General Characteristics and Heat Treatments of Steels—SAE J412h

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Society of Automotive Engineers, Inc.
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GENERAL CHARACTERISTICS AND HEAT TREATMENTS OF STEELS—SAE J412h

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Introduction—The information and data contained in this report are intended as a guide in the selection of steel grades for various purposes. SAE steels are generally purchased on the basis of chemical composition requirements (SAE J403, J404, and J405). This information report can be used as a reference for determining the general characteristics of commonly used SAE steels. The use of the typical heat treatments listed in Tables 1 and 2 is recommended.

Normalizing—The normalizing heat treatment consists of:

1. Uniformly heating steel to a temperature high enough to obtain complete transformation to austenite.
2. Holding at the austenitizing temperature until the mass is of equal temperature throughout.
3. Air cooling, allowing free air circulation to give uniform cooling. Normalizing temperatures are dependent upon the steel grade, while holding time at temperature will vary with the mass being heat treated. Hence, normalizing cycles and subsequent steel properties may vary considerably with steel grade, part size, individual furnace conditions and cooling facilities.

Normalizing is generally performed to obtain desired mechanical properties but is also used for the following functions:

1. Modify and refine coarse as-rolled or forged structures.
2. Improve hardening characteristics by refining grain size and homogenizing microstructure.
3. Improve machining characteristics. This treatment is especially beneficial for 0.15–0.40% carbon steels.

Annealing—When the term "annealing" is applied without qualification, the term implies full annealing. Full annealing consists of austenitizing [the process of forming austenite by heating a ferrous alloy into the transformation range (partial austenitizing) or above the transformation range (complete austenitizing)] and then cooling uniformly and slowly, through the transformation range. In isothermal annealing, the heating is the same as used for a full anneal, but the steel is held for a given time at a constant temperature in the transformation range before proceeding to a constant uniform cooling. These practices produce a coarse pearlitic structure which greatly improves machinability of medium carbon steels. Spheroidizing is an annealing process which under suitable conditions of temperature and time produces a spheroidal or globular form of carbide in steel and is recommended prior to machining steels higher than 0.60% carbon.

In addition to producing desired mechanical properties, improving machinability, and obtaining the desired microstructure, the various forms of annealing are also used to improve the cold forming properties of steels.

Time-temperature cycle used and microstructure obtained for the annealing process have a broad meaning to metallurgists. For example, the following terms are all means of identifying a type of annealing: bright anneal, black anneal, box anneal, flame anneal, isothermal anneal, process anneal, recrystallization anneal, spheroidizing, and full anneal. Definitions for the various annealing processes are given in SAE J415.

Carbon Restoration—Carbon restoration or carbon correction is a special thermal treatment for restoring carbon to the decarburized skin normally found on all grades of hot rolled, cold drawn, or cold drawn and annealed steel products. The process was originally applied to medium carbon steels where substantial differences in carbon content can occur between the base metal and the decarburized zone. The intent was to adjust the carbon potential of the furnace atmosphere to the carbon content of the steel being treated and, thus, the term "carbon restoration" came into use. More recent usage has found the process applied to low and high carbon steels as well as the medium carbon grades. Current practice also shows some application for products with an enrichment of the surface carbon content slightly above the base analysis. The principal application of the carbon restored product is in those cases in which the full hardness is desired on the as-rolled or drawn surface after a heat treating operation.

This special treatment consists of a gas carburizing process usually carried out at the steel mill or cold finishing plant in which time, temperature, and carbon potential of the atmosphere are so controlled that carbon content at the surface is at least as high as the minimum product analysis limit for the grade of steel being treated. Carbon restoration is normally limited to a depth of approximately 0.015 in (0.38 mm). Requirements and limits are generally agreed upon between producer and user and are usually determined by chemical analysis, microscopic examination or hardness tests. Dependent upon requirements and method of production, a shallow outer layer of essentially carbon free material may be present up to approximately 0.001 in (0.025 mm) deep. Because of its shallowness, this condition is normally not considered to be detrimental. Subsequent heat treating by austenitizing and quenching will usually obliterate this condition. The producer should be consulted if this condition is not acceptable.

The process is carried out in either a batch or continuous furnace, suitably instrumented to provide the necessary control. As in any process of this type, some leeway or tolerance is necessary to make the operation commercial. Therefore, the carbon content at the surface of the treated stock is often higher than that of the base stock. One of the important controls in this process is to avoid excessive carbon content in the restored layer, as it is a most important consideration in the application of the product. The higher the carbon in the restored layer, the greater the sensitivity of the product to cooling rate after restoration. Excessive surface hardness may result unless suitable precautions are taken. If the product is to be machined, this higher carbon content may also result in an excess of carbides in the restored layer when the material is controlled cooled for best machinability of the unrestored portion of the product. It is sometimes necessary, therefore, to perform a second thermal treatment to generate the optimum structure for subsequent operations: machining, cold extrusion, etc.

Although carbon restoration can be applied to any product that the available equipment can accommodate, its usual application is to bars and rods in either coils or cut lengths. The carbon restored product will approximate the mechanical properties of annealed bars or rods of the base carbon level. If they are cold drawn after carbon restoration, the product will have the appearance, characteristics, and mechanical properties of cold drawn material as given in SAE J414, except that it is essentially free of decarburization. In any application, it is well to keep in mind that the surface condition of the carbon restored product with respect to seams is the same as that of the hot rolled or cold drawn stock with which the process started.

TABLE 1—TYPICAL TREATMENTS FOR CASE HARDENING GRADES OF CARBON STEELS

SAE Steels[a]	Carbon Temperature, F	Cooling Method	Reheat Temperature, F	Cooling Medium	Carbonitriding, Temperature, F[b]	Cooling Method	Temper, F[c]
1010	—	—	—	—	1450–1650	Oil	250–400
1015	—	—	—	—	1450–1650	Oil	250–400
1016	1650–1700	Water or Caustic	—	—	1450–1650	Oil	250–400
1018	1650–1700	Water or Caustic	1450	Water or Caustic[d]	1450–1650	Oil	250–400
1019	1650–1700	Water or Caustic	1450	Water or Caustic[d]	1450–1650	Oil	250–400
1020	1650–1700	Water or Caustic	1450	Water or Caustic[d]	1450–1650	Oil	250–400
1022	1650–1700	Water or Caustic	1450	Water or Caustic[d]	1450–1650	Oil	250–400
1026	1650–1700	Water or Caustic	1450	Water or Caustic[d]	1450–1650	Oil	250–400
1030	1650–1700	Water or Caustic	1450	Water or Caustic[d]	1450–1650	Oil	250–400
1109	1650–1700	Water or Oil	1400–1450	Water or Caustic[d]	—	—	250–400
1117	1650–1700	Water or Oil	1450–1600	Water or Caustic[d]	1450–1650	Oil	250–400
1118	1650–1700	Oil	1450–1600	Oil	—	—	250–400
1513	1650–1700	Oil	1450	Oil	—	—	250–400
1518	1650–1700	Oil	1450	Oil	—	—	250–400
1522	1650–1700	Oil	1450	Oil	—	—	250–400
1524 (1024)	1650–1700	Oil	1450	Oil	—	—	250–400
1525	1650–1700	Oil	1450	Oil	—	—	250–400
1526	1650–1700	Oil	1450	Oil	—	—	250-400
1527 (1027)	1650–1700	Oil	1450	Oil	—	—	250-400

[a] Generally, it is not necessary to normalize the carbon grades for fulfilling either dimensional or machinability requirements of parts made from the steel grades listed in the table, although where dimension is of vital importance normalizing temperatures of at least 50 F above the carburizing temperatures are sometimes required.

