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SURFACE VEHICLE INFORMATION REPORT

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GENERAL CHARACTERISTICS AND HEAT TREATMENTS OF STEELS

Foreword—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

1. *Scope*—The information and data contained in this SAE Information Report are intended as a guide in the selection of steel types and grades for various purposes. Consideration of the individual types of steel is preceded by a discussion of the factors affecting steel properties and characteristics.

SAE steels are generally purchased on the basis of chemical composition requirements (SAE J403, J404, and J405). High-strength, low alloy (HSLA) steels (SAE J1392 and J1442) are generally purchased on the basis of mechanical properties; different chemical compositions are used to achieve the specified mechanical properties. Because these steels are characterized by their special mechanical properties obtained in the as-rolled condition, they are not intended for any heat treatment by the purchaser either before, during, or after fabrication.

In many instances, as in the case of steels listed in SAE J1268 and J1868, hardenability is also a specification requirement. This information report can be used as a reference for determining the general characteristics and applications of commonly used SAE steels. The use of the typical heat treatments listed in Tables 1 through 7 is recommended. These and other heat treatments commonly used on steel are briefly described at the end of this section.

2. *References*

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. The latest issue of SAE publications shall apply.

All of the heat treatments briefly described in this article are discussed in detail in *Metals Handbook—Ninth Edition—Volume 4—Heat Treating*, published by ASM International.

2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J403—Chemical Compositions of SAE Carbon Steels
SAE J404—Chemical Compositions of SAE Alloy Steels
SAE J405—Chemical Compositions of SAE Wrought Stainless Steels
SAE J406—Methods of Determining Hardenability of Steels
SAE J411—Carbon and Alloy Steels
SAE J1868—Restricted Hardenability Bands for Selected Alloy Steels

3. *Factors Affecting Properties and Characteristics of Steel*

3.1 Hardenability—Hardenability, or response to heat treatment, is one of the most important characteristics of heat-treated steels. Hardenability is the property of steels that determines the depth and distribution of hardness induced by quenching the steel from above the transformation temperature. Hardenability is usually measured by the end quench test described in SAE J406. Specified hardenability bands for standard carbon and alloy steels are shown in SAE J1268 and J1868.

The chemical composition and grain size of the steel completely determine its hardenability with almost all of the elements making varying degrees of contribution. Many elements are discussed in SAE J411; however, carbon, boron, manganese, chromium, and molybdenum have the strongest effect. Boron is a particularly potent hardenability agent. Typical additions in the range of 0.0005 to 0.003% will have a major effect on hardenability. Boron is most effective in lower carbon steels; it becomes less effective as carbon content increases. Carbon-manganese-boron steels generally fill a gap between plain carbon and alloy steels in terms of hardenability. Empirical relationships can be used to calculate or predict the hardenability for a given chemistry of steel. Actual depth and distribution of hardness will depend on quench severity.

Hardenability should not be confused with hardness per se or with maximum hardness. The maximum hardness obtainable with any steel quenched at the critical cooling rate depends only on the carbon content. That is to say, the maximum martensitic hardness obtainable on hardened steels is governed by the carbon content at the surface. It has been established that, under the conditions of scale-free heating, complete solution and achievement of critical cooling rate, maximum hardness is attained at about 0.60% carbon. If the material is decarburized, scaled, or overheated, or if it is quenched at less than the critical cooling rate, full hardness will not be achieved.

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 untempered martensite. If the quenching conditions produce a minimum of 90% martensite, followed by proper tempering, it may be reasonably expected that the surface hardness and the cross-sectional hardness will have achieved the commercial possibilities for that material and section size. Smaller percentages of martensite will result in a corresponding reduction in mechanical properties.

3.2 Grain Size—When used in reference to heat-treated steels, the term grain size implies austenitic grain size. It is an important parameter governing mechanical properties. A fine austenitic grain size will improve toughness, ductility, and fatigue strength, but will reduce hardenability. The inherent austenitic grain size is determined by the choice of deoxidizer or grain refiner used in the steel-making process. With few exceptions, steels to be heat-treated should have a fine austenitic grain size.

Ferritic grain size is a parameter that is important to nonheat-treated steels as it will affect formability, toughness, and ductility. Fine grain steels are stronger but will have less formability and ductility.

3.3 Microstructure—Microstructure means the quantity, size, shape, and distribution of various phases in steel. It depends totally on the chemistry, hardenability, heat treatment, and cooling rates employed. Ferrite, the purest form of iron in steel, is the softest and lowest strength constituent with highest ductility. Martensite, supersaturated solution of carbon in iron, is the hardest. Controlled diffusion of carbon from martensite achieved by controlling the heat treatment (tempering time and temperature) softens the steel and improves ductility. Slow cooling from high temperatures causes the carbon to precipitate out as iron carbide or cementite which is a hard phase. A mixture of ferrite and lamellar or plate-like cementite is called pearlite.

Austenite is a term applied to the solid solution of carbon in gamma iron (or face centered cubic) and is present in carbon steels when they are heated above the A3 transformation temperature. Retained austenite is austenite that remains in the microstructure after a part is quenched from its austenitizing temperature. It is a softer microstructure constituent.

