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Categorization and Properties of Low-Carbon Automotive Sheet Steels		

## RATIONALE

J2329 has been reaffirmed to comply with the SAE five-year review policy.

### Foreword

- a. **Categorization**—Mechanical property, surface quality, and manufacturing requirements for automotive sheet steels, together with improvements in steel manufacturing and processing techniques, have made earlier methods of categorizing sheet steel obsolete. Classification of steel quality by deoxidation process is no longer appropriate. Uniformity of material properties is of major importance. This SAE Recommended Practice furnishes a categorization procedure to aid in selecting low-carbon sheet steel for identified parts and fabrication processes.

It is necessary for both the steel user and producer to know the mechanical properties and the range in these properties. There is a wide variety of parts within the automotive industry, and different levels of specific mechanical properties, e.g.,  $r_m$  value,  $n$  value, yield strength, and total elongation may be required for specific applications. With the recent advent of computer simulation of the steel deformation process during die design, it is vitally important that certain minimum levels of formability exist within a particular category or grade of steel. It is suggested that the steel user and steel supplier consult early in the part and die design process to determine specific grade requirements. In the past, yield strength has been chosen as a major discriminator of the categorization system since this property has meaning to both automotive and steel engineers, this document builds on that rationale but also addresses certain minimum elongation,  $n$  value and  $r_m$  value discriminators. In this document, low-carbon sheet steel is classified by 5 grade levels with yield strength, tensile strength, elongation,  $r_m$  value, and  $n$  value requirements. In addition, surface quality and/or aging characteristics are an important consideration. Thus, the categorization system is as follows:

1. The first two alphabetic characters will designate hot-rolled or cold-rolled method of manufacture.
  2. The third numeric character defines grade based on yield strength range, minimum tensile strength, minimum percent elongation, minimum  $r_m$  value, and minimum  $n$  value.
  3. The fourth alphabetic character classifies the steel type with regards to surface quality and/or aging character.
  4. An optional fifth alphabetic character may restrict the carbon content to a minimum of 0.015%.
- b. **Properties**—The mechanical properties of the substrate (ductility, work hardening, and plastic anisotropy) determine the ability of the steel to withstand strain in various modes of forming (such as stretching and deep drawing). Mechanical properties are important to the formability of uncoated and coated steels, both cold-rolled and hot-rolled. Compared with uncoated steel sheets, hot-dip and electroplated coated steels have different characteristics which may affect automotive manufacturing operations such as stamping, welding, and painting. Material related factors greatly influence the formability of coated sheets. Coating characteristics although less important to forming than the substrate, can have a significant influence on forming because the coating can affect metal flow over tool and die surfaces.

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Definition of steel sheet properties is contained in Appendix A.

1. **Scope**—This SAE Recommended Practice establishes mechanical property ranges for low-carbon automotive hot-rolled sheet, cold-rolled sheet, and metallic-coated sheet steels. It also contains information that explains the different nomenclature used with these steels.
2. **References**
  - 2.1 **Applicable Publications**—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.
    - 2.1.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.
      - SAE J416—Tensile Test Specimens
      - SAE J863—Methods for Determining Plastic Deformation in Sheet Metal Stampings
      - SAE J1392—Steel, High-Strength, Hot-Rolled Sheet and Strip, Cold-Rolled Sheet, and Coated Sheet
      - SAE J1562—Selection of Galvanized (Hot-Dipped and Electrodeposited) Steel Sheet
    - 2.1.2 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.
      - ASTM A 370—Standard Test Methods and Definitions for Mechanical Testing of Steel Products
      - ASTM E 8—Standard Test Methods of Tension of Metallic Materials
      - ASTM E 517—Standard Test Method for Plastic Strain Ratio  $r$  for Sheet Metal
      - ASTM E 646—Standard Test Method for Tensile Strain-Hardening Exponents ( $n$  value) of Metallic Sheet Materials
    - 2.1.3 ASM PUBLICATION—Available from ASM International, Attn: MSC/Book Order, P. O. Box 473, Novelt, OH 44072-9901.
      - ASM Handbook
  - 2.2 **Related Publications**—The following publications are provided for information purposes only and are not a required part of this document.
    - 2.2.1 SAE PUBLICATIONS—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.
      - SAE J810—Classifications of Common Imperfections in Sheet Steel
      - SAE J940—Glossary of Carbon Steel Thickness and Tolerances
      - SAE J1058—Standard Sheet Steel Thickness and Tolerances
    - 2.2.2 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.
      - ASTM A 366/A 366M—Specification for Steel, Sheet, Carbon, Cold-Rolled, Commercial Quality
      - ASTM A 568/A 568M—Specification for Steel, Sheet, Carbon, and High Strength, Low Alloy, Hot-Rolled and Cold-Rolled, General Requirements for
      - ASTM A 569/A 569M—Specification for Steel, Carbon (0.15 Maximum, Percent), Hot-Rolled Steel and Strip, Commercial Quality
      - ASTM A 619A/619M—Specification for Steel, Sheet, Carbon Cold-Rolled Drawing Quality
      - ASTM A 620/A 620M—Specification for Steel, Sheet, Carbon, Drawing Quality, Special Killed, Cold-Rolled
      - ASTM A 621/A 621M—Specification for Steel, Sheet and Strip, Carbon, Hot-Rolled, Drawing Quality
      - ASTM A 622/A 622M—Specification for Steel, Sheet and Strip, Carbon, Drawing Quality, Special Killed, Hot-Rolled