[b] The higher manganese steels such as 1118 and the 1500 series are not usually carbonitrided. If carbonitriding is performed, care must be taken to limit the nitrogen content because high nitrogen will increase their tendency to retain austenite.

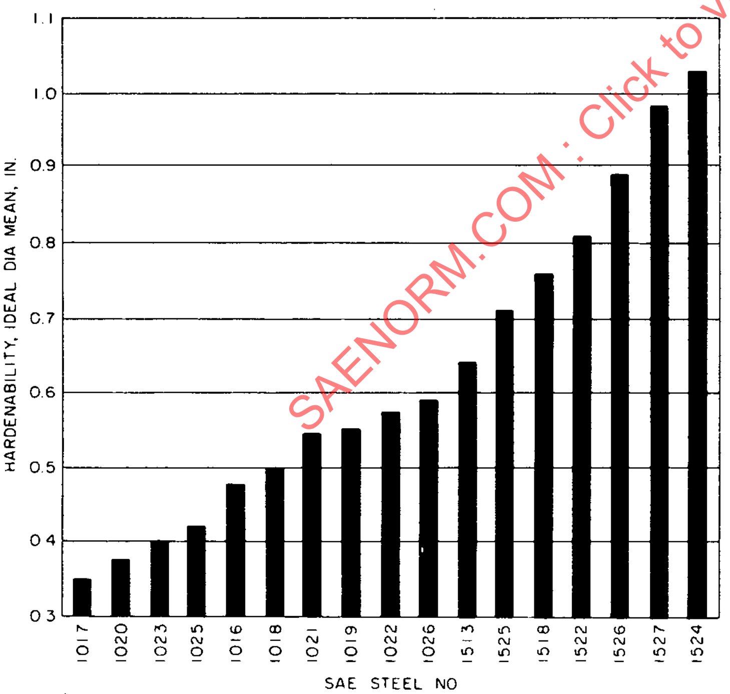
[c] Even where recommended draw temperatures are shown, the draw is not mandatory on many applications. Tempering is generally employed for a partial stress relief and improves resistance to cracking from grinding operations. Higher temperatures than those shown may be employed where the hardness specification on the finished parts permits.

[d] 3% sodium hydroxide.

TABLE 2 — TYPICAL TREATMENTS FOR HEAT TREATING GRADES OF CARBON STEELS

SAE Steels	Normalizing Temperature, F	Annealing Temperature, F	Hardening Temperature, F	Quenching Medium	Temper[a]
1030	—	—	1575–1600	Water or Caustic	To desired hardness
1035	—	—	1550–1600	Water or Caustic	To desired hardness
1037	—	—	1525–1575	Water or Caustic	To desired hardness
1038[b]	—	—	1525–1575	Water or Caustic	To desired hardness
1039[b]	—	—	1525–1575	Water or Caustic	To desired hardness
1040[b]	—	—	1525–1575	Water or Caustic	To desired hardness
1042	—	—	1500–1550	Water or Caustic	To desired hardness
1043[b]	—	—	1500–1550	Water or Caustic	To desired hardness
1045[b]	—	—	1500–1550	Water or Caustic	To desired hardness
1046[b]	—	—	1500–1550	Water or Caustic	To desired hardness
1050[b]	1600–1700	—	1500–1550	Water or Caustic	To desired hardness
1053	1600–1700	—	1500–1550	Water or Caustic	To desired hardness
1060	1600–1700	1400–1500	1575–1625	Oil	To desired hardness
1074	1550–1650	1400–1500	1575–1625	Oil	To desired hardness
1080	1550–1650	1400–1500[c]	1575–1625	Oil[d]	To desired hardness
1084	1550–1650	1400–1500[c]	1575–1625	Oil[d]	To desired hardness
1085	1550–1650	1400–1500[c]	1575–1625	Oil[d]	To desired hardness
1090	1550–1650	1400–1500[c]	1575–1625	Oil[d]	To desired hardness
1095	1550–1650	1400–1500[c]	1575–1625	Water and Oil	To desired hardness
1137	—	—	1550–1600	Oil	To desired hardness
1141	—	1400–1500	1500–1550	Oil	To desired hardness
1144	1600–1700	1400–1500	1500–1550	Oil	To desired hardness
1145	—	—	1475–1500	Water or Oil	To desired hardness
1146	—	—	1475–1500	Water or Oil	To desired hardness
1151	1600–1700	—	1475–1500	Water or Oil	To desired hardness
1536	1600–1700	—	1500–1550	Water or Oil	To desired hardness
1541 (1041)	1600–1700	1400–1500	1500–1550	Water or Oil	To desired hardness
1548 (1048)	1600–1700	—	1500–1550	Oil	To desired hardness
1552 (1052)	1600–1700	—	1500–1550	Oil	To desired hardness
1566 (1066)	1600–1700	—	1575–1625	Oil	To desired hardness

[a] Even where recommended draw temperatures are shown, the draw is not mandatory on many applications. Tempering is generally employed for a partial stress relief and improves resistance to cracking from grinding operations. Higher temperatures than those shown may be employed where the hardness specification on the finished parts permits.
[b] Commonly used on parts where induction hardening is employed. However, all steels from SAE 1030 up may have induction hardening applications.
[c] Spheroidal structures are often required for machining purposes and should be cooled very slowly or be isothermally transformed to produce the desired structure.
[d] May be water or brine quenched by special techniques such as partial immersion or time quenched; otherwise they are subject to quench cracking.



BASIS OF CALCULATION.
NO 7 GRAIN SIZE
MEAN CARBON OF GRADE
MEAN MANGANESE OF GRADE

FIG. 1—SELECTION OF CARBURIZING GRADES OF CARBON STEEL ON RELATIVE HARDENABILITY BASIS

Case Hardening—The process as considered in this report refers to the various dry or pack carburizing methods as well as to the processes utilizing gases or molten baths including nitriding and carbonitriding.

There are two methods of proceeding after carburizing: (1) quenching directly and (2) cooling slowly or box cooling.

