Normalizing temperatures at least 50 deg. F above the carburizing temperature are sometimes recommended where minimum heat-treatment distortion is of vital importance.

Thermal Modification of Steel

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

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.

Annealing: A term denoting a treatment, consisting of heating to and holding at a suitable temperature followed by cooling at a suitable rate, used primarily to soften but also to simultaneously produce desired changes in other properties or in microstructure. The purpose of such changes may be, but is not confined to, improvement of machinability; facilitation of cold working; improvement of mechanical or electrical 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 results desired.

Baking: Heating to a low temperature in order to remove entrained gases.

TESTING THE HARDNESS OF METALS

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 ball in millimeters, *d* = measured diameter at the rim of the impression in millimeters, and *P* = applied load in kilograms.

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

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 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 millimeters in diameter and a load of 3000, 1500, or 500 kilograms is used. It is desirable, although not mandatory, that the test load be of such magnitude that the diameter of the impression be in the range of 2.50 to 4.75 millimeters. The following test loads and approximate Brinell numbers for this range of impression diameters are: 3000 kg, 160 to 600 BHN; 1500 kg, 80 to 300 BHN; 500 kg, 26 to 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 the softer metals, loads of 250, 125, or 100 kg are sometimes used.)

According to the American Society for Testing and Materials Standard E10-66, a steel ball may be used on material having a BHN not over 450, a Hultgren ball on material not over 500, or a carbide ball on material not over 630. The Brinell hardness test is not recommended for material having a BHN over 630.

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 degrees. 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 usually is applied for 30 seconds, may be 5, 10, 20, 30, 50, or 120 kilograms. The 50 kilogram load is the most usual. The hardness number is based upon 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.

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 spheroconical penetrator. The hardness number is related to the depth of indentation and, as the number is higher, the harder the material. A minor load of 10 kg is first applied, causing an initial penetration; the dial is set at zero on the black-figure scale, and the major load is applied. This major load is customarily 60 or 100 kg when a steel ball is used as a penetrator, but other loads may be used when necessary. The ball penetrator is 1.16 inch in diameter normally, but other penetrators of larger diameter, such as 1.8 inch, may be employed for soft metals. When a diamond spheroconical penetrator is employed, the load usually is 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.

The Rockwell Hardness Scales The various Rockwell scales and their applications are shown in the following table.

Scale	Indenter	Minor Load (kgf)	Major Load (kgf)	Testing Application
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, 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 and medium case hardened steel and pearlitic malleable iron
HRE	1/16" ball	10	100	Cast iron, aluminum and magnesium alloys, bearing metals
HRF	1/16" ball	10	60	Annealed copper alloys, 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	

Comparison of Hardness Scales - All such 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 coldworked 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 such 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 on 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 the as-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-base alloys, constructional alloy steels, and nickel-base alloys in the coldworked condition.

The data shown is for hardness measurements of unhardened steel, steel of soft temper, grey and malleable cast iron, and most nonferrous metals. Again 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 coldworked metals of low B-scale hardness such as aluminum and the 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 Diam. Penetrator		
		Standard Ball	Hultgren Ball	Tungsten Carbide Ball	A-Scale 60-kgf Load Dia. Penetrator	D-Scale 100-kgf Load Dia. Penetrator	15-N Scale 15-kgf Load Dia. Penetrator	30-N Scale 30-kgf Load Dia. Penetrator	45-N Scale 45-kgf Load Dia. Penetrator
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
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
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	---	---	---	---	---

Relation Between Hardness and Tensile Strength The approximate relationship between the hardness and tensile strength is shown by the following formula:

Tensile strength = *Bhn* x 515 (for Brinell numbers up to 175).

Tensile strength = *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 Tests 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 indentor and the load applied.

Heat Treating and Special Processes Glossary

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.

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 such changes include improvement of machinability, facilitation of cold work, 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.

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 to 518° F) produces a part with maximum strength, while austempering at higher temperatures (680° F to 716° f) yields high ductility and toughness.

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.*

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.

Carbonitriding - Casehardening 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 Ac3, in contact with a suitable carbonaceous material. A form of casehardening 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.

Casehardening - 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.

Cyaniding - Casehardening method that introduces carbon and nitrogen to the workpiece simultaneously.

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.

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.

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.

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.

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.

Martempering - 1. A hardening procedure in which an austenitized ferrous workpiece is quenched into a medium whose temperature is maintained substantially at the M_s temperature (temperature at which martensite starts to form austenite) of 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 M_s temperature is that of the case. This variation of the process is frequently called marquenching.

Martensiting - Rapid quenching of carbon steel in the austenite state causes a new structure-martensite-to form. Martensite is extremely hard.

Nitriding - Introducing nitrogen into the surface layer of a solid ferrous alloy by holding at a suitable temperature (below Ac1 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.*

Normalizing - Heating a ferrous alloy to a temperature above the transformation range and then cooling in air to a temperature below the transformation range.

Preheating - Heating before some further thermal or mechanical treatment.

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.

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.

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.

Spheroidizing - Heating and cooling to produce a spheroidal or globular form of carbide in steel. Spheroidizing methods frequently used are: 1. Prolonged holding at a temperature just below Ae1. 2. Heating and cooling alternately between temperatures that are just above and below Ae1. 3. Heating to a temperature above Ae1 of Ae3, and then cooling very slowly in the furnace or holding at a temperature just below Ae1. 4. 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 1 or 2 above; applicable to hypereutectoid steel containing a carbide network.

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 870° C to 900° C to precipitate all carbon as titanium carbide.

Stress relieving - Annealing designed to relieve internal stresses caused by machining, welding, casting, cold working, quenching, or normalizing.

Supercooling - Cooling below the temperature at which an equilibrium phase transformation can take place, without actually obtaining the transformation.

Superheating - Heating above the temperature at which an equilibrium phase transformation should occur, without actually obtaining the transformation.

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 also is sometimes applied to normalized steel. 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.

Transformation range - Temperature range in which austenite forms as a tool is heated and disappears as the tool cools. This range is critical and must be known in order to heat-treat tooling.

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.

Warm working - Plastically deforming metal above room temperature but below the temperature at which the material undergoes recrystallization.

Workhardening - 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 superalloys Inconel and Monel.

MECHANICAL PROPERTIES OF METAL

Strength of materials deals with the relations between the external forces applied to elastic bodies, 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 materials are to be utilized and adequate proportions obtained to resist functional forces.

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

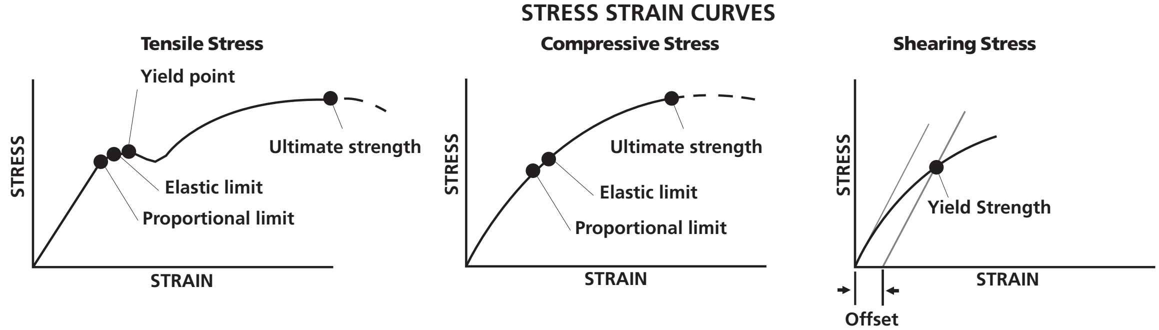
The time element in the application of a force on a body is an important consideration. Thus a force may be static or change so slowly that its maximum value can be treated as if it were static; it may be suddenly applied, as with an impact; or it may have a repetitive or cyclic behavior.