ASTM A 642/A 642M—Specification for Steel Sheet, Zinc-Coated (Galvanized by the Hot-Dip Process, Drawing Quality, Special Killed)

ASTM A 653/A 653M—Steel Sheet, Zinc Coated (Galvanized) or Zinc-Iron Alloy Coated (Galvannealed) by the Hot-Dip Process

ASTM A 924/A 924M—General Requirements for Steel Sheet, Metallic Coated by the Hot-Dip Process

### 2.2.3 OTHER PUBLICATION

Steel Products Manual, Sheet Steel; Iron and Steel Society Publication, January 1988

3. **Grades**—The specific grades are identified by a maximum of 5 characters. The first two characters will be letters defining method of manufacture of steel; HR for hot rolled and CR for cold rolled. The third character will consist of a single digit number defining the chemical and forming characteristics as specified in Tables 1 through 3. The fourth character, an alphabetic character, will define the type of steel as outlined in Section 4. An additional 5th suffix character, C, may be added if restriction to low-carbon steelmaking is desired by the purchaser. The single-digit number specifies the mechanical requirements for: yield and tensile strength in MPa, elongation %,  $r_m$  value, and n value.

**TABLE 1—COLD-ROLLED STEEL SHEET, COATED AND UNCOATED, MECHANICAL PROPERTIES<sup>(1)(2)</sup>**

SAE J2329 Designation	Yield Strength (MPa) at 0.2% Offset	Tensile Strength (MPa) Minimum	Total % Elongation in 50 mm Minimum	$r_m$ value <sup>(3)</sup> Min.	n Value <sup>(4)</sup> Min.
Grade 1	N/R	N/R	N/R	N/R	N/R
Grade 2	140 to 260	270	34	N/R	0.16
Grade 3	140 to 205	270	38	1.5	0.18
Grade 4	140 to 185	270	40	1.6	0.20
Grade 5	110 to 170	270	42	1.7	0.22

1. N/R = Not required.
2. ASTM A 370, Test parameters in all directions.
3. ASTM E 517, Parameter for r calculated at 17% strain,  $r_m$  calculation by  $(r_0 + r_{90} + 2r_{45})/4$ . The  $r_m$  value can be up to 0.2 lower for thickness greater than 1.4 mm and/or Galvanneal products.
4. ASTM E 646, n Value calculated from 10 to 20% strain or 10% to end of uniform elongation when uniform elongation is less than 20%.

**TABLE 2—HOT-ROLLED STEEL SHEET, COATED AND UNCOATED, MECHANICAL PROPERTIES<sup>(1)(2)</sup>**

SAE J2329 Designation	Yield Strength (MPa) at 0.2% Offset	Tensile Strength (MPa) Minimum	Total % Elongation in 50 mm Minimum	n Value <sup>(3)</sup> Min.
Grade 1	N/R	N/R	N/R	N/R
Grade 2	180 to 290	270	34	0.16
Grade 3	180 to 240	270	38	0.18

1. N/R = Not required.
2. ASTM A 370, Test parameters in all directions.
3. ASTM E 646, n Value calculated from 10 to 20% strain or 10% to end of uniform elongation when uniform elongation is less than 20%.

