

Submitted for recognition as an American National Standard

**Categorization and Properties of Dent Resistant, High Strength, and Ultra  
High Strength Automotive Sheet Steel**

**Foreword**—The primary reason higher strength steels are used is because their yield and tensile strengths are higher than those of low-carbon sheet steel, which are described in SAE J2329. Higher strength steels are desirable for dent resistance, increased load bearing capability, better crash energy management, or for part mass reduction through a decrease in sheet metal thickness.

An increase in strength generally leads to reduced ductility or formability. Care must be taken in designing parts, tooling, and fabrication processes to obtain the greatest benefit from the higher strength sheet steels. Consultation in grade selection between user and steel producer is recommended to insure compatibility of the strength and forming characteristics.

Strength in these steels is achieved through chemical composition (alloying) and special processing. Special processing includes mechanical rolling techniques, temperature control in hot rolling, and time/temperature control in annealing of cold-reduced steel. Further or additional thermal treatment may modify the original mechanical properties.

- 1. Scope**—This SAE Recommended Practice defines and establishes mechanical property ranges for seven grades of continuously cast high strength automotive sheet steels that can be formed, welded, assembled, and painted in automotive manufacturing processes. The grade of steel specified for an identified part should be based on part requirements (configuration and strength) as well as formability. Material selection should also take into consideration the amount of strain induced by forming and the impact strain has on the strength achieved in the finished part. These steels can be specified as hot-rolled sheet, cold-reduced sheet, uncoated, or coated by hot dipping, electroplating, or vapor deposition of zinc, aluminum, and organic compounds normally applied by coil coating. The grades and strength levels are achieved through chemical composition and special processing. Not all combinations of strength and coating types may be commercially available. Consult your steel supplier for details.

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## 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 and ASTM publications shall apply.

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

SAE J1058—Standard Sheet Thickness' and Tolerances

SAE J1562—Selection of Zinc and Zinc-Alloy (Hot Dipped and Electrodeposited) Coated Steel Sheet

SAE J2329—Categorization and Properties of Low Carbon Automotive Sheet Steels

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 A 980—Standard Specification for Steel Sheet, Carbon, Ultra High Strength Cold Rolled

ASTM E 8M—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 ANSI/AWS/SAE PUBLICATION—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ANSI/AWS/SAE D8.8-97—A Specification for Automotive and Light Truck Component Weld Quality - Arc Welding

2.1.4 OTHER PUBLICATION

AZ-017-02-295 1.0C RI—Weld Quality Test Method Manual; Standardized Welding Test Method Task Force, Auto/Steel Partnership (A/SP)

**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 J416—Tensile Test Specimens

SAE J810—Classifications of Common Imperfections in Sheet Steel

SAE J1392—Steel, High Strength, Hot Rolled Sheet and Strip, Cold Rolled Sheet, and Coated Sheet

SAE J2328—Selection and Specification of Steel Sheet, Hot Rolled, Cold Rolled, and Coated for Automotive Applications

2.2.2 ASTM PUBLICATIONS—Available from ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

ASTM A 463—Standard Specification for Cold Rolled Aluminum Coated Type 1 & Type 2 Steel Sheet

ASTM A 568—General Requirements for Carbon and High Strength, Low Alloy Steel Sheet

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

ASTM A 751—Standard Test Methods for Determining Chemical Composition of Steel Products

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

2.2.3 ISO PUBLICATION—Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 13887—Cold Reduced Steel Sheet of Higher Strength with Improved Formability

## 2.2.4 OTHER PUBLICATION

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

3. **General Information**—This document defines seven grades of higher strength steel based on material type and processing. These strength grades are shown in Table 1.

TABLE 1—STEELS AND STRENGTH GRADES

Steel Description	Grade Type	Available Strength Grade - MPa
Dent Resistant Non-Bake-Hardenable	A	180, 210, 250, 280
Dent Resistant Bake-Hardenable	B	180, 210, 250, 280
High Strength Solution Strengthened	S	300, 340
High Strength Low Alloy	X & Y	300, 340, 380, 420, 490, 550
High Strength Recovery Annealed	R	490, 550, 700, 830
Ultra High Strength Dual Phase	DH & DL	500, 600, 700, 800, 950, 1000
Ultra High Strength Low Carbon Martensite	M	800, 900, 1000, 1100, 1200, 1300, 1400, 1500

4. **Condition**—Several conditions of hot-rolled and cold-reduced uncoated and coated sheet steels are used by the automotive stamping and assembly operations. The conditions of sheet steel are referred to by letter code that follows the class designation.