The environment in which forces act on a machine or part is also important. Such factors as high and low temperatures; the presence of corrosive gases, vapors and liquids; radiation, etc. may have a marked effect on how well parts are able to resist stresses.

Many mechanical properties of materials are determined from tests, some of which give relationships between stresses and strains as shown by the curves in the accompanying figures.

Stress Stress is the force per unit area and is usually expressed in pounds per square inch. If the stress tends to stretch or lengthen the material, it is called *tensile* stress; if to compress or shorten the material, a *compressive* stress; and if to shear the material, a *shearing* stress. 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).

STRESS STRAIN CURVES



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

Proportional limit is the point on a stress-strain curve at which it begins to deviate from the straight-line relationship between stress and strain.

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. A material 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 does exceed the elastic limit. The elastic limit for steel is for all practical purposes the same as its proportional limit.

Yield *Yield point* is a point on the 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.

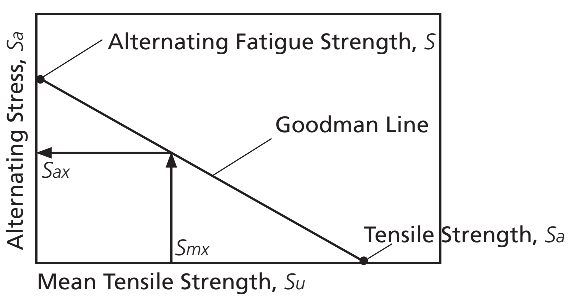
Yield strength is the maximum stress that can be applied without permanent deformation of the test specimen. This is the value of the stress at the elastic limit for materials for which there is an elastic limit. Because of the difficulty in determining the elastic limit, and because many materials do not have an elastic region, yield strength is often determined by the offset method as illustrated for shearing strength. Yield strength in such a case is the stress value on the stress-strain curve corresponding to a definite amount of permanent set or strain, usually 0.1 or 0.2 per cent of the original dimension.

Ultimate strength (also called *tensile strength*) is the maximum stress value obtained on a stress-strain curve.

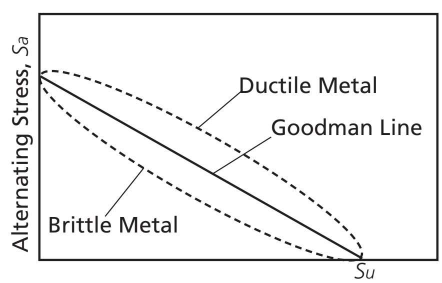
Shear Properties - The properties of *shear yield strength* are determined by direct shear and torsional tests. Single shear strength is the amount of the force applied against the side of the object in on place causing it to break into two pieces. Double shear strength is the amount of force applied against the side of the object in two places causing is to break into three pieces.

Fatigue When a material 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.

Ductility Ductility is the amount of steel to undergo permanent changes in shape without fracturing at room temperature. The opposite of ductility is brittle.

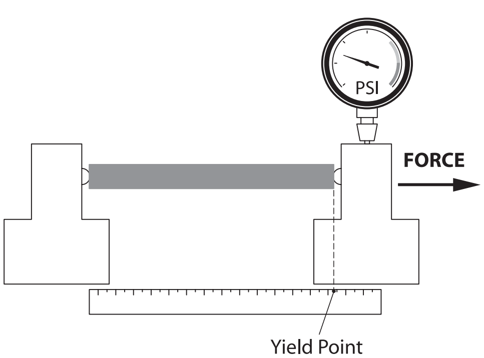


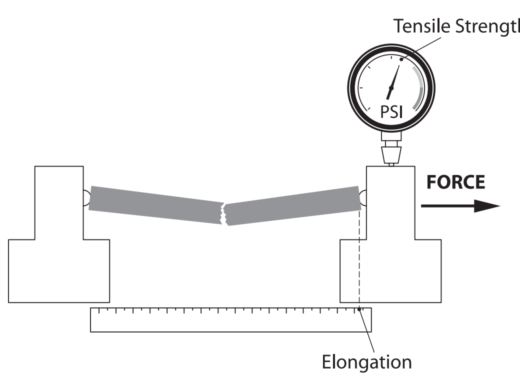
Goodman Diagram



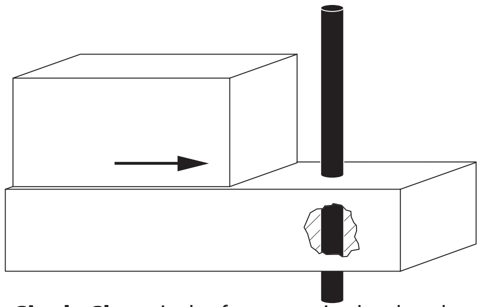
Mean Tensile Strength

Mechanical properties of metal are tested using fixtures and gages for such purpose. Yield strength, tensile strength, and elongation are tested using a fixture similar to that shown below.

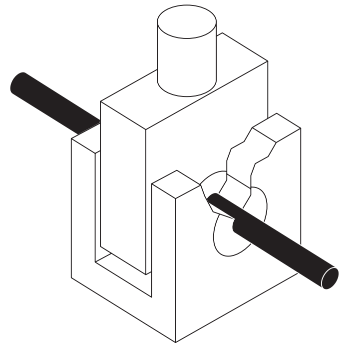




Shear strength is expressed as either single shear or double shear, depending on the engineering application. Shear strength is tested as follows:



Single Shear is the force required to break a part into two pieces.



Double Shear is the force required to break a part into three pieces.

Modes of Fatigue Failure 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 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; traditionally, this has been called "high-cycle fatigue." The other domain has cyclic loads that are relatively high, significant amounts of plastic strain induced during each cycle, and short lives or a low number of cycles to failure. This domain has commonly been called "low-cycle fatigue" or cyclic strain-controlled fatigue.

The transition from low- to high-cycle fatigue behavior occurs in the range from approximately 10,000 to 100,000 cycles. Many define low-cycle fatigue 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 Hertz contact stresses that cause the maximum values of cyclic 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.

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.