The first method involves removal of the work from the furnace or from the carburizing box and quenching the parts while they are at or slightly below the carburizing temperature or by direct quenching from gas carburizing furnaces.

The second method allows the work to cool slowly without any quenching, in the box or container or in a cooling chamber provided in the furnace. The work is subsequently austenitized and quenched in either water or oil.

The relative value of these two methods is dependent upon the type of steel treated, the method of carburizing, the kind of furnace installation, and the mechanical properties desired.

Tempering of parts after carburizing, cyaniding, and activated bath treatments is sometimes omitted in commercial practice, but is included in the accompanying recommendations as being in accord with good heat treating practice.

Parts carburized in activated baths should be treated similarly to other carburized work and may be given any of the hardening treatments shown under the specific steels.

CHARACTERISTICS OF PLAIN CARBON STEELS

SAE 1005, 1006, 1008, 1010, 1011, 1012, 1013, 1015

Group I—These steels are the lowest carbon steels of the plain carbon type and are selected when cold formability is the primary requisite. They are produced as rimmed, semikilled or capped, and killed steels. Rimmed steel is used for sheet and strip where excellent surface finish or good drawing qualities are required. Rimmed steel is also used for cold headed wire products. Semikilled and capped steels represent intermediate deoxidizing practices. Capped steels are used for sheet, strip and wire products, and semikilled steels are used for structural steel applications. Aluminum killed steel is used for some difficult stampings or where nonaging properties are needed. Killed steels should be used for hot forging or heat treating applications.

These steels have relatively low tensile values and should not be selected when strength is important. Within the carbon range of the group, strength and hardness will increase with increase in carbon and with cold work. Such increases in strength are at the sacrifice of ductility or the ability to withstand cold deformation.

When under 0.15% carbon, the steels are susceptible to grain growth, causing brittleness and surface roughness in subsequent forming which may occur as the result of cold work followed by heating to elevated temperatures. Consequently, if cold worked parts formed from these steels are to be later heated to temperatures in excess of 1100 F, the user should exercise care to avoid brittleness. If the coarse grain condition develops, it can be overcome by heating the parts to a temperature well in excess of the upper critical point, approximately 1750 F minimum to 1850 F maximum.

The machinability of bar, rod, and wire products in this group is improved by cold drawing. In general, these steels are considered suitable for welding or brazing.

SAE 1016, 1017, 1018, 1019, 1020, 1021, 1022, 1023, 1025, 1026, 1029, 1030, 1513, 1518, 1522, 1524(1024), 1525, 1526, 1527(1027)

Group II—Steels in this group have increased strength and hardness and reduced cold formability compared to the lowest carbon group. For heat treating purposes, they are commonly known as carburizing or case hardening grades. Killed steel is preferred for forgings and when uniform response to heat treatment is required. Semikilled or rimmed steel may be indicated for other uses depending on the combination of properties desired. Rimmed steels can ordinarily be supplied up to 0.25% carbon.

Selection of one of these steels for carburizing applications depends on the nature of the part, the properties desired, and the processing practices preferred. Increase in carbon content of the base steel results in greater core hardness with a given quench. Increase in manganese improves the hardenability of both the core and the case; in carbon steels, this is the only change in composition that will increase case hardenability. The information in Fig. 1 indicates the calculated hardenability of this group and can be used as a guide for the selection of a steel grade of appropriate hardenability.

In this group, the intermediate manganese grades (0.60 to 1.00) machine better than the lower manganese grades. For carburizing applications, SAE 1016, 1018, and 1019 are widely used for water quenched parts. SAE 1022 and the 1500 series in this group, are used for heavier sections or with thin sections where oil quenching is desired. SAE 1527 (1027) is used for parts given a light case to obtain satisfactory core properties, without drastic quenching. SAE

1025, 1029, and 1030, while not usually regarded as carburizing types, are sometimes used in this manner for larger sections or where greater core hardness is needed.

In cold formed or headed parts, the lowest manganese grades offer the best formability at their carbon level. The next higher manganese types (SAE 1018, 1021, and 1026) provide increased strength.

In general, these steels may be considered as suitable for welding or brazing. These steels are used for numerous forged parts. Forgings usually machine better in the as-forged or normalized condition compared with an annealed condition.

SAE
1030
1034
1035
1037
1038
1039
1040
1042
1043
1044
1045
1046
1049
1050
1053
1536(1036)
1541(1041)
1547(1047)
1548(1048)
1551(1051)
1552(1052)

Group III—Steels of the medium carbon type are selected for uses where their higher mechanical properties are needed, and are frequently further hardened and strengthened by heat treatment or by cold work. These grades are produced as semi-killed or capped, and killed steels. Steels in this group are suitable for a wide variety of automotive applications. Selection of the particular carbon and manganese level is governed by a number of factors. Increase in mechanical properties required, section thickness, or depth of hardening, ordinarily necessitates either higher carbon or a higher manganese, or both. The heat treating practice used, especially the quenching medium, also has a great effect on the steels selected. In general, any of the grades over 0.30% carbon may be induction or flame hardened.

The lower carbon and manganese steels in this group find wide usage for certain types of cold formed parts. In practically all cases, the parts cold formed from these steels are generally annealed or normalized prior to use. Stampings are usually limited to flat parts or simple bends. The higher carbon grades are frequently cold drawn to specified mechanical properties for use without heat treatment for some applications.

All of these steels can be used for forgings, the selection being governed by the section size and the mechanical properties desired after heat treatment. Thus, SAE 1030 and 1035 are used for many small forgings where moderate properties are desired. SAE 1536 (1036) is used for more critical parts where a higher strength level and better uniformity is essential. The SAE 1038, 1052, 1053, and the 1500 groups are used for larger forgings. They are also used for small forgings where high hardness after oil quenching is desired. Suitable heat treatment is necessary on forgings from this group to provide machinability.

These steels are also widely used for parts machined from bar stock. They are used both with and without heat treatment, depending upon the application and the level of properties needed. As a class, they are considered good for normal machining operations. It is also possible to weld these steels by most commercial methods, but precautions should be taken to avoid cracking from rapid heating or cooling.

SAE
1055
1059
1060
1064
1065
1069
1070
1074
1075
1078
1080
1084
1085
1086
1090
1095
1561(1061)
1566(1066)
1572(1072)

Group IV—Steels in this group are of the high carbon type which are used for applications where the higher carbon is needed to improve wear characteristics and where strength levels required are higher than those attainable with the lower carbon groups.

In general, cold forming methods are not practical with this group of steels, being limited to flat stampings and springs coiled from small diameter wire. Practically all parts from these steels are heat treated before use. Variations in heat treating methods are required to obtain optimum properties for particular composition and application.