**TABLE 3—HOT-ROLLED AND COLD-ROLLED STEEL SHEET, LOW CARBON, CHEMICAL COMPOSITION<sup>(1)</sup>**

SAE J2329 Designation	Carbon % max <sup>(2)</sup>	Manganese Max. %	Phosphorus Max. %	Sulfur Max. %	Aluminum Min. %
Grade 1	0.13	0.60	0.035	0.035	—
Grade 2	0.10	0.50	0.035	0.030	0.020
Grade 3	0.10	0.50	0.030	0.030	0.020
Grade 4	0.08	0.40	0.025	0.025	0.020
Grade 5	0.02	0.30	0.025	0.025	0.020

1. Ladle or Heat Analysis

2. 0.015% Carbon minimum requirement if suffix C is used. C cannot be specified for Grade 5.

Under certain circumstances particular parts may require steel properties that do not conform exactly to the specific grades defined herein. These deviations should be resolved through agreement between the steel user and the steel producer.

Cold-rolled and metallic-coated cold-rolled coated steels specified to a 180 MPa or greater minimum yield strength are considered high-strength steels.

Hot-rolled and metallic-coated hot-rolled steels specified to a 260 MPa or greater minimum yield strength are considered high-strength steels.

Titanium, Niobium, and other alloy elements can be used in combination, if fully stabilized product is required. Stabilization elements must be reported on chemical certification.

**4. Types**—There are several types of cold-rolled/coated steels and hot-rolled steels that result from differences in steel manufacturing processes and automotive stamping operations. The types of steels are referred to by letter code that follows the class designation.

**4.1 Cold-Rolled and Metallic-Coated Cold-Rolled Sheet Steel**—Two types of these steels are produced. These types are based on surface quality.

4.1.1 Type E is intended for the most critical exposed applications where surface appearance is of primary importance. This type of steel will meet requirements for controlled surface texture, surface quality, and flatness.

4.1.2 Type U is intended for unexposed applications and may also have special use where improved ductility over a temper-rolled product is desired. Type U can be produced without temper rolling; this type of steel may be expected to exhibit coil breaks, fluting, and stretcher straining. Standard tolerances for flatness and surface texture are not applicable. In addition, surface imperfections are more prevalent and severe than with Type E.

**4.2 Hot-Rolled and Metallic-Coated Hot-Rolled Sheet Steel**—Four types of hot-rolled steel are available.

4.2.1 Type R is an as-hot-rolled coiled product. Typically known as Hot Roll Black Band. Therefore, it has not been processed in any way; i.e., pickled, oiled, temper-rolled, side trimmed, rewound, or cut back to established thickness and width tolerances. Yield strength range classes apply only to material that has been cut back to established thickness and width tolerances. Processed coils may have had any or all of the processing steps listed in the previous paragraph performed subsequent to hot rolling. Ends of coils are cut back to established width and thickness tolerances.

- 4.2.2 Type F has been processed and is available in coils or cut lengths. This material is susceptible to coil breaks and aging.
- 4.2.3 Type N has been processed and is available in coils or cut lengths. This material is nonaging at room temperature but is susceptible to coil breaks.
- 4.2.4 Type M has been processed and is available in coils or cut lengths. This material is free from coil breaks and does not strain age at room temperature.

Some of the product characteristics available for each type of hot-rolled steel are listed in Table 4.

**TABLE 4—PRODUCT CHARACTERISTICS OF HOT-ROLLED STEEL<sup>(1)</sup>**

Type	Freedom from Coil Breaks	Non Aging	Pickle and Oil	Cut Edge	Special Surface
R	No	No	n	n	n
F	No	No	a	a	n
N	No	Yes	a	a	n
M	Yes	Yes	a	a	a

1. a = available but not required; n = not available

**5. Examples**—As previously discussed, categorization is made by commodity, grade, and type.

CR2E: Cold-rolled sheet steel with chemical requirements of Table 3 — Grade 2, minimum mechanical properties as specified in Table 1 — Grade 2 and of critical exposed surface quality.

HR3MU: Hot-rolled sheet steel with chemical requirements of Table 3 — Grade 3, minimum mechanical properties as specified in Table 2 — Grade 3, unexposed, M product characteristics as specified in Table 4.

For metallic-coated sheet products, SAE J1562 is used to designate coatings of hot-dipped and electrodeposited zinc. SAE J1562 should be referenced for full explanation of the nomenclature and product characteristics.

CR4C EG60G60GE: Cold-rolled sheet steel with the chemical requirements of Table 3 — Grade 4, minimum mechanical properties as specified in Table 1 — Grade 4, critical exposed surface quality, 0.015% minimum carbon, and two side electrogalvanized coated to 60 g/m<sup>2</sup> each side.