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

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

Size, in.	As Cold-Drawn					Cold-Drawn followed by Low-Temperature Stress Relief					Cold-Drawn followed by High-Temperature Stress Relief				
	Strength		Elongation in 2 in., Per cent	Reduction in Area Per Cent	Hardness, Bhn	Strength		Elongation in 2 in., Per cent	Reduction in Area Per Cent	Hardness, Bhn	Strength		Elongation in 2 in., Per cent	Reduction in Area Per Cent	Hardness, Bhn
	Tensile	Yield				Tensile	Yield				Tensile	Yield			
	1000 lb/in.^{2}					1000 lb/in.^{2}					1000 lb/in.^{2}				
AISI 1018 and 1025 Steels															
5/8–7/8	70	60	18	40	143	---	---	---	---	---	65	45	20	45	131
Over 7/8-1-1/4	65	55	16	40	131	---	---	---	---	---	60	45	20	45	121
Over 1-1/4–2	60	50	15	35	121	---	---	---	---	---	55	45	16	40	111
Over 2–3	55	45	15	35	111	---	---	---	---	---	50	40	15	40	101
AISI 1117 and 1118 Steels															
5/8–7/8	75	65	15	40	149	80	70	15	40	163	70	50	18	45	143
Over 7/8-1-1/4	70	60	15	40	143	75	65	15	40	149	65	50	16	45	131
Over 1-1/4–2	65	55	13	35	131	70	60	13	35	143	60	50	15	40	121
Over 2–3	60	50	12	30	121	65	55	12	35	131	55	45	15	40	111
AISI 1035 Steel															
5/8–7/8	85	75	13	35	170	90	80	13	35	179	80	60	16	45	163
Over 7/8-1-1/4	80	70	12	35	163	85	75	12	35	170	75	60	15	45	149
Over 1-1/4–2	75	65	12	35	149	80	70	12	35	163	70	60	15	40	143
Over 2–3	70	60	10	30	143	75	65	10	30	149	65	55	12	35	131
AISI 1045,1145, and 1146 Steels															
5/8–7/8	95	85	12	35	187	100	90	12	35	197	90	70	15	45	179
Over 7/8–1-1/4	90	80	11	30	179	95	85	11	30	187	85	70	15	45	170
Over 1-1/4–2	85	75	10	30	170	90	80	10	30	179	80	65	15	40	163
Over 2–3	80	70	10	30	163	85	75	10	25	170	75	60	12	35	149
AISI 1050, 1137, and 1151 Steels															
5/8–7/8	100	90	11	35	197	105	95	11	35	212	95	75	15	45	187
Over 7/8–1-1/4	95	85	11	30	187	100	90	11	30	197	90	75	15	40	179
Over 1-1/4–2	90	80	10	30	179	95	85	10	30	187	85	70	15	40	170
Over 2–3	85	75	10	30	170	90	80	10	25	179	80	65	12	35	163
AISI 1144 Steel															
5/8–7/8	110	100	10	30	223	115	105	10	30	229	105	85	15	40	212
Over 7/8–1-1/4	105	95	10	30	212	110	100	10	30	223	100	85	15	40	197
Over 1-1/4–2	100	90	10	25	197	105	95	10	25	212	95	80	15	35	187
Over 2–3	95	85	10	20	187	100	90	10	20	197	90	75	12	30	179

Source: AISI Committee of Hot-Rolled and Cold-Finished Bar Producers and published in 1974 DATABOOK issue of the American Society for Metals' *METAL PROGRESS* magazine and used with its permission.

Typical Mechanical Properties of Selected Carbon and Alloy Steels

Hot Rolled, Normalized, and Annealed

AISI No.[a]	Treatment	Strength Tensile	Strength Yield	Elongation Per cent	Reduction in Area, Per cent	Hardness, Bhn	Impact Strength (Izod), ft-lb
		1b/in.^{2}					
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	80,000	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	55,00	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
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 (1600 F)	148,000	95,000	17.7	46.8	302	16.7
	Annealed (1500 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

a) All grades are fine-grained except those in the 1100 series that are coarse-grained. Austenitizing temperatures are given in parentheses. Heat-treated specimens were oil-quenched unless otherwise indicated. *Source:* Bethlehem Steel Corp. and Republic Steel Corp. as published in 1974 DATABOOK issue of the American Society for Metals' METAL PROGRESS magazine and used with its permission.

Typical Mechanical Properties of Selected Carbon and Alloy Steels

Quenched and Tempered

AISI No[a]	Tempering Temperature F°	Strength Tensile (1000 lb/in.²)	Strength Yield (1000 lb/in.²)	Elongation Per cent	Reduction in Area, Per cent	Hardness, Bhn
1030b	400	123	94	17	47	495
	600	116	90	19	53	401
	800	106	84	23	60	302
	1000	97	75	28	65	255
	1200	85	64	32	70	207
1040b	400	130	96	16	45	514
	600	129	94	18	52	444
	800	122	92	21	57	352
	1000	113	86	23	61	269
	1200	97	72	28	68	201
1040	400	113	86	19	48	262
	600	113	86	20	53	255
	800	110	80	21	54	241
	1000	104	71	26	57	212
	1200	92	63	29	65	192
1050b	400	163	117	9	27	514
	600	158	115	13	36	444
	800	145	110	19	48	375
	1000	125	95	23	58	293
	1200	104	78	28	65	235
1050	400	---	---	---	---	---
	600	142	105	14	47	321
	800	136	95	20	50	277
	1000	127	84	23	53	262
	1200	107	68	29	60	223
1060	400	160	113	13	40	321
	600	160	113	13	40	321
	800	156	111	14	41	311
	1000	140	97	17	45	277
	1200	116	76	23	54	229
1080	400	190	142	12	35	388
	600	189	142	12	35	388
	800	187	138	13	36	375
	1000	164	117	16	40	321
	1200	129	87	21	50	255
1095b	400	216	152	10	31	601
	600	212	150	11	33	534
	800	199	139	13	35	388
	1000	165	110	15	40	293
	1200	122	85	20	47	235
1095	400	187	120	10	30	401
	600	183	118	10	30	375
	800	176	112	12	32	363
	1000	158	98	15	37	321
	1200	130	80	21	47	269
1137	400	157	136	5	22	352
	600	143	122	10	33	285
	800	127	106	15	48	262
	1000	110	88	24	62	229
	1200	95	70	28	69	197
1137b	400	217	169	5	17	415
	600	199	163	9	25	375
	800	160	143	14	40	311
	1000	120	105	19	60	262
	1200	94	77	25	69	187
1141	400	237	176	6	17	461
	600	212	186	9	32	415
	800	169	150	12	47	331
	1000	130	111	18	57	262
	1200	103	86	23	62	217
1144	400	127	91	17	36	277
	600	126	90	17	40	262
	800	123	88	18	42	248
	1000	117	83	20	46	235
	1200	105	73	23	55	217

a) All grades are fine-grained except those in the 1100 series that are coarse-grained. Austenitizing temperatures are given in parentheses. Heat-treated specimens were oil-quenched unless otherwise indicated.
b) Water quenched.

Typical Mechanical Properties of Selected Carbon and Alloy Steels Cont.

Quenched and Tempered

AISI No[a]	Tempering Temperature F°	Strength Tensile (1000 lb/in.²)	Strength Yield (1000 lb/in.²)	Elongation Per cent	Reduction in Area, Per cent	Hardness, Bhn
1330b	400	232	211	9	39	459
	600	207	186	9	44	402
	800	168	150	15	53	335
	1000	127	112	18	60	263
	1200	106	83	23	63	216
1340	400	262	231	11	35	505
	600	230	206	12	43	453
	800	183	167	14	51	375
	1000	140	120	17	58	295
	1200	116	90	22	66	252
4037	400	149	110	6	38	310
	600	138	111	14	53	295
	800	127	106	20	60	270
	1000	115	95	23	63	247
	1200	101	61	29	60	220
4042	400	261	241	12	37	516
	600	234	211	13	42	455
	800	187	170	15	51	380
	1000	143	128	20	59	300
	1200	115	100	28	66	238
4130b	400	236	212	10	41	467
	600	217	200	11	43	435
	800	186	173	13	49	380
	1000	150	132	17	57	315
	1200	118	102	22	64	245
4140	400	257	238	8	38	510
	600	225	208	9	43	445
	800	181	165	13	49	370
	1000	138	121	18	58	285
	1200	110	95	22	63	230
4150	400	280	250	10	39	530
	600	256	231	10	40	495
	800	220	200	12	45	440
	1000	175	160	15	52	370
	1200	139	122	19	60	290
4340	400	272	243	10	38	520
	600	250	230	10	40	486
	800	213	198	10	44	430
	1000	170	156	13	51	360
	1200	140	124	19	60	280
6150	400	280	245	8	38	538
	600	250	228	8	39	483
	800	208	193	10	43	420
	1000	168	155	13	50	345
	1200	137	122	17	58	282
81B45	400	295	250	10	33	550
	600	256	228	8	42	475
	800	204	190	11	48	405
	1000	160	149	16	53	338
	1200	130	115	20	55	280
8630	400	238	218	9	38	465
	600	215	202	10	42	430
	800	185	170	13	47	375
	1000	150	130	17	54	310
	1200	112	100	23	63	240
8640	400	270	242	10	40	505
	600	240	220	10	41	460
	800	200	188	12	45	400
	1000	160	150	16	54	340
	1200	130	116	20	62	280
8650	400	281	243	10	38	525
	600	250	225	10	40	490
	800	210	192	12	45	420
	1000	170	153	15	51	340
	1200	140	120	20	58	280