Typical uses in the spring industry include SAE 1065 for pretempered wire, SAE 1064 for small washers and thin stamped parts, SAE 1074 for light, flat springs formed from annealed stock, and SAE 1080 and 1085 for thicker flat springs. SAE 1085 is also used for heavier coiled springs.

Because of good wearing properties when properly heat treated, the high carbon steels find wide usage in the farm implement industry. Typical applications are plow beams, plow shares, scraper blades, discs, mower knives, and harrow teeth.

CHARACTERISTICS OF FREE CUTTING CARBON STEELS

This class of steels is intended for those uses where improved machinability is desired as compared with carbon steels of similar carbon and manganese content. Machinability refers to the effects of hardness, strength, ductility, grain size, microstructure, and chemical composition upon the cutting tool wear, chip formation, ease of metal removal and surface finish quality of the steel being cut. Sulfur, sulfur and phosphorus combination, and lead additions to carbon steels are made for the sole purpose of decreasing machining costs. Lower costs are achieved either by increased production through greater machining speeds and improved tool life, or by eliminating secondary operations through an improvement in finish. Sulfur and phosphorus additions result in some sacrifice of cold forming properties, weldability, and forging characteristics, whereas lead additions have very little effect on these characteristics. The addition of bismuth, selenium, or tellurium are known to further enhance the machinability of free-cutting steels, but SAE standard grade designations have not been assigned to these steels.

SAE
1110
1111
1112
1113
12L13
12L14
1215

These steels are nonkilled free-machining screw stock grades. They have excellent machining characteristics and are used for a wide variety of machined parts. While of excellent strength in the cold drawn condition, they have an unfavorable property of cold shortness. They are also subject to nonuniformity, particularly when made as Bessemer steels. These steels may be cyanided or carburized, but when best response to heat treating is necessary, killed open hearth or killed electric furnace steels are recommended, although killed steels are not recommended for best machinability. Machinability improves within the 1100 series groups as sulfur goes up. Sulfur combines mostly with the manganese in steel and precipitates as sulfide inclusions. These inclusions favor machining by causing the formation of a broken chip and by providing a built-in lubricant that prevents the chips from sticking to the tool and undermining the cutting edge. By minimizing this adherence, less power is required, finish is improved, and the speed of machining may often be doubled as compared with a similar nonresulfurized grade. The 1200 series steels are both rephosphorized and resulfurized. Phosphorus is soluble in iron and promotes chip breakage in cutting operations through increased hardness and brittleness. Like carbon, an excessive amount of phosphorus could raise strength and hardness levels so high as to impair machinability. Hence, the 1200 series phosphorus content is limited to either a 0.04–0.09% or 0.07–0.12% range and carbon is limited to 0.13% max for the same reason. Lead is insoluble in steel, dispersed microscopically in the rolled product. These lead particles act as a lubricant helping to prevent tool buildup during machining and to serve as chip breakers in a manner similar to sulfide inclusions. The lead addition in 12L13 and 12L14 augments the effect of sulfur, permitting a further increase of machining speed and better finish. Economic reasons usually limit leaded resulfurized steels to high speed screw machining products wherein the superior machinability of the steel can be used to the fullest extent.

SAE
1108
1109
1116
1117
1118
1119

Steels in this group are used where a combination of good machinability and response to heat treatment is needed. The lower carbon varieties are used for small parts which are to be cyanided or carbonitrided. SAE 1117, 1118, and 1119 carry more manganese for better hardenability, permitting oil quenching after case hardening heat treatments in many instances. These steels are available with lead added to further enhance machinability.

SAE
1132
1137
1140
1141
1144
1145
1146
1151

This group of steels has characteristics comparable to carbon steels of the same carbon level, except for changes as noted previously.

They are widely used for parts where a large amount of machining is necessary, or where threads, splines, or other operations offer special tooling problems. SAE 1137, for example, is widely used for nuts, bolts, and studs with machined threads. The higher manganese SAE 1132, 1137, 1141, and 1144 offer greater hardenability, the higher carbon types being suitable for oil quenching for many parts. All these steels may be selectively hardened by induction or flame heating if desired.

These steels are available with lead added to further enhance the machinability.

COMMON CONSTRUCTIONAL ALLOY STEELS (OTHER THAN STAINLESS AND AUSTENITIC)

A steel is classified as an alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: manganese 1.65%, silicon 0.60%, copper 0.60%; or, when there is specified a definite range or a minimum quantity of chromium (up to 3.99%), nickel, molybdenum, aluminum, cobalt, columbium, titanium, tungsten, vanadium, or zirconium.

The principal uses for alloying elements in the common construction steels are:

1. To develop maximum mechanical properties with minimum distortion and cracking.
2. To develop to a lesser degree special qualities such as resistance to tempering, increased toughness, low notch sensitivity, better machinability in the hardened and tempered condition than possessed by a carbon steel of equivalent carbon content similarly heat treated.

Alloy steels are generally not specified for use without appropriate heat treatment. Some special properties which certain alloying elements influence are: retardation of transformation, lowering of transformation temperature, resistance to creep at elevated temperatures, retention of toughness at subzero temperature, resistance to wear, and effect on hardness and machinability. Other special properties may be imparted by the proper choice of alloying elements.

The HARDENABILITY or response to heat treatment is probably the most important single criterion for the selection of steel. Hardenability is that property of steels which determines the depth and distribution of hardness induced by quenching from above the transformation range. For alloy steels, hardenability is usually measured by the end quench test described in SAE J406. This test provides a comparison of the hardenability of various steel compositions and permits the determination of variations from one heat to another of the same composition or of the variations in different parts of the same heat. In other words, the end quench hardenability is a convenient summation of all of the characteristics which determine the depth and distribution of hardness in a particular material. By tempering the end-quench test bar, the final hardness of the product produced by quenching and tempering may be predicted.

Hardenability should not be confused with hardness per se or with maximum hardness. The maximum hardness obtainable with any steel quenched at the necessary minimum cooling rate depends only on the carbon content. That is to say, the maximum surface hardness obtainable in hardened steels is governed entirely by the carbon content at the surface. It has been established that, under the conditions of scale free heating, complete solution of excess constituents, either ferrite or carbides, and achievement of critical cooling rate, maximum surface hardness is attained at about 0.60% carbon. Further increase of carbon, speed of quenching, or alloy content does not increase the hardness.

Decarburized, scaled, or overheated material or surfaces that have been quenched at less than the critical cooling rate may not be expected to attain full hardness. Mechanical properties such as yield strength, fatigue strength, and toughness are related to the thoroughness with which the quenching is done. It must be kept in mind that for lower carbon material, or for sections above a certain limiting size (see SAE J406, Fig. 10) the minimum cooling rate necessary for production of maximum surface hardness may be greater than that obtainable by oil quenching and a more drastic quench must be used to obtain expected results.