- 4.1 **Cold-Reduced Uncoated and Metallic Coated Sheet Steel**—Three conditions of sheet steel surface characteristics are produced.

4.1.1 Exposed (E) is intended for the most critical exposed applications where painted surface appearance is of primary importance. This surface condition of sheet steel will meet requirements for controlled surface texture, surface quality, and flatness.

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

4.1.3 Semi Exposed (Z) is intended for non-critical exposed applications. This is typically a hot-dip galvanized temper-rolled product, see SAE J1562 for full explanation. Acceptability of surface characteristics or discontinuities shall be negotiated between user and supplier.

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

4.2.1 Condition P is an as hot-rolled coiled product, typically known as hot roll black band, which has not been pickled, oiled, temper rolled, side trimmed, rewound, or cut back to established thickness and width tolerances.

4.2.2 Condition W has been processed and is available in coils or cut lengths. This material may be susceptible to coil breaks and aging. Yield strength range classes apply only to material that has been cut back to established thickness and width tolerances. Processed coils may receive any or all of the processing steps listed in 4.2.1.

4.2.3 Condition N has been processed and is available in coils or cut lengths. This material possesses mechanical properties that do not deteriorate at room temperature, however, condition N material is susceptible to coil breaks.

- 4.2.4 Condition V has been processed and is available in coils or cut lengths. This material is free from coil breaks and its mechanical properties do not deteriorate at room temperature.

Some of the product characteristics available for each type of hot-rolled steel are listed in Table 2.

**TABLE 2—PRODUCT CHARACTERISTICS OF HOT-ROLLED SAE J2340 STEEL**

Condition	Freedom From Coil Breaks	Non Aging	Pickle and Oil <sup>(1)(2)</sup>	Cut Edge <sup>(1)(2)</sup>	Special Surface <sup>(1)(2)</sup>
P	No	No	n	n	n
W	No	No	a	a	n
N	No	Yes	a	a	n
V	Yes	Yes	a	a	a

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

## 5. Steels and Strength Grades

- 5.1 **Dent Resistant Cold-Reduced Sheet Steels**—There are two types of dent-resistant steel; non-bake-hardenable and bake-hardenable. Both are available in grades with minimum yield strengths from 180 MPa and higher. Both are available uncoated or coated.

Non-bake-hardenable, dent resistant steels achieve their final strength in the part through a combination of their initial yield strength and the work hardening imparted during forming. Bake-hardenable steels exhibit an additional increase in strength due to age hardening after forming which is accelerated by subsequent paint baking.

Although dent-resistant steels are not specified by chemistry, the following is provided for information purposes only. Both non-bake-hardenable and bake-hardenable dent resistant steels can be based on conventional low carbon steel (0.02 to 0.08% C), steel vacuum-degassed to very low carbon levels (<0.02% C), or interstitial-free (IF) steel. IF steel is vacuum degassed to ultra-low carbon levels (<0.01% C) and then any carbon remaining in solution is removed by adding titanium, niobium (columbium), or vanadium to form carbide precipitates. Solid solution strengthening elements such as phosphorous, manganese, or silicon may also be added to increase the as-received strength while not significantly reducing the material's work hardenability. A material's bake hardenability depends upon the amount of carbon remaining in solution, which is controlled through the steel chemistry and thermomechanical processing.

In this document, classification is based on minimum yield strength of the steel sheet and the strengthening that occurs during forming and paint baking. Classification of dent resistant steel is not based on chemistry.

- 5.1.1 **TYPES AND MECHANICAL PROPERTY REQUIREMENTS**—Mechanical property requirements of dent resistant cold-reduced uncoated and coated sheet steel grades are based on the minimum values of the following: As received yield strength (180, 210, 250, and 280 MPa), n value, tensile strength and the yield strength after strain (for non-bake-hardenable grades) or strain and bake (for bake-hardenable grades). These are the only mechanical requirements of this document for dent resistant cold-reduced uncoated and coated sheet steel grades (see Table 3). Typical mechanical properties of dent resistant cold-reduced uncoated and coated sheet steel grades are shown in Table A1 (“A” designates the Appendix).

- 5.1.1.1 *Type A*—This is a non-bake-hardenable dent resistant steel in which increase in yield strength due to work hardening results from strain imparted during forming. For the purpose of this document, a non-bake-hardenable dent resistant steel shall gain at least 35 MPa in yield strength (longitudinal direction) after a 2% tensile prestrain that represents the forming strain. This is considered the “strain hardening index” (SHI).