a) All grades are fine-grained except those in the 1100 series that are coarse-grained. Austenitizing temperatures are given in parentheses. Heat-treated specimens were oil-quenched unless otherwise indicated.
b) Water quenched.

Nominal Mechanical Properties of Selected Standard Stainless Steels

Grade	Condition	Tensile Strength (psi)	0.2 Per Cent Yield Strength (psi)	Elongation in 2 in. (%)	Reduction of Area (%)	Hardness	
						Rockwell	Bhn
Austenitic Steels							
302	Annealed	90,000	37,000	55	65	B82	155
	1.4-hard (sheet, strip)	125,000a	75,000a	12a	---	C25	---
	Cold-drawn (bar, wire)[b]	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
	Hardened[d]	---	---	---	---	C54	540
	Tempered at						
	600°F	230,000	195,000	8	25	C50	500
440C, 440F	Annealed	110,000	65,000	13	25	B97	230
	Hardened[d]	---	---	---	---	C60	C10
	Tempered						
	600°F	285,000	275,000	2	10	C57	580

Source: Metals Handbook, 8th edition, Volume 1.
a) Minimum.
b) Depending on size and amount of cold reduction.
c) Hardening temperature 1800 degrees F, 1-in.-diam. bars.
d) Hardening temperature 1900 degrees F, 1-in.-diam. bars.

Mechanical Properties and Testing Glossary

AA, arithmetical average - Mathematical expression denoting surface finish or surface texture. Represents the average difference between peaks and valleys on the workpiece surface, measured in microinches.

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.

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 test.*

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.

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

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.*

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

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.

Edge finder - Gage mounted in the spindle of a vertical mill and used, while rotating, to find the center of a part relative to the toolholder.

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 versus distance from the quenched end.

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.

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.

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.

In-process gaging, 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.*

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.*

Knoop Hardness Test - Determines microhardness from the resistance of metal to indentation by a pyramidal diamond indenter, having edge angles of 172°30' and 130°, making a rhombohedral impression with one long and one short diagonal. See *Brinell hardness test; Vickers hardness test.*

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.

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.*

Metalcutting dynamometer - Device for measuring cutting forces developed during machining.

Metrology - Science of measurement; the principles on which precision machining, quality control, and inspection are based. See *precision machining, measurement.*

Modulus of elasticity - A measure of the rigidity of metal. Ratio of stress, below the proportional limit, to corresponding strain.

NDT, nondestructive testing - Same as nondestructive inspection, but implying use of a method in which the part is stimulated and its response measured quantitatively or semi-quantitatively.

Nondestructive inspection, nondestructive examination - Inspection by methods that do not destroy the part or impair it's serviceability.

Precision machining, measurement - 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.

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 *SPC, statistical process control.*

Process control - Method of monitoring a process. Relates to electronic hardware and instrumentation used in automated process control. See *in-process gaging, inspection; SPC, statistical process control.*

QA, quality assurance; QC, Quality control - 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.

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.*

Salt fog test, salt spray 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.

S-N diagram - A plot showing the relationship of stress, S, and the number of cycles, N, before fracture in fatigue testing.

SPC, statistical process control - statistical techniques to measure and analyze the extent to which a process deviates from a set standard.

SQC, statistical quality control - Statistical techniques to measure and improve the quality of a given process.

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 gage length. Conventional strain is the linear strain over the original gage 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-rupture test, creep-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.

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.*

TIR, total indicator runout - Combined variations of all dimensions of a workpiece, measured with an indicator, determined by rotating the part 360°.

Tolerance - Minimum and maximum amount a workpiece dimension is allowed to vary from a set standard and still be acceptable.

Ultimate strength - The maximum conventional stress (tensile, compressive, or shear) that a material can withstand.

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.

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.*

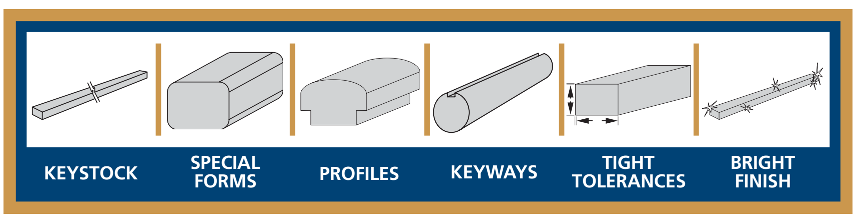
MANUFACTURING PROCESSES

G.L. Huyett is unique in the breadth of its manufacturing operations. These operations are complemented with a state-of-the-art world class warehouse containing over 75,000 non-threaded fasteners and industrial components. This section sets forth some of the major manufacturing operations performed by or contracted for by the company. A list of key capabilities and a defined niche is listed for each.

Cold Drawing

The process of pulling steel bar or sheet through a progressive set of rollers or dies at room temperature, so as to modify the shape and structure.

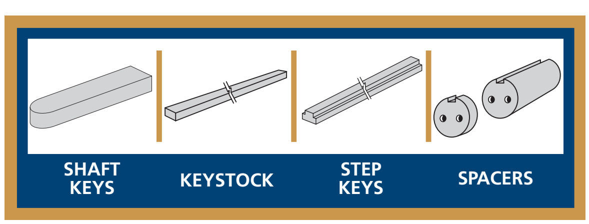
G.L. Huyett, in conjunction with steel mills here and in Europe, has perfected a number of profiling techniques that are conducive to the manufacturing of high quality keystock.



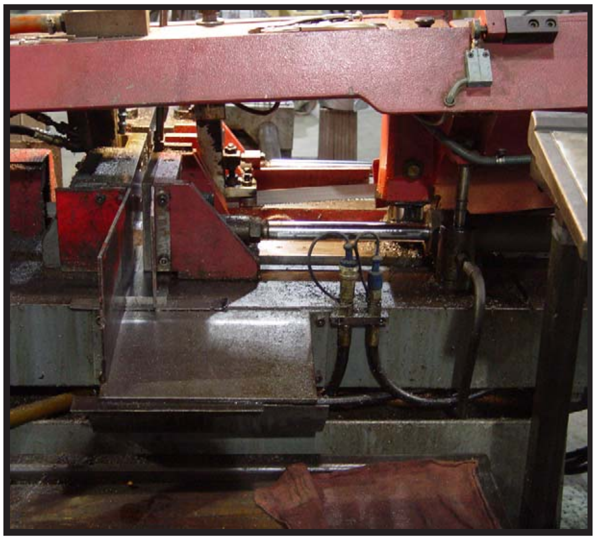
Band Sawing

Uses a long, endless blade with many small teeth traveling between wheels. Produces a continuous and uniform cutting action.