The term hardening implies that the hardness of the material is increased by suitable treatment, usually involving heating to a suitable austenitizing temperature followed by cooling at a certain minimum rate which depends upon the alloy content. If quenching is complete, the resulting structure is martensite. As indicated previously, its hardness depends upon carbon content of the steel. If the quenching conditions are such that a minimum of 90% of martensite is produced, followed by proper tempering, it may reasonably be expected that the surface hardness and cross-sectional hardness are commercially satisfactory measures of the mechanical properties. If the quenching rate is such that a smaller percentage of martensite is produced (and a correspondingly larger percentage of other transformation products) a corresponding reduction in mechanical properties may be expected. This may be summarized by saying that steels that have the same hardenability may, after quenching and tempering, be expected to have very nearly the same mechanical properties and that, as a result, many different compositions may be used interchangeably to obtain a similar range of mechanical properties in the finished part.

Properties such as case of annealing, degree of hardening from cold working, ease of machining, and some other characteristics may be peculiar to either composition or heat treatment or both. The choice of steel for a given application is more often dictated by the overall economic consideration than by any other factor.

TABLE 3—TYPICAL HEAT TREATMENTS FOR CARBURIZING GRADES OF ALLOY STEELS

SAE Steels[a]	Pretreatments			Carburizing Temperature,[e] F	Cooling Method	Reheat Temperature, F	Quenching Medium	Tempering[f] Temperature, F
	Normalize[b]	Normalize and Temper[c]	Cycle Anneal[d]					
4012 4023 4024 4027 4028 4032	Yes	—	—	1650–1700	Quench in oil[g]	—	—	250–350
4118	Yes	—	—	1650–1700	Quench in oil[g]	—	—	250–350
4320	Yes	—	Yes	1650–1700 1650–1700	Quench in oil[g] Cool slowly	— 1525–1550[i]	— Oil	250–350 250–350
4419 4422 4427	Yes	—	Yes	1650–1700	Quench in oil[g]	—	—	250–350
4615 4617 4620 4621 4626 4718	Yes	—	Yes	1650–1700 1650–1700 1650–1700	Quench in oil[g] Cool slowly Quench in oil	— 1500–1550[i] 1500–1550[h]	— Oil Oil	250–350 250–350 250–350
4720	Yes	—	Yes	1650–1700	Quench in oil	1500–1550[h]	Oil	250–350
4815 4817 4820	—	Yes	Yes	1650–1700 1650–1700 1650–1700	Quench in oil[g] Cool slowly Quench in oil	— 1475–1525[i] 1475–1525[h]	— Oil Oil	250–325 250–325 250–325
5015 5115 5120	Yes	—	—	1650–1700	Quench in oil[g]	—	—	250–350
6118	Yes	—	—	1650	Quench in oil[g]	—	—	325
8115 8615	Yes	—	—					
8617 8620 8622 8625 8627 8720 8822	Yes	—	Yes	1650–1700 1650–1700 1650–1700	Quench in oil[g] Cool slowly Quench in oil	— 1550–1600[i] 1550–1600[h]	— Oil Oil	250–350 250–350 250–350
9310	—	Yes	—	1600–1700 1600–1700	Quench in oil Cool slowly	1450–1525[h] 1450–1525[i]	Oil Oil	250–325 250–325
94B15 94B17	Yes	—	—	1650–1700	Quench in oil[g]	—	—	250–350

[a] These steels are fine grain. Heat treatments are not necessarily correct for coarse grain.

[b] Normalizing temperature should be at least as high as the carburizing temperature followed by air cooling.

[c] After normalizing, reheat to temperature of 1100-1200 F and hold at temperature approximately 1 hr per in. of maximum section or 4 hr minimum time.

[d] Where cycle annealing is desired, heat to at least as high as the carburizing temperature, hold for uniformity, cool rapidly to 1000-1250 F, hold 1 to 3 hr, then air cool or furnace cool to obtain a structure suitable for machining and finish.

[e] It is general practice to reduce carburizing temperatures to approximately 1550 F before quenching to minimize distortion and retained austenite. For 4800 series steels, the carburizing temperature is reduced to approximately 1500 F before quenching.

[f] Tempering treatment is optional. Tempering is generally employed for partial stress relief and improved resistance to cracking from grinding operations. Temperatures higher than those shown are used in some instances where application requires.

[g] This treatment is most commonly used and generally produces a minimum of distortion.

[h] This treatment is used where the maximum grain refinement is required and/or where parts are subsequently ground on critical dimensions. A combination of good case and core properties is secured with somewhat greater distortion than is obtained by a single quench from the carburizing treatment.

[i] In this treatment the parts are slowly cooled, preferably under a protective atmosphere. They are then reheated and oil quenched. A tempering operation follows as required. This treatment is used when machining must be done between carburizing and hardening or when facilities for quenching from the carburizing cycle are not available. Distortion is at least equal to that obtained by a single quench from the carburizing cycle, as described in note e.

The commonly used alloy steels may be divided into two grades:

1. The low carbon carburizing grade.
2. The higher carbon directly hardenable grade.

Carburizing Grades of Alloy Steels

Properties of the Case—The properties of carburized and hardened cases depend upon the carbon and alloy content, the depth of case, the structure of the case, and the degree and distribution of residual stresses. The carbon content of the case depends upon the details of the carburizing process and the response of iron and the alloying elements present to carburization. The original carbon content of the steel has little or no effect upon the carbon content produced in the case. The hardenability in the case, therefore, depends upon the alloy content of the steel and the FINAL carbon content produced by carburizing, but not upon the INITIAL carbon content of the steel.

When heating for hardening results in complete carbide solution in the case, the effect of alloying elements upon the hardenability of the case will in general be the same as the effect of these elements upon the hardenability of the core. An exception is that boron increases significantly the hardenability of the low carbon core, but has little effect upon the hardenability of the higher carbon case. It is also true that some elements which raise the hardenability of the core may tend to produce more retained austenite and consequently somewhat lower indentation hardness in the case.

Alloy steels are frequently used for case hardening because the required surface hardness can be obtained by moderate rates of cooling such as may be secured with an oil quench. This may mean less distortion than would be encountered with water quenching. It is usually desirable to select a steel which will attain a minimum surface hardness of 58 Rockwell C (RC) after carburizing and oil quenching. Where section sizes are large, a high hardenability alloy steel may be necessary, while for medium and light sections, a low hardenability steel will suffice.

In general, the case hardening alloy steels may be divided into three classes so far as the hardenability of the case is concerned. The three classes are: low hardenability such as the 4000, 5000, 5100, 6100, and 8100 series: intermediate hardenability such as the 4300, 4400, 4500, 4600, 4700, 8600, 8800,[1] and 94B00 series; high hardenability such as 4800 and 9300 series. Since the carbon content or hardenability of the case, there is no appreciable difference in the case hardenability of 4815 steel compared with 4820.

