The Engineering Society For Advancing Mobility Land Sea Air and Space®

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SAE J401 DEC88

Selection and Use of Steels

SAE Information Report
Reaffirmed December 1988

The Engineering Society For Advancing Mobility Land Sea Air and Space ®
400 COMMONWEALTH DRIVE, WARRENDALE, PA 15096

MATERIALS REPORT

SAE J401

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Ø SELECTION AND USE OF STEELS

1. STEEL DESIGNATION:

The SAE system of designating steels, described in SAE J402, classifies and numbers them according to chemical composition. In the case of the high strength, low alloy steels in SAE J410 and the high strength carbon and alloy die drawn steels in SAE J935, minimum mechanical property requirements have been included in the designations. In addition, hardenability data on most of the alloy steels and some of the carbon steels will be found in SAE J1268.

The steels so designated have been developed cooperatively by producers and users and have been found through long experience to cover most of the wrought ferrous materials used in automotive vehicles and related equipment. Because the SAE designations provide a convenient way for engineers to state briefly but clearly the chemical composition, and in some instances, some of the properties desired, they are widely recognized and used throughout the United States and in many other countries.

It should be recognized that the many technological variations of the steel-making process, coupled with the diverse requirements of the numerous processes used in the manufacture of components, make it impossible for these brief SAE designations to completely describe any steel. A specification consists of a designation and whatever supplementary information may be necessary to describe the product desired. For this reason these designations should never be referred to as specifications, nor should they be used for purchasing unless accompanied by the necessary supplementary information to describe commercially the product desired.

2. SELECTION:

A material for any particular use is properly selected when a part made from it satisfies the engineering and service requirements at the lowest final cost. Many factors enter into such a selection, the principal ones being: the mechanical and physical properties required to satisfy the engineering and service requirements; the cost and availability of the material; the cost of processing, such as machining, welding, or heat treating; and the suitability of available processing equipment or the cost of new equipment that must be purchased. These considerations require input from the designer, the test engineer, the metallurgist, the manufacturing or process engineer, and the buyer. Since the pertinent factors vary widely, the correct choice of material for any set of conditions is the one that provides the best balance among all the factors. Thus, a categorical selection for a given part is impractical. The successful use of different steels for similar parts is ample evidence of the complexity of the problem.

3. STATIC LOADING:

Selection of materials is least complicated when the loading is static or the frequency of application of load during the expected life is so low that the possibility of fatigue may be neglected. In such cases, yield strength or the more precisely determined proportional limit is the strength criterion, together with a determination of the section modulus (stiffness) required to keep the stress within the elastic range. The finished structure is designed to operate only within the elastic range of its members; no part is intended to deform plastically under any reasonably expected overload.

The opposite is true in those cases where the structure is intended to provide maximum protection with minimum weight for only one major load application as in roll-over or falling object protection structures (ROPS and FOPS). Here the maximum yield strength and the section modulus are so controlled that the structure will plastically deform under load; that is, it is the major energy absorber in the system and is an expendable item.

4. DYNAMIC LOADING:

When the loading is primarily dynamic (cyclic) as is the case in many automotive applications, resistance to fatigue becomes the foremost consideration. When tested as a rotating beam (R. R. Moore) specimen with a surface finish of 10 µin (0.2 µm) or less, the fatigue resistance of any steel, regardless of composition or condition, is more closely related to tensile strength than to any other property. For material up to about 175 000 psi (1210 mPa) the fatigue strength is about 50% of the tensile strength. For higher strength materials, this percentage decreases somewhat and the test results show increased scatter. See also Reference 8.

4. (Continued):

The fatigue limits thus determined are seldom realized in practice because few actual components are so highly finished, that is, free from surface imperfections in critical areas. If the surface of a critically stressed area is as-cast, as-forged, turned only, or decarburized, the fatigue strength may be reduced. Because they concentrate stress, undersize fillets, undercuts, notches, grooves, tool marks, weld cracks, and the like are highly detrimental. Since the effect increases as tensile strength rises, an attempt to increase fatigue strength by increasing tensile strength may actually decrease component life. The remedy lies in improving the design to remove the cause of the damaging stress concentration.

If the stress concentration is caused by excessive elastic deflection under load then the best and, usually, the least expensive way to remedy the difficulty is to either increase the section modulus of the affected area or decrease that of the adjacent areas, or both, the effect in either case being to reduce the deflection and the unit stress in the troubled area. This is because the elastic modulus (Young's modulus) is, for all practical purposes, the same for all steels regardless of composition or condition.

It is well established that the fatigue strength of a component can often be substantially increased by inducing compressive stresses into the outer layer in critical areas in such a way that a significant portion of the induced stress is retained after processing. In service the algebraic sum of this residual compressive stress and the applied stress (usually a tensile stress from a bending or a torsional load) results in a net decrease in the stress on the component, thus increasing fatigue life. Processes commonly used to induce residual compressive stresses are shot peening, cold rolling of radii, induction hardening, shell hardening, nitriding, carbonitriding, and, sometimes, carburizing and hardening.

The corollary of the above is that any process or condition that leaves a residual tensile stress in the outer layer of a component is usually detrimental to fatigue life.