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



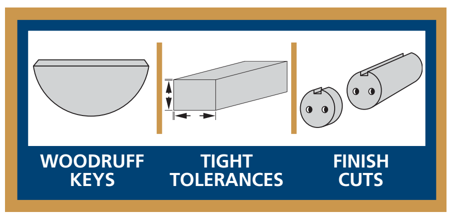
Award Winning Quality

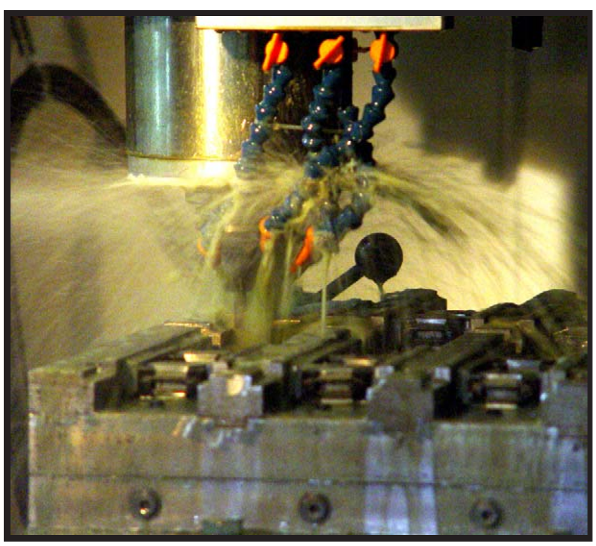


Cold Sawing

Uses a slow-moving angular blade which provides highly accurate finish-quality cuts, but in lower volume.

Cold sawing is highly accurate and is used when fine length tolerances are considered.

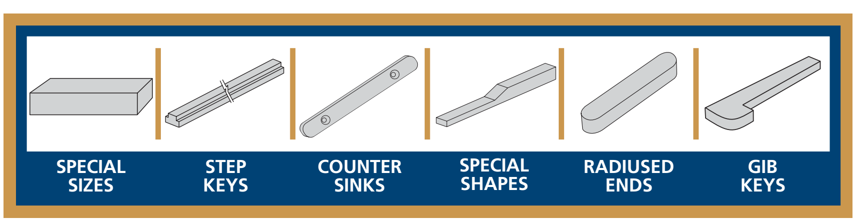


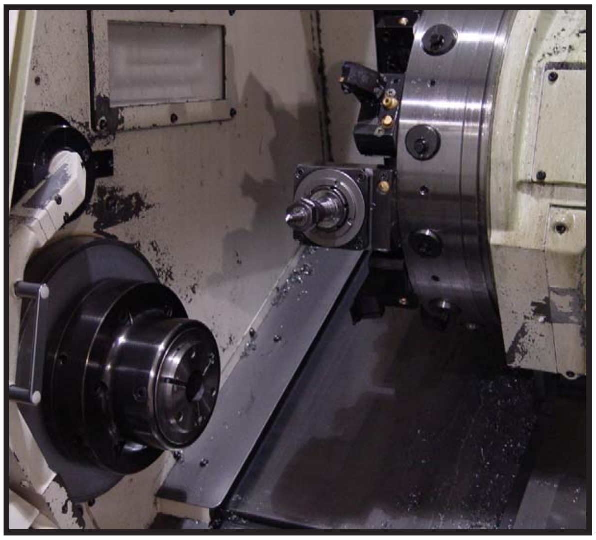


Milling

Machining operation in which metal is removed by applying power to a rotating cutter.

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

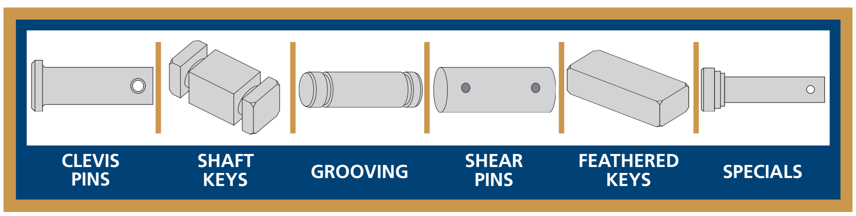




Turning

Machining operation in which a workpiece is rotated while a cutting tool removes material.

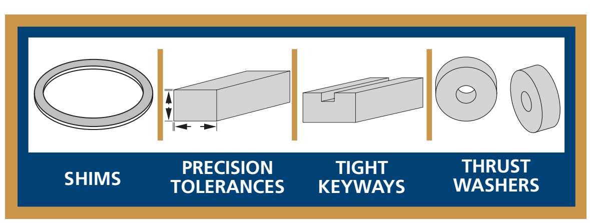
Huyett uses automatic bar feed equipment and off-line programming to increase production and minimize setup time.



Grinding

Machining operation in which material is removed by a powered abrasive wheel, stone, belt, paste, sheet, compound, etc.

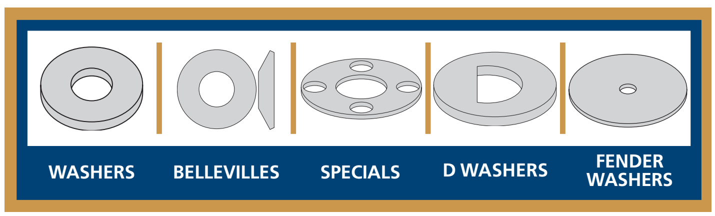
Grinding is used to realize fine finish tolerances and surface finishes.

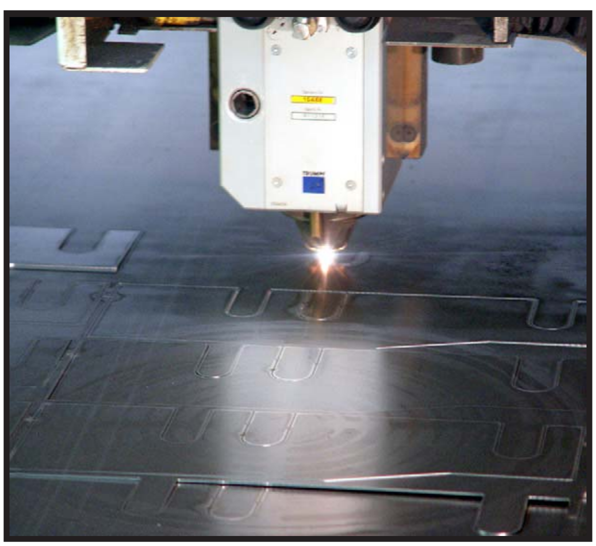


Stamping

Mechanical operation that uses a tool and die to form an impression in metal that is broken out in a carefully machined operation.

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.

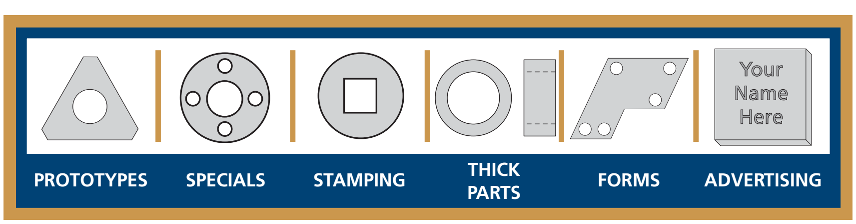




Laser

Use of intensified beams of light to drill or cut forms into metal to finished tolerances.

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.