HR2M 45A45AU: Hot-rolled sheet steel with the chemical requirements of Table 3 — Grade 2, minimum mechanical properties as specified in Table 2 — Grade 2, unexposed, M product characteristic as specified in Table 4, two side galvanized coated to 45 g/m<sup>2</sup> each side.

**6. Sampling Procedure**—When questions arise as to steel meeting the minimum or maximum criteria, the following procedure applies. When tested as outlined in the following section, tests must fall within the ranges for the grade specified: otherwise the lift of blanks, cut lengths, or coil can be considered unacceptable.

**7. Yield Strength Determination**—The procedures given in SAE J416, ASTM E 8, and ASTM A 370 shall be followed in determining tensile properties. However, within these specifications latitude exists in determining yield strength/yield point. For this document, the following procedures apply.

**7.1 Specimen Geometry**—The 12.5 mm (0.5 in) wide sheet type specimen will be used. The width of the grip section will be 20 mm (3/4 in).

- 7.2 Speed of Testing**—ASTM A 370—87c Section 11.4.1 applies with the addition that the speed change from a maximum of 1.6 mm (1/16 in) per minute per millimeter (inch) of gage length shall not be made until a minimum of 2% elongation is achieved.
- 7.3 Discontinuous Yielding**—For material showing discontinuous yielding, the lower yield point shall be considered to be the yield strength. The lower yield point is defined as the lowest stress at which an increase in strain occurs without an increase in stress. For steels with continuous yielding, the 0.2% offset method shall be used to determine the yield strength.

PREPARED BY THE SAE IRON AND STEEL TECHNICAL COMMITTEE DIVISION 32—  
SHEET AND STRIP STEEL

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## APPENDIX A

**A.1 Introduction**—Problems associated with the evaluation of formability or deep drawability of sheet metals are complex and may be difficult to solve due to the number of variable involved. As long ago as 1940, the AISI Technical Committee on Sheet Steel reviewed this problem. Volume 1 of the Ninth Edition of the ASM Metals Handbook contains sections on “Low Carbon Steel Sheet and Strip” and “Formability of Steel Sheet” that provide suggestions to help evaluate parts and select materials. The purpose of this document is to summarize the sheet metal characteristics that are commonly used when attempting to predict the formability of sheet metal.

**A.2 Tension Test**—Data from tension tests can give a more complete measurement of formability, ASTM A 370 and ASTM E 8 describe testing procedures.

NOTE—Any taper in the width of the bar between the gage marks could affect the total elongation adversely.

**A.2.1 Yield Strength**—The measured strength depends on both the steel and the conditions under which the prepared specimen is loaded. This term is applicable to those materials having an engineering stress-strain diagram in the transition from elastic to plastic strain which is a smooth curve as well as to those which exhibit an upper yield point or sharp knee. In reporting yield strength, the method by which it was determined should be stated (0.2% offset method, 0.5% extension under load method, half of the pointer or from a stress-strain diagram). See ASTM E 8 for a description of these methods.

In forming sheet metal, the upper yield point has to be overcome before any deformation occurs in the flat blank. Experience has indicated that when the upper yield point is high in relation to the lower yield and approaches the ultimate strength, the material will have a greater tendency to split than material which has an upper yield point only slightly higher than the lower yield point. A low yield strength is preferred when formability is the major consideration.

**A.2.2 Tensile Strength**—The strength at the highest load reached during the tension test is the tensile strength. It is calculated in psi or MPa units using the specimen cross-sectional area measured before testing.

**A.2.3 Yield to Tensile Ratio**—The yield strength divided by the tensile strength expressed as a decimal value is the elastic ratio. Steels with low yield to tensile ratios have a greater capacity for being formed due to the greater separation between the yield load and the ultimate load during which forming can take place.

**A.2.4 Total Elongation**—The total elongation is the percent increase of a gage length on the tension test specimen. For low-carbon sheet steel, a 50 mm (2 in) gage length and a 12.5 mm (0.5 in) gage width is normally used. Steels with a higher percent elongation will stretch further before failure. This elongation is a direct measure of ductility and represents an important consideration in evaluating formability. Caution must be used, however, in comparing elongation values since they depend on specimen preparation and testing procedure. Total elongation also may vary with sample orientation in relation to the sheet rolling direction.

**A.2.5 Uniform Elongation**—The amount of deformation that can occur before any measurable localized necking of the tension specimen starts, is known as uniform elongation. This is designated as  $e_u$  and will usually vary between 20 and 28% for low-carbon steel.