TABLE 3—REQUIRED MINIMUM MECHANICAL PROPERTIES<sup>(1)</sup> OF DENT RESISTANT SHEET STEEL

SAE J2340 Grade Designation and Type	As Received Yield Strength <sup>(2)</sup> MPa	As Received Tensile Strength MPa	As Received n Value <sup>(3)</sup>	Yield Strength After 2% Strain MPa	Yield Strength After Strain and Bake MPa <sup>(4)</sup>
180 A	180	310	0.20	215	
180 B	180	300	0.19		245
210 A	210	330	0.19	245	
210 B	210	320	0.17		275
250 A	250	355	0.18	285	
250 B	250	345	0.16		315
280 A	280	375	0.16	315	
280 B	280	365	0.15		345

1. The mechanical property requirements shall be determined in longitudinal direction unless otherwise specified and shall be performed per Section 10.
2. Yield Strength is 0.2% offset or, in the presence of yield point elongation, lower yield point.
3. n value shall be calculated, per ASTM E 646, from 10 to 20% strain or to the end of uniform elongation when uniform elongation is less than 20%.
4. 2% tensile prestrain and baking at 175 °C for 30 min at temperature. The upper yield point is used for determination of yield strength. With lower yield point, requirement is 5 MPa lower.

5.1.1.2 *Type B*—This is a bake-hardenable dent resistant steel in which increase in yield strength due to work hardening results from strain imparted during forming and an additional strengthening increment that occurs during the paint-baking process. For the purposes of this document, bake-hardenable dent resistant steels are defined as those products which possess a “bake hardening index” (BHI) (as shown in Figure A1). This is an increase in yield strength of at least 30 MPa in upper yield strength or 25 MPa based on lower yield point (longitudinal direction) after a 2% tensile strain and baking at 175 °C for 30 min (representing the paint-baking process). The total hardening response is the sum of the SHI and the BHI.

In order to help visualize the concept of the SHI and BHI, Figure A1 in the Appendix shows a portion of a stress strain curve and how these two characteristics are determined.

In practice, the magnitudes of the forming strain and the paint-baking temperature may be different than those designated for the purposes of this specification. Figures A2 and A3 in the Appendix describe their typical effects on the strain hardening and bake hardening increments.

- 5.1.2 SUB TYPE T—Sub Type T may be specified to denote an interstitial free dent resistant steel (Type A grades only). When interstitial free steel is used the tensile strength shall be 30 MPa higher than a non-interstitial free steel. Sub Type T steels shall be specified by the “T” designator (e.g., SAE J2340 - 180AT).
- 5.1.3 BASE METAL—Dent resistant steel furnished to this document shall be cold-reduced low carbon deoxidized steel made by basic oxygen, electric furnace, or other process which will produce a material which satisfies the requirements for the specific grade. This steel shall be continuously cast. The chemical composition shall be capable of achieving the desired mechanical and formability properties for the specified grade and type. For grades 180 and 210 using an interstitial free (IF) base metal having a carbon content less than 0.010, an effective boron addition of <0.001% may be required to minimize secondary work embrittlement (SWE) and to control grain growth during welding. The steel supplier shall define the chemical composition range that will be furnished on a production basis. The steel supplier shall not change the product/process without complying with the purchaser’s supplier quality assurance requirements.

**5.2 High Strength Solution Strengthened and High Strength Low Alloy (HSLA) Hot-Rolled and Cold-Reduced Sheet Steels and High Strength Recovery Annealed Cold-Reduced Sheet Steels**—High strength, HSLA, and high strength recovery annealed categories include steel grades with minimum yield strengths in the range of 300 to 830 MPa. These sheet steels can be ordered and supplied as uncoated or coated.

Several different types of high strength steel based on chemistry can fall under this category. Solution strengthened high strength steels are those that contain additions of phosphorus, manganese, or silicon to conventional low carbon (e.g., 0.02 to 0.13% carbon) steels. HSLA steels have additions of carbide formers, such as, titanium, niobium (columbium), or vanadium made to conventional low carbon (0.02 to 0.13% carbon) steel. High strength recovery annealed steels have chemistries similar to the previous varieties of steels, but special annealing practices prevent recrystallization in the cold-rolled steel.