Abrasive - Garnet, emery, carborundum, aluminium 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 band - Diamond- or other abrasive-coated endless band fitted to a special 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, saw - Machine that uses blade-like discs impregnated with abrasive particles to cut/part stock. See *saw, sawing 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 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-wire bandsawing - A variation of bandsawing 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 bandsawing is an alternative to electrical-discharge machining for product dies, stripper plates, electrodes, and cams from difficult-to -machine conductive and nonconductive materials. See *bandsawing.*

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

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

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 for inspection.

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.

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

Automatic bar machine - Production machine for turning bar stock. 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 toolholding 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 bar stock. 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 toolchanger - 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 toolchanger 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.

AWJ, abrasive waterjet - System that uses high-pressure waterjets in combination with a slurry of fine abrasive grains to machine materials. See *waterjet cutting.*

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

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.

Backoff - 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.*

Band, bandsaw blade - Endless band, normally with serrated teeth, that serves as the cutting tool for cutoff or contour band machines.

Band polishing - A variation of bandsawing that uses an abrasive band to smooth or polish parts previously sawed or filed.

Bandsaw - Powered machine that utilizes an endless band, normally with serrated teeth, for cutoff or contour sawing. See *saw, sawing machine.*

Bandsawing - Power bandsawing, 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. Bandsawing machines are available in a wide variety of types to suit many different applications.

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.*

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

Boring - Enlarging a hole that already has 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.

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 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, boring tool - 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 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.*

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 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.

BUE, built-up edge - 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, or waterjet equipment.

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 bushing.

CAD, computer-aided design - Product-design functions performed with the help of computers and special software.

CAM, computer-aided manufacturing - Use of computers to control machining and manufacturing.

Canned cycle, fixed 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.

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

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

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.*

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.

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

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

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.

Chuck - Workholding 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.*

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.

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.*

CNC, computer numerical control - 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.*

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

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.

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

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.

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, 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.*

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.

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, tool 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 chipmaking 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--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.

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.

DNC, direct numerical control - Actions of multiple machine tools controlled by a single computer. See *CNC, computer numerical control; NC, numerical control.*

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

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

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 endmill to prevent undesirable contact with the work. Similar to 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, drilling tool - 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 top 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.

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.

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.*

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

Endmill - 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.*

ECM, electrochemical machining - 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 such forms as electrochemical grinding, electrochemical honing, and electrochemical turning.

EDG, electrical-discharge grinding - A process similar to conventional EDM except a grinding-wheel type of electrode is used.

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 ultraprecise, electrical, contour-sawing operation.

EP (extreme pressure) additives - Cutting-fluid additives (chlorine, sulfur, or phosphorous compounds) that chemically react with the workpiece material to minimize chipwelding; good for high-speed machining.

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.

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-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.

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.

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

Endmill - 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.*

Endmilling - 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*.

FMS, flexible manufacturing system - 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 workhandling system and peripherals. Also associated with the machine tools grouped in "cells" for efficient production. See *cell manufacturing.*

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

Facemill - Milling cutter for cutting flat surfaces. See *milling cutter.*

Facemilling - 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 workholder 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.

Feather burr - A very fine or thin 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.

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.

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.

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

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

Flat, screw flat - Flat surface machined into the shank of a cutting tool for enhanced holding of the tool.

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.

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, endmills, 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.*

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*.

Friction sawing - Sawing with a special band machine capable of achieving band velocities of 15,000 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.*

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

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

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 ultrasmooth 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 ultrasmooth 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; facemill and endmill 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.

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 workhandling.

Gundrill - 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.

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

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

Headchanging 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.

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

Helical cutter - Endmill 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 endmills at high speeds. See *universal milling attachment*.

Hob - A rotating tool with teeth arranged along a helical path, used fur 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*.

Holemaking - 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 then 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 such a way as to allow floating and no clamping or chucking, there is no distortion. Also used to give cutting tools ultrafine 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, ultrasharp 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.

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 *AWJ, abrasive waterjet; waterjet cutting.*

ID, inner diameter - Dimensions that define the inside of a part. See *OD, outer diameter.*

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 toolholder, 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 such 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 endmill or other cutter have been properly ground. See *clearance; relief.*

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*.

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 is used in subassembly or final assembly might 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 workholding 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.

JIT, just in time - Philosophy based on identifying, then removing, impediments to productivity. Applies to machining processes, inventory control, rejects, changeover time, and other elements affecting production.

Kerf - Width of cut left after a blade or tool makes a pass.

Keyseating - Milling or grinding an internal keyway. See *slotting*.

Knockout - A mechanism for releasing workpieces from a die; it is also called ejector, kickout, liftout, or shedder.

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.

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, powder - Light, abrasive material used for finishing a surface.

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 neodium-doped yttrium aluminum garnet (Nd:YAG)--that drill, weld, engrave, mark, slit, caseharden, etc. Usually under computer numerical control, often at both high cutting rates (100 linear in./sec/) 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, toolpost, compound rest, leadscrew and reversing leadscrew, 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. Toolroom 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, lathe tool - 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 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.

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.

MRP, MRP-II, materials requirements planning, manufacturing resources planning - 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.

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 toolchanger. See *automatic toolchanger.*

Magnetic chuck - Workholding 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*.

Mandrel - Workholder for turning that fits inside hollow workpieces. Types available include expanding, pin, and threaded.

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.

Metalcutting - 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.

Metalforming - 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.

Metalworking - Any manufacturing process in which metal is processed or machined such that the workpiece is given 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.

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.

Mill, milling machine - Runs endmills 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 endmill to accomplish the milling steps; vertical milling machines also feed endmills 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 of 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, endmilling, facemilling, angle milling, form milling, and profiling.

Milling arbor - Shaft or toolholder that inserts in the machine spindle and holds a peripheral-milling or facemilling 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, facemilling 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 endmills, T-slot cutters, Woodruff keyseat cutters, and dovetail; these may also be used on horizontal mills.

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 bandsawing 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 design, construction - 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.

Modular tooling - Tooling system comprised of standardized tools and toolholders. Devices that allow rapid mounting and replacement of tools. Commonly used with carousel toolchangers and other computerized machining operations.

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.

NC, numerical control - Any controlled equipment that allows an operator to program its movement by entering a series of coded numbers, symbols, etc. See *CNC, computer numerical control; DNC, direct numerical control.*

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.

OD, outer diameter - Dimensions that define the exterior of a part. See *ID, inner diameter.*

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/computer-numerical-control machining. See *undershoot.*

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).

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 ask 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.

Pitch - On a saw blade, the number of teeth per inch. In threading, the number of threads per inch.

Planer, 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.

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.

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-to-point system - Numerical-control 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, counterbores, 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 used fine-grit belts to grind and polish.

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.

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, computer-aided manufacturing, and computer-integrated manufacturing, 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 endmill in a vertical spindle on a milling machine or with a profiler, following a pattern.

Quick-change toolholder - Cutter holder that permits rapid tool changes. Generally associated with automatic or semiautomatic machining operations. See *toolholder.*

RIM, reaction injection molding - 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 postmolding operations; and simultaneous, multipart molding.

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 worms.

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.

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.

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.*

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.

Rotary attachment - Bolts to a milling machine to permit machining such shapes as circular T-slots and cams.