The steels having high case hardenability generally have reasonably high core hardenabilities; although, the core hardenability is dependent upon the carbon content of the basic steel as well as the alloy content. These steels are used particularly for carburized parts having thick sections, such as heavy duty truck bevel drive pinions and gears and large roller bearings. Good case properties can be obtained by oil quenching. These steels are likely to have substantial amounts of retained austenite in the case after carburizing and quenching. The amount of retained austenite may be held to reasonable limits by controlling the carbon content of the case to produce near eutectoid case, by refrigerating the parts, or by reheating and quenching after carburizing. Lower case hardenability steels are used in smaller parts which are less heavily loaded. Steels with intermediate case hardenability are used for tractor and automotive gears, piston pins, ball studs, universal crosses, and roller bearings. Satisfactory case hardness should be produced in most cases by oil quenching.

Core Properties—The core properties of the case hardened steels depend upon the carbon and alloy content of the original steel and the severity of the quench. Many of the generally used types of alloy case hardening steels are made with two or more carbon contents so as to provide a choice of core hardness. The most desirable hardness for the core depends upon the design and function of the individual part. In general, where high compressive loads are encountered, relatively high core hardness is beneficial in supporting the case. Low core hardnesses may be desirable where more than normal toughness is essential.

The case hardening steels may be divided into three general classes with respect to hardenability of the core. (For hardenability of individual steels, see SAE J407.) Due to the fact that H bands have not been established for all steels, it is impossible to give an accurate comparative rating of hardenability of all of the steels in any one group. Low hardenability core steels include SAE 4012, 4023, 4024, 4027[2], 4028[2], 4118[2], 4419[2], 4422[2], 4615, 4617, 4626[2], 5015, 5115, 5120[2], 6118[2], and 8615.

Medium hardenability core steels include SAE 4032, 4427, 4620, 4621, 4720, 4815[2], 8617, 8620, 8622 and 8720.

High hardenability core steels include SAE 4320, 4718, 4817, 4820, 8625, 8627, 8822, 9310, 94B15 and 94B17. 94B15 and 94B17 have been classed as high hardenability steels in the core due to the marked effect of boron upon the hardenability of low carbon steels.

Heat Treatment—With few exceptions the alloy carburizing steels are made of fine grain, and most are therefore suitable for direct quenching from the carburizing temperature (1700 F) or from a reduced temperature of 1500–1600 F. If the carburizing is to be done at temperatures above 1700 F and the parts are direct quenched, careful studies should be made of the suitability of the products so treated. Several other types of heat treatment involving single and double quenching are also used for some of these steels. See Table 3.

Directly Hardenable Grades of Alloy Steel—These steels may be considered in five groups on the basis of approximate mean carbon content of the SAE specification. In general, the last two figures of the specification agree with the mean carbon content. Consequently, the heading "0.30–0.37 Mean Carbon Content of SAE Specification" includes steel such as SAE 1330 and 4137.

Mean Carbon Content of SAE Specification, %	Common Applications (See also more detailed discussion below)
0.30–0.37	Heat treated parts requiring moderate strength and great toughness.
0.40–0.42	Heat treated parts requiring higher strength and good toughness.
0.45–0.50	Heat treated parts requiring fairly high hardness and strength with moderate toughness.
0.50–0.60	Springs and hand tools.
1.02	Ball and roller bearings.

It is necessary to deviate from the preceding plan in the classification of the carbon-molybdenum steels. When carbon-molybdenum steels are used, it is customary to specify higher carbon content for any given application than would be specified for other alloy steels, due to the low alloy content of these steels. For example, SAE 4063 is used for the same applications as SAE 4140, 4145, and 5150. Consequently, in the following tables and discussion, the carbon-molybdenum steels have been shown in the groups where they belong on the basis of applications rather than carbon content.

For the present discussion, steels of each carbon content are divided into two or three groups on the basis of hardenability. Transformation ranges and consequently heat treating practices vary somewhat with different alloying elements even though the hardenability is not changed.

0.30–0.37 Mean Carbon Content—These steels are frequently used for water quenched parts of moderate section size and for oil quenched parts of small section size. Typical applications of these steels are connecting rods, steering arms and steering knuckles, axle shafts, bolts, studs, screws, and other parts requiring strength and toughness where section size is small enough to permit obtaining the desired mechanical properties with the customary heat treatment. Steels falling in this classification may be subdivided into two groups on the basis of the hardenability:

Low hardenability steels in the 0.30–0.37 mean carbon content classification include SAE 1330, 1335, 4037, 4130, 5130, 5132, 5135, and 8630. Medium hardenability steels in the 0.30–0.37 mean carbon content classification include SAE 4135, 4137, 8637, and 94B30.

0.40–0.42 Mean Carbon Content—In general, these steels are used for medium and large size parts requiring a high degree of strength and toughness. The choice of the proper steel depends upon the section size and the mechanical properties which must be produced. The low and medium hardenability steels are used for average size automotive parts such as steering knuckles, axle shafts, and propeller shafts. The high hardenability steels are used particularly for large axles and shafts and for large aircraft parts. These steels are usually considered as oil quenching, although some large parts made of the low and medium hardenability classifications may be quenched in water under properly controlled conditions. These steels may be roughly divided into three groups on the basis of hardenability:

1. Low hardenability steels in the 0.40–0.42 mean carbon content classification include SAE 1340, 4047, and 5140.
2. Medium hardenability steels in the 0.40–0.42 mean carbon content classification include 4140, 4142, 50B40, 8640, 8642, and 8740.
3. High hardenability steels in the 0.40–0.42 mean carbon content classification include SAE 4340.

0.45–0.50 Mean Carbon Content—These steels are used primarily for gears and other parts requiring fairly high hardness as well as strength and toughness. Such parts are usually oil quenched, and a minimum of 90% martensite in the as-quenched condition is desirable.

1. Low hardenability steels in the 0.45–0.50 mean carbon content classification include SAE 5046, 50B44, 50B46, and 5145.
2. Medium hardenability steels in the 0.45–0.50 mean carbon content classification include SAE 4145, 5147, 5150, 81B45, 8645 and 8650.
3. High hardenability steels in the 0.45–0.50 mean carbon content classification include SAE 4150 and 86B45.

0.50–0.60 Mean Carbon Content—These steels are used primarily for springs and hand tools. The hardenability necessary depends upon the thickness of the material and the quenching practice.

1. Medium hardenability steels in the 0.50–0.60 mean carbon content classification include SAE 50B50, 5060, 50B60, 5150, 5155, 51B60, 6150, 8650, 9254, 9255, and 9260.

[1]These are borderline cases which might be considered in the group with high case hardenability.

[2]These are borderline cases which might be considered in the next higher hardenability group.