SAE J1099, Technical Report on Fatigue Properties, gives some basic information on the approach to fatigue problems. The fact remains, however, that the surest guide to satisfactory fatigue resistance of a part or a structure is life testing either in actual service or under conditions that closely simulate it. The method is expensive, but the alternative can be a disappointing lack of product reliability.

5. BRITTLE FRACTURE:

When improved resistance to failure by brittle fracture is of concern, toughness becomes an important additional consideration. The principal factors in determining if a material behaves in a tough or brittle manner are: (1) the type of load, static or dynamic, and its magnitude; (2) the rate of loading; (3) the stress pattern, uniaxial, biaxial or triaxial; (4) the minimum service temperature; (5) the metallurgical history of the material, rimmed, semi-killed or killed and its microstructure, including grain size; (6) the tensile strength; and (7) the section size, rolling direction and surface condition. In the structure in which the material is used, the presence of stress raisers of any kind from any cause will affect the behavior of the material. A detailed discussion of these factors and their interrelationship is beyond the scope of this information report. See References 5 and 6.

6. NOTCH TOUGHNESS:

The most commonly used measure of toughness is the charpy V-notch (CVN) test, a single-blow impact test employing a sharply notched test bar and a high strain rate. The results are reported in foot-pounds (joules) absorbed in breaking the specimen or by measuring the lateral expansion at the fracture site. The test has two serious limitations: first, it is not applicable to material less than 0.10 in (2.5 mm) thick and, second, because the strain rate employed is considerably higher than that normally encountered in commercial applications of steel, the results cannot be used directly in design calculations, and it is often impossible to correlate them with service.

The test is of value in two areas: first, many times, it is successfully used to compare the relative toughness of different conditions of the same steel or of different steels in any desired condition; second, it is used to determine the temperature at which the ductile-brittle transition occurs. This measure of behavior is used to provide some degree of insurance against unexpected catastrophic failure when selecting steels for low-temperature applications, provided the charpy values are related to a particular design which has been tested at the service temperature. This correlation is, perhaps, the most important use of the test, and it should, wherever and whenever possible, precede the addition of CVN requirements to a specification.

The fact remains that many machines and structures operate successfully at low temperatures without any consideration of the notch-toughness level of the material used simply because the test is so much more severe than the application that the added protection is not needed. Since the addition of a notch-toughness requirement to the material specification increases cost, failure to carefully consider the need for it can mean unnecessary material cost.

7. FRACTURE TOUGHNESS:

This test is growing in favor for evaluating the toughness of materials and structures subjected to various loading rates. It is based on the concepts of linear elastic fracture mechanics and its results are considered to be a constant of the material for a given temperature and loading rate under conditions of plane strain. The results are used to determine the stress required to cause a flaw of any given size, such as a scratch, a crack, or any unfused portion of the weld, to propagate unstably.

The concepts of fracture mechanics have also been applied extensively to analyze subcritical crack growth rates under static loading in an aggressive environment (stress-corrosion cracking), cyclic loading in a noncorrosive environment (fatigue), and under the combined effects of cyclic loading and aggressive environment (corrosion fatigue).

8. REFERENCES:

More detailed information on the characteristics, application and heat treatment of SAE steels is given in the SAE Information Report J412 in the SAE Handbook. References 1-4 are representative of meaningful articles that have appeared in other publications. References 5 and 6 deal with the various tests for toughness and their significance. Reference 7 details the application of linear elastic fracture mechanics.

1. R. F. Kern, "Selection of Steels for Heat Treated Parts." Metal Progress, Vol. 94, No. 5, November 1968, p. 60, and No. 6, December 1968, p. 71.

2. C. F. Weymueller, "Selecting Steels for Heat Treated Auto and Truck Parts." Metal Progress, Vol. 94, No. 4, October 1968, p. 125.

3. M. M. Fox, "Saving by Substituting for Alloy Steels." Metal Progress, Vol. 96, No. 6, December 1969, p. 95.

4. R. F. Kern, "Selecting Steels for Carburized Gears." Metal Progress, Vol. 102, No. 1, July 1972, p. 53.

5. "The Selection of Steel for Notch Toughness." ASM Handbook, 8th Edition, Vol. 1, p. 225, American Society for Metals, Metals Park, OH, 1961.

6. "Toughness and Fracture Mechanics." ASM Handbook, 8th Edition, Vol. 10, p. 30, American Society for Metals, Metals Park, OH, 1975.

7. S. T. Rolfe and J. M. Barsom, "Fracture and Fatigue Control in Structures, Applications of Fracture Mechanics." Prentiss-Hall, 1977.

8. "Fatigue Design Handbook." SAE Publication AE-4, SAE, Warrendale, PA 15096, 1968.

RATIONALE:

Not applicable.

RELATIONSHIP OF SAE STANDARD TO ISO STANDARD:

Not applicable.

REFERENCE SECTION:

R. F. Kern, "Selection of Steels for Heat Treated Parts." Metal Progress, Vol. 94, No. 5, November 1968, p. 60, and No. 6, December 1968, p. 71.

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"Fatigue Design Handbook." SAE Publication AE-4, SAE, Warrendale, PA 15096, 1968.

APPLICATION:

Not applicable.

COMMITTEE COMPOSITION:

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