3.4 Cleanliness—Cleanliness is a measure of nonmetallic oxides, sulfides, coarse-nitrides, silicates, and other such inclusions developed during the steel-making process. Depending on their size, shape, population, and distribution, nonmetallic inclusions may adversely affect toughness, ductility, and fatigue properties. Cleanliness is of utmost importance in critical components under high stresses, impact, cyclic loading, or low temperatures.

3.5 Surface Quality—Surface quality, a measure of the surface condition of steel, is important in cyclic loading, contact fatigue, and wear resistance applications. It is also very important in applications requiring surface coating, plating, painting, or aesthetics in exposed parts. Surface conditioning or scarfing of ingots, slabs, blooms, and billets may be utilized to improve surface quality.

3.6 Homogeneity—Chemical and microstructural homogeneity and soundness (absence of voids, pinholes, and porosity) are important in predicting the consistency of product performance and integrity. Proper deoxidation and stirring of molten steel alleviate some of these problems.

4. Characteristics of Plain Carbon Steels

4.1 Group I (SAE 1005, 1006, 1008, 1010, 1012, 1013)—These steels are the lowest carbon steels of the plain carbon type and are selected when cold formability or drawability is the primary requisite. These steels have relatively low tensile values. 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 and consequent brittleness if they are cold worked and subsequently heated to temperatures between 595 °C (1100 °F) and the lower transformation temperature. If coarse grains develop, they can be refined by heating above the A3 transformation temperature and then cooling.

Cold-rolled sheets are made from the lower carbon steels in the group. They have excellent surface appearance and are used in automobile panels, appliances, and so forth. 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 but may suffer strength reductions either locally in the heat affected zone or overall, depending upon process details.

4.2 Group II (SAE 1015, 1016, 1017, 1018, 1019, 1020, 1021, 1022, 1023, 1025, 1026, 1029, 1513, 1522, 1524, 1526, 1527)—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.

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 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.

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

These steels are used for numerous forged parts. In general, these steels are suitable for welding or brazing prior to carburizing. If welding is to be performed after carburizing, the area to be welded must be protected from the carburizing media during the process. An alternative to protection is to machine away the area to be welded after carburizing, but before hardening.

A typical application for carburized plain carbon steel is for parts requiring a hard wear-resistant surface, but with little need for increased mechanical properties in the core; e.g., small shafts, plungers, and lightly loaded gearing.

4.3 **Group III (SAE 1030, 1035, 1037, 1038, 1039, 1040, 1042, 1043, 1044, 1045, 1046, 1049, 1050, 1053, 1536, 1541, 1548, 1551, 1552)—**Steels of the medium carbon type are selected for uses where higher mechanical properties are needed. They are frequently further hardened and strengthened by heat treatment or by cold work. 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 necessitate either higher carbon, 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 nearly all cases, the parts cold formed from these steels are annealed, normalized, or quenched and tempered 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 is used for more critical parts where a higher strength level and better uniformity is essential. The SAE 1038, 1052, 1053, and 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 possible to weld these steels by most commercial methods, but precautions should be taken to avoid cracking from rapid heating or cooling.

4.4 **Group IV (SAE 1055, 1059, 1060, 1065, 1069, 1070, 1074, 1075, 1078, 1080, 1085, 1086, 1090, 1095, 1561, 1566)—**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 as they are 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.

5. ***Characteristics of Free-Cutting Carbon Steels*****—**This class of steel is intended for 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 on cutting tool wear, chip formation, ease of metal removal, and surface finish quality of the steel being cut. 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.

These steels contain sulfur for chip formation and, in the 1200 series, phosphorus to increase the strength and reduce the ductility of ferrite so chips will break up more easily. Calcium is also used to improve shape of the sulfides. The use of other additions such as lead, bismuth, or selenium has declined due to environmental restrictions. Sulfur and phosphorus negatively affect weldability, cold-forming, forging, and so forth. Lead in steel wire causes a poor quality, low-strength welded, or brazed joint. The lower carbon grades can be used for case hardening operations while the grades over 0.30 carbon can be quenched and tempered or induction hardened.

Machinability improves within the 1100 series as sulfur levels increase. Sulfur combines mostly with the manganese 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. Steels high in phosphorus are notoriously notch sensitive. As with carbon, an excessive amount of phosphorus can raise strength and hardness levels so high as to impair machinability. Hence, the 1200 series phosphorus content is limited to either a 0.04 to 0.09% or 0.07 to 0.12% range and carbon is limited to 0.13% maximum for the same reason. 1200 series steels are normally used in applications where ease of machining is the primary requisite. They are not normally heat-treated, but they may be case hardened by carburizing or carbonitriding.

5.1 **Group I (SAE 1117, 1118)—**Steels in this group are used where a combination of good machinability and response to heat treatment is needed. These varieties can be used for small parts that are to be carbonitrided. SAE 1117 and 1118 carry more manganese for better hardenability, permitting oil quenching after case hardening heat treatments.

5.2 **Group II (SAE 1137, 1140, 1141, 1144, 1146)—**This group of steels has characteristics comparable to carbon steels of the same carbon content. They are widely used for parts where a large amount of machining is necessary, or where threads, splines, grooves, 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 1137, 1141, and 1144 offer greater hardenability, the higher carbon types being suitable for oil quenching for many parts. All of these steels may be selectively hardened by induction or flame heating, if desired.