TABLE 4—TYPICAL HEAT TREATMENTS FOR DIRECTLY HARDENABLE GRADES OF ALLOY STEELS

SAE Steels[a]	Normalizing Temperature, F	Annealing[d] Temperature, F	Hardening[e] Temperature, F	Quenching Medium	Temper
1330	1600–1700[b]	1550–1650	1525–1575	Water or oil	To desired hardness
1335, 1340, 1345	1600–1700[b]	1550–1650	1500–1550	Oil	To desired hardness
4037, 4042	—	1500–1575	1525–1575	Oil	To desired hardness
4047	—	1450–1550	1500–1575	Oil	To desired hardness
4130	1600–1700[b]	1450–1550	1500–1600	Water or oil	To desired hardness
4135, 4137, 4140, 4142	—	1450–1550	1550–1600	Oil	To desired hardness
4145, 4147, 4150	—	1450–1550	1500–1550	Oil	To desired hardness
4161	—	1450–1550	1500–1550	Oil	To desired hardness, 700 F, min
4340	1600–1700[b, c]	1450–1550	1500–1550	Oil	To desired hardness
50B40, 50B44, 5046, 50B46	1600–1700[b]	1500–1600	1500–1550	Oil	To desired hardness
50B50, 5060, 50B60	1600–1700[b]	1500–1600	1475–1550	Oil	To desired hardness
5130, 5132	1600–1700[b]	1450–1550	1525–1575	Water, caustic solution, or oil	To desired hardness
5135, 5140, 5145	1600–1700[b]	1500–1600	1500–1550	Oil	To desired hardness
5147, 5150, 5155, 5160, 51B60	1600–1700[b]	1500–1600	1475–1550	Oil	To desired hardness
50100, 51100, 52100	—	1350–1450	1425–1475 1500–1600	Water Oil	To desired hardness
6150	—	1550–1650	1550–1625	Oil	To desired hardness
81B45	1600–1700[b]	1550–1650	1500–1575	Oil	To desired hardness
8630	1600–1700[b]	1450–1550	1525–1600	Water or oil	To desired hardness
8637, 8640	—	1500–1600	1525–1575	Oil	To desired hardness
8642, 8645, 86B45, 8650	—	1500–1600	1500–1575	Oil	To desired hardness
8655, 8660	—	1500–1600	1475–1550	Oil	To desired hardness
8740	—	1500–1600	1525–1575	Oil	To desired hardness
9254, 9255, 9260	—	—	1500–1650	Oil	To desired hardness
94B30	1600–1700[b]	1450–1550	1550–1625	Oil	To desired hardness

[a] These steels are fine grain unless otherwise specified.
[b] These steels should be either normalized or annealed for optimum machinability.
[c] Temper at 1100-1225.
[d] The specific annealing cycle is dependent upon the alloy content of the steel, the type of subsequent machining operations and desired surface finish.
[e] Frequently, these steels, with the exception of 4340, 50100, 51100, and 52100, are hardened and tempered to a final machinable hardness without preliminary heat treatment.

2. High hardenability steels in the 0.50–0.60 mean carbon content classification include SAE 4161, 8655, and 8660.

1.02 Mean Carbon Content—These are straight chromium electric furnace steels used primarily for the races and balls or rollers of antifriction bearings. They are also used for other parts requiring high hardness and wear resistance. The compositions of the three steels are identical except for a variation in chromium with a corresponding variation in hardenability.

1. The low hardenability steel in the 1.02 mean carbon content classification is SAE 50100.

2. The medium hardenability steels in the 1.02 mean carbon content classification are SAE 51100 and 52100.

Heat Treatments—Typical treatments are given in Table 4.

Resulfurized Steel—Some of the alloy steels (SAE 4024 and 4028) are resulfurized to give better machinability at a relatively high hardness.

CHARACTERISTICS OF WROUGHT STAINLESS STEELS

The composition and corresponding physical characteristics of these steels divides them into three broad groups or types:

1. Stainless Chromium-Nickel Austenitic Steels (Not Hardenable)—The first group are high nickel-chromium alloys. They are austenitic at room temperature and higher and cannot be hardened by thermal treatment.

Table 5 gives typical heat treatments for these steels.

SAE 30201 is an austenitic chromium-nickel-manganese stainless steel usually required in flat products. In the annealed condition it exhibits higher strength values than the corresponding chromium-nickel stainless steel (SAE 30301). It is nonmagnetic in the annealed condition but may be magnetic when cold worked. SAE 30201 is used to obtain high strength by work hardening and is well suited for corrosion resistant structural members requir-

TABLE 5—TYPICAL HEAT TREATMENTS FOR GRADES OF CHROMIUM-NICKEL AUSTENITIC STEELS NOT HARDENABLE BY THERMAL TREATMENT

SAE Steels	AISI No.	Treatment No.	Normalizing Temperature, F	Annealing[a] Temperature, F	Hardening Temperature, F	Quenching Medium	Temper
30201	201	1	—	1850–2050	—	Water or air	—
30202	202	1	—	1850–2050	—	Water or air	—
30301	301	1	—	1800–2100	—	Water or air	—
30302	302	1	—	1800–2100	—	Water or air	—
30303F[b]	303	1	—	1800–2100	—	Water or air	—
30304	304	1	—	1800–2100	—	Water or air	—
30305	305	1	—	1800–2100	—	Water or air	—
30309	309	1	—	1800–2100	—	Water or air	—
30310	310	1	—	1800–2100	—	Water or air	—
30316	316	1	—	1800–2100	—	Water or air	—
30317	317	1	—	1800–2100	—	Water or air	—
30321	321	1	—	1800–2100	—	Water or air	—
30325	325	1	—	1800–2100	—	Water or air	—
30330	—	1	—	2050–2250	—	Air	—
30347	347	1	—	1800–2100	—	Water or air	—

[a] Quench to produce full austenitic structure using water or air in accordance with thickness of section. Annealing temperatures given cover process and full annealing as already established and used by industry, the lower end of the range being used for process annealing.
[b] Suffix A denotes steel dffering only in carbon content. Suffix F denotes a free machining steel.

ing high strength with low weight. It has excellent resistance to a wide variety of corrosive media, showing behavior comparable to stainless grade SAE 30301. It has high ductility and excellent forming properties. Due to this steel's work hardening rate and yield strength, tools for forming must be designed to allow for a higher springback or recovery rate. It is used for automotive trim, automotive wheel covers, railroad passenger car bodies and structural members, truck trailer bodies.

SAE 30202, like its corresponding chromium-nickel stainless steel SAE 30302, is a general purpose stainless steel. It has excellent corrosion resistance and deep drawing qualities. It is nonhardenable by thermal treatments but may be cold worked to high tensile strengths. In the annealed condition it is nonmagnetic but slightly magnetic when cold worked. Applications for this stainless steel are hub cap, railcar and truck trailer bodies, and spring wire.