**5.2.1 TYPES AND MECHANICAL PROPERTY REQUIREMENTS**—Mechanical properties of these high strength sheet steels shall be measured in longitudinal direction unless otherwise specified and shall conform to the requirements for the grades specified in Tables 4 and 5. Classification is based on the minimum yield strength: 300 to 830 MPa. Several categories at each strength level are defined as follows:

**5.2.1.1 Type S**—High strength solution strengthened steels use carbon and manganese in combination with phosphorus or silicon (as solution strengtheners) to meet the minimum strength requirements. Carbon content is restricted to 0.13% maximum for improved formability and weldability. Phosphorus is restricted to a maximum of 0.100%. Sulfur is restricted to a maximum of 0.020%.

**5.2.1.2 Type X**—Typically referred to as HSLA steels, these high strength steels are alloyed with carbide and nitride forming elements, commonly niobium (columbium), titanium, and vanadium either singularly or in combination. These elements are used with carbon, manganese, phosphorus, and silicon to achieve the specified minimum yield strength. Carbon content is restricted to 0.13% maximum for improved formability and weldability. Phosphorus is restricted to a maximum of 0.060%. The specified minimum for niobium (columbium), titanium, or vanadium is 0.005%. Sulfur is restricted to a maximum of 0.015%. A spread of 70 MPa is specified between the required minima of the yield and tensile strengths.

**5.2.1.3 Type Y**—Same as Type X, except that a 100 MPa spread is specified between the required minima of the yield and tensile strengths.

**5.2.1.4 Type R**—High strength recovery annealed or stress-relief annealed steels achieve strengthening primarily through the presence of cold work. Alloying elements mentioned under Types S and X may also be added. Carbon is restricted to 0.13% maximum for improved formability and weldability. Phosphorus is restricted to a maximum of 0.100%. Sulfur is restricted to a maximum of 0.015%. These steels are best suited for bending and roll-forming applications since the mechanical properties are highly directional and ductility and formability are limited.

**5.2.2 SUB TYPE F**—Sub Type F may be specified to denote sulfide inclusion controlled. These steels are specified for forming applications and are generally used in unexposed applications only. Special steel making practice is used to control the shape or the volume fraction of manganese sulfide inclusions to improve edge stretching or bending in some applications. It is recommended that the producer and purchaser consult to determine the specific forming requirements prior to specifying Sub Type F. Sub Type F steels may be specified by the "F" designator (e.g., SAE J2340 - 340XF).

**5.2.3 BASE METAL**—High strength steel furnished to this document shall be a low carbon deoxidized steel made by basic oxygen, electric furnace, or other process which will produce a material which satisfies the requirements for the specific grade. This steel shall be continuously cast. The chemical composition shall be capable of achieving the desired mechanical and formability properties for the specified grade and type. The steel supplier shall define the chemical composition range that will be furnished on a production basis. The steel supplier shall not change the product/process without complying with the purchaser's supplier quality assurance requirements.

**TABLE 4—REQUIRED MECHANICAL PROPERTIES<sup>(1)</sup> OF HIGH STRENGTH AND HSLA HOT-ROLLED AND COLD-REDUCED UNCOATED AND COATED SHEET STEEL<sup>(2)</sup>**

SAE J2340 Grade Designation and Type	Yield Strength <sup>(3)</sup> MPa		Tensile Strength MPa Minimum	% Total Elongation Min	
	Minimum	Maximum		Cold-Reduced	Hot-Rolled <sup>(4)</sup>
300 S	300	400	390	24	26
300 X	300	400	370	24	28
300 Y	300	400	400	21	25
340 S	340	440	440	22	24
340 X	340	440	410	22	25
340 Y	340	440	440	20	24
380 X	380	480	450	20	23
380 Y	380	480	480	18	22
420 X	420	520	490	18	22
420 Y	420	520	520	16	19
490 X	490	590	560	14	20
490 Y	490	590	590	12	19
550 X	550	680	620	12	18
550 Y	550	680	650	12	18

1. The mechanical property requirements shall be determined in longitudinal direction unless otherwise specified and shall be performed per Section 10.
2. Consultation between user and producer is recommended regarding the selection of specific steel grade and welding process optimization.
3. Yield strength is 0.2% offset or, in the presence of yield point elongation, lower yield point.
4. For thickness less than 2.5 mm, minimum percent elongation is permitted to be 2% less than the value shown.