Roughing cutter, tool - Tool for high-volume metal removal; normally followed by finishing passes. See *finishing tool.*

Saw, sawing machine - 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: hacksaw (a simple, rugged machine that uses a reciprocating motion to part metal or other material); cold or circular saw (powers a circular blade that cuts structural materials); bandsaw (runs an endless band; the two basic types are cutoff and contour band machines, which cut intricate contours and shapes); and 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 bandsawing, band machining). Four basic types of sawing operations are: 1. hacksawing: power or manual operation in which the blade moves back and forth through the work, cutting on one of the strokes; 2. cold or circular sawing: a rotating, circular, toothed blade parts the material much as a workshop table saw or radial-arm saw cuts wood; 3. bandsawing: a flexible, toothed blade rides on wheels under tension and is guided through the work; and 4. abrasive sawing: abrasive points attached to a fiber or metal backing part stock; could be considered a grinding operation.

Scalloping, scallops - Wavy surface condition caused by deflection, unbalanced tool, loose workpiece or tooling, worn machine, etc.

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, 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.*

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.

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.

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.

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 ration 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 ration is used to improve lubricity. Additives include emulsifying agents that help keep the oil in suspension and substances that promote wetting, enhance lubricity, prevent chipwelding, 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" to 6" in diameter. Space drills consist of an interchangeable cutting blade and a toolholder 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 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.

Spindle adapters - Bushings of toolholders 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, the lowered into a rotating tub containing the finishing media. In most applications, the spindles rotate at 10 to 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 endmill and twist-drill blanks.

Spotfacer - Tool, guided by a pilot, used to machine a recess around a hole.

Spotfacing - Similar to counterboring except that, in spotfacing, material around the original hole is cut. Application example: the recessed area that a washer fits into. See *counterboring; countersinking.*

Straight-cut system - Numerical-control 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.

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*.

StereoLithography--metal - A process similar to plastic StereoLithography, but uses powder metal to build up the part.

StereoLithography--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.

Superabrasive tools - Abrasive tools made from diamond or cubic boron nitride (CBN), the hardest materials known.

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-slot cutter - Milling cutter for machining T-slots. Desired T-slot shape is reverse of cutter shape.

TOP, technical office protocol - Standardized computer communications for the office; combines with manufacturing automation protocol to permit office/plat computer integration of multi-vendor systems and software. See *MAP, manufacturing automation protocol.*

Tailstock drill and tapholder - 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, endmill, 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 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.

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 often is 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.*

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 leadscrews ensure a precise traverse to impart the correct lead to a thread.

Threading machine - Typically takes the form of multi-spindle, universal threading machines that use dieheads and thread chasers to cut threads, often automatically or semiautomatically. Threading also is performed on lathes and automatic screw machines.

Toolchanger - Carriage or drum attached to a machining center that holds tools until needed; when a tool is needed, the toolchanger inserts the tool into the machine spindle.

Toolholder - Secures a cutting tool during a machining operation. Basic types include block, cartridge, chuck, collet, fixed, modular, quick-change, and rotating.

Toolroom lathe - High-precision lathe built to hold tighter tolerances than regular, general-purpose lathes can hold tighter tolerances than regular, general-purpose lathes can hold. 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.

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.

Trepanning - Drilling deep holes that are too large to be drilled by high-pressure coolant drills or gundrills. 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.*

Turning - A workpiece is held in a chuck, mounted on a face plate, 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 cutting edges, and having helical grooves adjacent thereto 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 from 1/16" to 1 1/2", wire-gage sizes from 1 to 80, letter sizes from A to Z, and metric sizes.

Ultrasonic machining - Material-removal operation in which an abrasive slurry flows between a tool, vibrating at a high frequency, and a workpiece.

Undercut - In numerical-control 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 preshaving.

Undershoot - Tendency of a numerical-control/computer-numerical-control 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 helix angle greater than 45°. 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-block - Workholding device with V-shaped slot for holding pipe and other round stock during machining or inspection.

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.

Viscosity - Measure of a fluid's tendency to flow; varies with temperature.

Vertical milling attachment - Permits a horizontal mill to perform vertical and angled milling.

Vise - Workholding 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.

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 from between 0.004" to 0.016" (0.10mm to 0.41mm), producing a very narrow kerf. See *AWJ, abrasive waterjet.*

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-squaring bar - Mounts to the table of a contour band machine and automatically squares the work to the blade.

CONVERSION COATING, PLATING, AND THE COLORING OF METALS

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, 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 decreasing and/or chemical or electrochemical cleaning or etching. Then 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.

Coloring of Iron and Steel 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 nitrites. These coatings serve as paint bases and, in some cases, as 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.

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.

Anodizing Aluminum Alloys In the anodizing process, the aluminum object to be treated is immersed as the anode in an acid electrolyte, and a direct current is applied. Oxidation of the surface occurs, producing a greatly thickened, hard, porous film of aluminum oxide. The object is then immersed in boiling water 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.

Surface Coatings The following is a list of military plating and coating specifications.

Anodize (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 non-dyed; Class 2 dyed. Color is to be specified on the contract. Prior to dying or sealing, coatings shall meet the 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 shall have a thickness between 0.00002 and 0.0007 in. Type II shall have a thickness between 0.0007 and 0.0010 in.

Black Oxide Coating, MIL-C-13924C: A uniform, mostly decorative black coating for ferrous metals used to decrease light reflection. 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, 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 Rc) 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 thicknesses shall be 0.0005, 0.0003, and 0.0002 in. 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 shall be met after the supplementary treatment.

Lubrication, Solid Film MIL-L-46010D: The Military Plating 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, and chromium, and nickel bearing surfaces.

Types I, II, and III have a thicknesses of 0.008 - 0.013 mm. 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, QQ-N-290A*:* There is a nickel finish for almost any need. Nickel can be deposited soft, hard-dull, or bright, depending on process used and conditions employed in plating. Thus, hardness can range from 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 220,000 or greater shall not be a nickel plate without specific approval of procuring agency.

Class 1 is used for corrosion protection. Plating shall be applied over an underplating of copper or yellow brass on zinc and zinc based alloys. In no case, shall 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 in.; Grade B, 0.0012 in.; Grade C, 0.001 in.; Grade D, 0.0008 in.; Grade E, 0.0006 in.; Grade F, 0.0004 in.; and Grade G, 0.002 in.

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 from 0.0002-0.0004 in. and Type Z, 0.0002-0.0006 in. 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, no supplementary treatment is required. For Type M, Class 4 is chemically converted (may be dyed to color as specified) with no supplementary coating or supplementary coating as specified. 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, ASTM-B633*:* This specification covers requirements for electrodeposited 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) shall not be electroplated.

Stress relief: All parts with ultimate tensile strength 1000 Mpa and above at minimum 190°C for three hours or more before cleaning and plating.

Hydrogen embrittlement relief: All electroplated parts 1200 Mpa or higher shall be baked at 190°C for three hours or more within four hours after electroplating.