SAE 30301 is capable of developing high tensile strength, while retaining high ductility, by moderate to severe cold working. It is used largely in the cold rolled or cold drawn condition in the form of sheet, strip, and wire. It is nonmagnetic when annealed but is magnetic when cold worked. Its corrosion resistance is not quite equal to SAE 30302. This steel is used for applications requiring a combination of high strength and excellent forming properties such as in structural members, automotive trim, wheel discs, and rings. It is used for flat and wire springs, windshield wiper arms, grills, steering wheel spokes, and similar applications. It is also used for cream separators and milking machine parts and other such products where a combination of formability and resistance to corrosion by food products is needed.

SAE 30302 is the general purpose stainless steel of this type. Its corrosion resistance is superior to that of SAE 30301, and it is the most widely used of all the chromium-nickel stainless and heat resisting steels. It is used for deep drawing largely in the softer tempers. It can be worked to high tensile strength but with lower ductility than SAE 30301. It is nonmagnetic when annealed but is magnetic when cold worked. This steel is used on automotive parts where excellent corrosion resistance and high physical properties or good forming and drawing properties are required. It is used for hub caps, radiator grills, windshield wiper parts such as tension bars and binder strips, hose clamps, antennas, control cables, fender guards, fire walls, and hydraulic tubing. It is used for other similar parts which have severe forming requirements combined with a need for resistance to rusting or tarnishing.

SAE 30303F has elements added to improve its machining and nonseizing characteristics. This steel, the free machining modification of SAE 30302, is recommended for the manufacture of parts produced on automatic machines. It can be forged but requires much more care than is necessary with SAE 30302. Its corrosion resistance is slightly inferior to that of SAE 30302. It is nonmagnetic when annealed but is slightly magnetic when cold worked. It is used for screws, nuts, carburetor parts, aircraft fittings, water pump shafts, and other machined parts requiring some corrosion resistance. It is not recommended for applications involving severe cold working, cold upsetting, or welding.

SAE 30304 is a low carbon steel similar to SAE 30302 but somewhat superior in corrosion resistance and having superior welding properties for certain types of equipment. It is nonmagnetic when annealed but is slightly magnetic when cold worked. It is used for diesel injection pump valve springs, roller chains, parachute hardware, and welded parts that can be heat treated after welding or that are not liable to damage by intergranular corrosion if heat treating after welding is not performed. This steel is also available with 0.03/0.05% carbon for certain applications.

SAE 30305 is similar to SAE 30302 and 30304 but it does not harden as rapidly with cold working as do either of those grades. It also has much less change in magnetic permeability when cold worked. Because of its lower work hardening tendency, it is better suited for spun parts, multiple drawing operations, severe cold heading, and parts requiring large amounts of cold deformation.

SAE 30309 has higher corrosion and oxidation resistance than SAE 30304. It is resistant to oxidation at temperatures up to about 2000 F. It is nonmagnetic when annealed but may be very slightly magnetic when cold worked. It is used primarily in high temperature applications such as thermocouple wells, heat exchangers, glass lehr belts, and aircraft cabin heaters.

SAE 30310 has very high corrosion and heat resisting properties. Like SAE 30309, it resists oxidation at temperatures up to about 2000 F. It is more stable and somewhat stronger at high temperature and is more safely hot worked than SAE 30309. It is nonmagnetic when annealed or cold worked. It is used in such applications as diesel injector cup wipers, jet engine burner liners, and nozzle vanes.

SAE 30316 is similar to SAE 30304 in fabricating qualities and general corrosion resistance. However, it has superior corrosion resistance to other chromium-nickel steels when exposed to sea water and many types of chemical corrodents, especially those of a reducing nature. It also has superior strength at elevated temperatures. It is nonmagnetic when annealed but is slightly magnetic when cold worked. It is used in applications such as wire screens, dye making and chemical processing equipment, and in elevated temperature service, especially where strength is important, up to about 1500 F. This steel is also available with 0.03/0.05% carbon for certain applications.

SAE 30317 is similar to SAE 30316 but with greater corrosion resistance in many environments and with somewhat greater high temperature strength. It is primarily used for paper making equipment.

SAE 30321 has a specified titanium content. Its properties are similar to those of SAE 30304 except that it can be recommended for use in the manufacture of welded parts requiring immunity to intergranular attack and where heat treating after welding is not feasible. It may also be used where temperatures in the range of about 800 to 1650 F are encountered in fabrication or service and where the possibility of intergranular corrosion exists. It is nonmagnetic when annealed but is slightly magnetic when cold worked. It is used for exhaust manifolds, manifold flanges, and high temperature bolts and locknuts.

SAE 30325 is primarily used in hot caustic solutions. It has been used for valve trim, and pump shafting.

SAE 30330 alloy, in the wrought and cast form is used for high temperature oxidation resistance essentially over 1650 F and utilized in the construction of heat treating baskets, similar items, and heat treating furnace parts.

SAE 30347 is similar to SAE 30321 except it contains columbium instead of titanium. This columbian bearing alloy is used in the same applications as SAE 30321 except that it does not cold form as satisfactorily.

*2. **Stainless Martensitic Chromium Steels (Hardenable)***—The second group are chromium alloys that may contain small amounts (up to about 3%) of nickel. They are ferritic at room temperature but become austenitic at elevated temperature and can be rapidly cooled to produce a hard, martensitic structure in the same manner as other hardenable steels are heat treated. As they can be heat treated to produce martensite, they are commonly known as martensitic stainless steels.

SAE 51409 is an 11% chromium alloy developed especially for automotive mufflers and tailpipes. Resistance to corrosion and oxidation is very similar to SAE 51410. It is nonhardenable and has good forming and welding characteristics. This alloy is recommended for mildly corrosive applications where surface appearance is not critical.

SAE 51410 is the general purpose steel of this type. It can be hardened by heat treating to develop a wide range of mechanical properties. 39/41 RC is about the maximum useful hardness obtainable. It has fair machining properties and corrosion resistance, although in this respect, it is inferior to SAE 51430. Best corrosion resistance is obtained in the heat treated condition. It is magnetic in all conditions. It is used in applications requiring high strength combined with moderate resistance to corrosion. Possessing fair strength and good oxidation resistance to about 1200 F, it is used in manifold stud bolts, heat control shafts, steam valves, bourdon tubes, and gun mounts.

SAE 51414 has somewhat better corrosion resistance than SAE 51410. It will attain slightly higher mechanical properties when heat treated than SAE 51410 and will develop a maximum useful hardness of about 41/43 RC. It is magnetic in all conditions. It is used in the form of tempered strip and in bars and forgings for heat treated parts. It is also used for valve trim and stems.

SAE 51416F is similar to SAE 51410. It can be heat treated to a maximum of about 39/41 RC. Elements have been added to improve its machining and nonseizing characteristics at some sacrifice in corrosion resistance and