**TABLE 5—REQUIRED MECHANICAL PROPERTIES<sup>(1)</sup> OF HIGH STRENGTH RECOVERY ANNEALED COLD-REDUCED SHEET STEEL<sup>(2)</sup>**

SAEJ2340 Grade Designation and Type	Yield Strength <sup>(3)</sup> MPa		Tensile Strength MPa Minimum	% Total Elongation Minimum
	Minimum	Maximum		
490 R	490	590	500	13
550 R	550	650	560	10
700 R	700	800	710	8
830 R	830	960	860	2

1. The mechanical property requirements shall be determined in longitudinal direction unless otherwise specified and shall be performed per Section 10.
2. Consultation between user and producer is recommended regarding the selection of specific steel grade and welding process optimization.
3. Yield strength is 0.2% offset or, in the presence of yield point elongation, lower yield point.

**5.3 Ultra High Strength Cold-Rolled Steels; Dual Phase and Low Carbon Martensite**—The Ultra High Strength Dual Phase and Low Carbon Martensite (LCM) categories include steel grades with minimum tensile strengths in the range of 500 to 1500 MPa. These sheet steels may be ordered and supplied as uncoated or coated. Contact your steel supplier to determine coating availability.

Special heat treating practices that involve quenching and tempering treatments are used to generate a martensite phase in the steel microstructure. The volume fraction and carbon content of the martensite phase determines the strength level. These steels are primarily alloyed with carbon and manganese. Boron may be added in some cases.

Specification of chemical limits for low carbon martensitic grades may be found in ASTM A 980.

5.3.1 TYPES AND MECHANICAL PROPERTY REQUIREMENTS—The mechanical property requirements of ultra high strength sheet steels are specified in Tables 6 and 7. Classification is based on the minimum tensile strength of the sheet steel: 500 to 1500 MPa. Typical mechanical properties of ultra high strength sheet steels are shown in Tables A2 and A3.

The formability and weldability characteristics of these ultra high strength steels shall be agreed upon between purchaser and supplier.

**TABLE 6—REQUIRED MECHANICAL PROPERTIES<sup>(1)</sup> OF ULTRA HIGH STRENGTH DUAL PHASE HOT-ROLLED AND COLD-REDUCED SHEET STEEL<sup>(2)</sup>**

SAE J2340 Grade Designation and Type	Yield Strength MPa Minimum <sup>(3)</sup>	Tensile Strength MPa Minimum	% Total Elongation in 50 mm Minimum
500 DL	300	500	22
600 DH	500	600	14
600 DL1	350	600	16
600 DL2	280	600	20
700 DH	550	700	12
800 DL	500	800	8
950 DL	550	950	8
1000 DL	700	1000	5

1. The mechanical property requirements shall be determined in longitudinal direction unless otherwise specified and shall be performed per Section 10.
2. Consultation between user and producer is recommended regarding the selection of specific steel grade and welding process optimization.
3. Minimum yield strength can be waived upon agreement between user and supplier.

**TABLE 7—REQUIRED MECHANICAL PROPERTIES<sup>(1)</sup> OF LOW CARBON MARTINSITE HOT-ROLLED AND COLD-REDUCED SHEET STEEL<sup>(2)(3)</sup>**

SAE J2340 Grade Designation and Type	Yield Strength MPa Minimum <sup>(4)</sup>	Tensile Strength MPa Minimum
800M	600	800
900 M	750	900
1000 M	750	1000
1100 M	900	1100
1200 M	950	1200
1300 M	1050	1300
1400 M	1150	1400
1500 M	1200	1500

1. The mechanical property requirements shall be determined in longitudinal direction unless otherwise specified and shall be performed per Section 10.
2. Consultation between user and producer is recommended regarding the selection of specific steel grade and welding process optimization.
3. Minimum total elongation for all grades is 2%.
4. Minimum yield strength can be waived upon agreement between user and supplier.

5.3.1.1 *Type DH/DL*—The ultra high strength dual phase steel microstructure is comprised of ferrite and martensite, (dual phase), with the volume fraction of low-carbon martensite primarily determining the strength level. Two types of dual phase steels are available; a) a high yield ratio (ratio of YS/TS) product designated as DH in Table 6; and b) a low yield ratio product designated as DL in Table 6. For the purpose of this specification, products with yield ratios of 0.7 or lower are designated as DL and products with yield ratios greater than 0.7 are designated as DH.

5.3.1.2 *Type M*—In these fully martensitic ultra high strength sheet steels, carbon content determines the strength level. These steels have limited ductility.