Corrosion Resistance Requirements	
Types	**Test Period Hr.**
II	**96**
III	**12**

CONVERSION CHARTS

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

Decimal Equivalents of Fractions of an Inch

1/64	0.015 625	11/32	0.343 75	43/64	0.671 875
1/32	0.031 25	23/64	0.359 375	11/16	0.687 5
3/64	0.046 875	3/8	0.375	45/64	0.703 125
1/16	0.062 5	25/64	0.390 625	23/32	0.718 75
5/64	0.078 125	13/32	0.406 25	47/64	0.734 375
3/32	0.093 75	27/64	0.421 875	3/4	0.750
7/64	0.109 375	7/16	0.437 5	49/64	0.765 625
1/8	0.125	29/64	0.453 125	25/32	0.781 25
9/64	0.140 625	15/32	0.468 75	51/64	0.796 875
5/32	0.156 25	31/64	0.484 375	13/16	0.812 5
11/64	0.171 875	1/2	0.500	53/64	0.828 125
3/16	0.187 5	33/64	0.515 625	27/32	0.843 75
13/64	0.203 125	17/32	0.531 25	55/64	0.859 375
7/32	0.218 75	35/64	0.546 875	7/8	0.875
15/64	0.234 375	9/16	0.562 5	57/64	0.890 625
1/4	0.250	37/64	0.578 125	29/32	0.906 25
17/64	0.265 625	19/32	0.593 75	59/64	0.921 875
9/32	0.281 25	39/64	0.609 375	15/16	0.937 5
19/64	0.296 875	5/8	0.625	61/64	0.953 125
5/16	0.312 5	41/64	0.640 625	31/32	0.968 75
21/64	0.328 125	21/32	0.656 25	63/64	0.984 375

Metric and English Equivalents

Use of Conversion Tables - On the following pages, tables are given that permit conversion from English 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.

.4	in	=	10.16000 mm
.04	in	=	1.01600 mm
.007	in	=	.17780 mm
.0006	in	=	.01524 mm
.4476	in	=	11.36904 mm

Example 2: Find the inch equivalent of 84.9 mm.

80.	mm	=	3.14961 in
4.	mm	=	0.15748 in
0.9	mm	=	0.03543 in
84.9	mm	=	3.34252 in

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, and 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
Temperature		
temperature Celsius, t_C	temperature Fahrenheit, t_F	$t_F=1.8t_C+32$
temperature Fahrenheit, t_F	temperature Celsius, t_C	$t_C=(t_F-32)/1.8$

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

Linear Measure

1 kilometer = 0.6214 mile
1 meter = 39.37 inches = 3.2808 feet = 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 = 304.8 millimeters
1 inch = 2.54 centimeters = 25.4 millimeters

To convert millimeters to inches, multiply millimeters by .03937. To convert inches to metric, divide inches by .03937.

Inch to Millimeters and Millimeters to Inch Conversion Table

Inches To Millimeters											
in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
10	254.00000	1	25.40000	0.1	2.54000	.01	0.25400	0.001	0.02540	0.0001	0.00254
20	508.00000	2	50.80000	0.2	5.08000	.02	0.50800	0.002	0.05080	0.0002	0.00508
30	762.00000	3	76.20000	0.3	7.62000	.03	0.76200	0.003	0.07620	0.0003	0.00762
40	1,016.00000	4	101.60000	0.4	10.16000	.04	1.01600	0.004	0.10160	0.0004	0.01016
50	1,270.00000	5	127.00000	0.5	12.70000	.05	1.27000	0.005	0.12700	0.0005	0.01270
60	1,524.00000	6	152.40000	0.6	15.24000	.06	1.52400	0.006	0.15240	0.0006	0.01524
70	1,778.00000	7	177.80000	0.7	17.78000	.07	1.77800	0.007	0.17780	0.0007	0.01778
80	2,032.00000	8	203.20000	0.8	20.32000	.08	2.03200	0.008	0.20320	0.0008	0.02032
90	2,286.00000	9	228.60000	0.9	22.86000	.09	2.2860	0.009	0.22860	0.0009	0.02286
100	2,540.00000	10	254.00000	1.0	25.40000	.10	2.54000	0.010	0.25400	0.0010	0.02540

Millimeters to Inches											
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	.000039	0.001	0.00004
200	7.87402	20	0.78740	2	0.07874	0.2	0.00787	0.02	.00079	0.002	0.00008
300	11.81102	30	1.18110	3	0.11811	0.3	0.01181	0.03	.00118	0.003	0.00012
400	15.74803	40	1.57480	4	0.15748	0.4	0.01575	0.04	.00157	0.004	0.00016
500	19.68504	50	1.96850	5	0.19685	0.5	0.01969	0.05	.00197	0.005	0.00020
600	23.62205	60	2.36220	6	0.23622	0.6	0.02362	0.06	.00236	0.006	0.00024
700	27.55906	70	2.75591	7	0.27559	0.7	0.02756	0.07	.00276	0.007	0.00028
800	31.49606	80	3.14961	8	0.31496	0.8	0.03150	0.08	.00315	0.008	0.00031
900	35.43307	90	3.54331	9	0.35433	0.9	0.03543	0.09	.00354	0.009	0.00035
1,000	39.37008	100	3.93701	10	0.39370	1.0	0.03937	0.10	.00394	0.010	0.00039

Fractional Inch - Millimeter and Foot - Millimeter Conversation Tables

(Based on 1 inch = 25.4 millimeters, exactly)

Fractional Inch to Millimeters							
in.	mm	in.	mm	in.	mm	in.	mm
16/4	0.397	17/64	6.747	33/64	13.097	49/64	19.447
1/32	0.794	9/32	7.144	17/32	13.494	25/32	19.844
3/64	1.191	19/64	7.541	35/64	13.891	51/64	20.241
1/16	1.588	5/16	7.938	9/16	14.288	13/16	20.638
5/64	1.984	21/64	8.334	37/64	14.684	53/64	21.034
3/32	2.381	11/32	8.731	19/32	15.081	27/32	21.431
7/64	2.778	23/64	9.128	39/64	15.478	55/64	21.828
1/8	3.175	3/8	9.525	5/8	15.875	7/8	22.225
9/64	3.572	25/64	9.922	41/64	16.272	57/64	22.622
5/32	3.969	13/32	10.319	21/32	16.669	29/32	23.019
1/164	4.366	27/64	10.716	43/64 1	7.066	59/64	23.416
3/16	4.762	7/16	11.112	11/16	17.462	15/16	23.812
13/64	5.159	29/64	11.509	45/64	17.859	61/64	24.209
7/32	5.556	15/32	11.906	23/32	18.256	31/32	24.606
15/64	5.953	31/64	12.303	47/64	18.653	63/64	25.003
1/4	6.350	1/2	12.700	3/4	19.050	1	25.400

Inches to Millimeters											
in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm
1	25.4	3	76.2	5	127.0	7	177.8	9	228.6	11	279.4
2	50.8	4	101.6	6	152.4	8	203.2	10	254.0	12	304.8

Weight

1 metric ton =0.9842 ton (of 2240 pounds) = 2204.6 pounds.
1 kilogram = 2.2046 pounds = 35.274 ounces avoirdupois.
1 pound = 0.4536 kilogram = 453.6 grams.
1 kilogram per square millimeter = 1422.32 pounds per square inch.
1 pound per square inch = 0.0703 kilogram per square centimeter.

Pound - Kilogram and Ounce - Gram Conversion Tables

Pounds to Kilograms (1 pound = 0.4535924 kilogram)									
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 kilogram = 2.204622 pounds)									
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

The use of the Newton as the 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. Thus, the unit of force in those systems is that 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, and thus 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 9.80665 meters per second squared or 32.174 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 9.81 meters per second squared).

Pound-Inches to Newton-Meters Conversion Tables

Pound-Inches to Newton-Meters (1 pound-force-inch = 0.1129848 newton-meter)									
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
1000	112.985	100	11.298	10	1.130	1.0	0.113	0.10	0.011

Newton-Meters to Pound-Inches (1 newton meter = 8.850748 pound-force-inches)									
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	40	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
1000	8850.75	100	885.07	10	88.51	1.0	8.85	0.10	0.89

LINKS AND RELATED SITES

Industrial Fasteners Institute (IFI)

http://www.industrial-fasteners.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.ch/

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/

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