**A.2.6 Yield Point Elongation**—The yield point elongation indicates the intensity of stretcher strains that can develop in certain low-carbon steels in lightly formed areas. It is caused by interstitial elements such as carbon and nitrogen, or in the case of certain high-strength steels, a very fine grain size. The tendency to strain can be minimized by temper rolling at the producing mill. However, in grades subject to aging, the effect of temper rolling is only temporary and it is necessary for the user to properly roller level the sheet immediately before forming a shape. Sheet steels are available that will not exhibit yield point elongation.

**A.2.7 Mechanical Properties**—Mechanical properties have not been typically used in specifications unless special structural properties are required in the part, this has changed due to the process control methods now used by automotive manufacturing facilities. Due to the range of properties possible, the expected distribution can overlap among the various grades. The ranges are broader for hot-rolled sheets than for cold-rolled.

**A.3 Special Tests of Formability**—During the late 1960s, the new test methods more directly related to the actual mechanism of deformation began to be developed and accepted. These tests are used to obtain a more complete characterization of sheet steel formability.

**A.3.1 Plastic Strain Ratio ( $r_m$  value)**—This is a measure of a sheet metal's resistance to thinning as controlled by the crystallographic orientation of its structure, which is dependent on the chemistry and processing of the material. When a tensile test specimen from a sheet of ductile metal having isotropic mechanical properties is stretched 20%, the width and thickness will each contract 10%. This is essentially true for steel in the as-hot-rolled condition, or for a normalized low-carbon sheet steel. If the sheet has been cold reduced and annealed subcritically by conventional methods, it will have a degree of anisotropic mechanical properties. In that case, a tensile test specimen stretched 20% will exhibit a different amount of contraction in the thickness than in the width. The degree of anisotropy is measured by the plastic strain ratio,  $r$ . The procedure for determining  $r$  can be found in ASTM E 517. For anisotropic materials, the  $r$  value changes with test direction, and for convenience, it is measured in directions longitudinal (0 degrees), diagonal (45 degrees), and transverse (90 degrees) to the rolling direction. An average value,  $r_m$ , is usually reported.

Higher  $r$  values indicate greater resistance to thinning, and are directly related to an increased ability of the sheet to be formed by deep drawing.

The plastic strain ratio can also be measured by the MODUL- $r$  method. This device measures Young's modulus from a vibrating beam. Small strips are blanked at 0, 45, and 90 degrees to the rolling direction to use as test samples. The MODUL- $r$  employs a simple feed-back system called a Magnetostrictive oscillator, consisting of a measuring head, an amplifier, and an electronic counter. The measuring head consists of three coils that form the sample chamber. When a sample is inserted and the test button depressed, an alternating field is created by the current passing through the coil network, producing cyclical longitudinal expansion and contraction in the sample through a process called magnetostriction.

These vibrations match a characteristic velocity of sound for that particular sample, or resonant frequency. This frequency is displayed on the front of the unit and an empirical graph converts the readings to  $r_m$  and  $\Delta r$  values.

**A.3.2 Strain Hardening Exponent ( $n$  value)**—The strain hardening exponent, known as the  $n$  value, is defined as the exponent of the power law relationship of true stress ( $\sigma$ ) to true strain ( $\epsilon$ ),  $\sigma = K\epsilon^n$ , where  $K$  is a strength coefficient. True stress and true strain are based on the instantaneous cross section area, rather than the initial area used for engineering stress and strain. Determination of  $n$  from load elongation curves is described in ASTM E 646. A higher  $n$  value indicates a capability for the metal to strain harden in areas that have been cold worked by deformation processes, and in turn cause further straining to occur in less cold worked areas. This capacity to transfer strain contributes to a better response to biaxial stretch deformation modes.

**A.3.3 Strain Rate Hardening ( $m$  value)**—The  $m$  value is a measure of the change of the flow stress as the rate of strain is changed. It becomes important beyond uniform elongation, when a tension tests specimen necks-down by a diffuse, and finally localized reduction of cross section prior to fracture. It is the strain rate sensitivity of the flow stress ( $\sigma$ ) in the modified power law equation,  $\sigma = K\epsilon^n \cdot \dot{\epsilon}^m$ . Since the  $m$  value is strain rate dependent, its determination requires loading control based on changes in the strain. In general, higher positive  $m$  values are desired. For low-carbon steels, the  $m$  value is positive and generally in the range of 0.006 to 0.012. Its significance is apparent in that it accounts for the total elongation being on the order of two times the uniform elongation for most low-carbon high-ductility sheet steels.