- 5.3.2 **BASE METAL**—High strength steel furnished to this document shall be a low carbon deoxidized steel made by basic oxygen, electric furnace, or other process which will produce a material which satisfies the requirements for the specific grade. This steel shall be continuously cast. The chemical composition shall be capable of achieving the desired mechanical and formability properties for the specified grade and type. The steel supplier shall define the chemical composition range that will be furnished on a production basis. The steel supplier shall not change the product/process without complying with the purchaser's supplier quality assurance requirements.
6. **Weldability**—When the steel is used in welded applications, welding procedures shall be suitable for the steel chemistry and intended service. Unspecified chemical elements may be present. Limits on chemistry shall be as stated in Table 8. The sum Cu, Ni, Cr, and Mo shall not exceed 0.50% on heat analysis. When one or more of these elements are specified, the sum does not apply; in which case, only the individual limits on the remaining unspecified elements will apply.

TABLE 8—CHEMICAL LIMITS ON UNSPECIFIED ELEMENTS

Element	Maximum Weight Percent Allowed Type A, B, and R	Maximum Weight Percent Allowed Type S	Maximum Weight Percent Allowed Type X and Y	Maximum Weight Percent Allowed Type D and M
P	0.100 <sup>(1)</sup>	0.100	0.060	0.020
S	0.015	0.020	0.015	0.015
Cu	0.200	0.200	0.200	0.200
Ni	0.200	0.200	0.200	0.200
Cr	0.150	0.150	0.150	0.150
Mo	0.060	0.060	0.060	0.060

1. Maximum phosphorus shall be less than 0.050 on grades 180A and 180B.

- 6.1 **High Strength Steel**—In welding high strength steels it is important to consider several factors usually not considered in welding lower strength steels; for example, welding process, welding parameters and, of course, material combinations. Integration of these types of considerations can result in a successful system of welding for HSS. Various welding methods (arc welding, resistance welding, laser welding and high frequency welding) all have unique advantages in welding specific sheet steel combinations. Considerations for production rate, heat input, weld metal dilution, weld location access, etc., may make one system more weldable than another system. For instance, an HSS that is problematic for spot welding may not exhibit the same difficulty in arc or high frequency welding. In fact, a low heat input resistance seam welding method has been successfully employed for commercial production of bumper beams with a 1300M grade. Considerations with respect to material combinations are important for those welding processes that solidify from a molten pool, or that are constrained by thickness ratio. In general, caution should be exercised in spot welding an HSS to itself because of possible weld metal interfacial fracture tendencies, but even a problematic HSS can be spot welded to a low carbon mild steel.

The resistance spot weldability requirements for low strength steels evaluate the operational robustness of the candidate steel. This often embodies measurements of current range and electrode wear (for galvanized coatings). The resistance spot weldability requirements for HSS may be similar to those of low strength steels with the added requirement for mechanical performance. The evaluation of mechanical performance alone may also be sufficient to assess weldability. End use requirements will determine required spot weld performance. These requirements may limit the current range and/or electrode life based on individual company weld quality specifications. For instance, fast quenching of the weld may damage the weld metal integrity causing interfacial fracture, or excessive weld heat input may cause metallurgical changes that soften the heat affected zone. Both of these conditions could result in a loss of joint strength. Incorporation of appropriate weld and temper cycles or modification of weld chemistry through selective dilution of the joint can lead to acceptable weld strength and thus ensure the retention of advantages to using HSS for weight reduction in automotive components.

Weld Quality Test Method Manual (AZ-017-02 295 1.0C RI) or AWS/ANSI/SAE Standard D8.9-97, should be used as reference documents for further details. Note these standard test methods are intended for strength levels up to 420 MPa and modifications may be required for higher strength levels. Due to unique properties of HSS, selection of the weld process parameters should be determined in consultation with the steel supplier. It is recommended that product validation include production intent weld processes, preferably at the extremes of expected spot properties as determined by the laboratory studies.

Similar to resistance spot welding, the evaluation of other welding methods should take into account the appropriate operational robustness measures and the mechanical and/or fracture performance of the resulting weld quality. Weld performance, not absolute base material chemistry, is the important distinction between low and high strength steels. Since weldability requirements differ for different weld methods, it is difficult to summarize these requirements into a unified document. For example, ANSI/AWS/SAE Standard D8.8-97, may be used as a reference document for further details. Consultation is recommended between user and steel producer regarding the selection of specific steel grade as well as weld process optimization.

7. **Cold Bending**—High strength steels are frequently fabricated by cold bending. There are a multiplicity of inter-related factors which affect the ability of a given piece of steel to form over any given radius in shop practice. These factors include thickness, strength level, degree of restraint in bending, relationship to rolling direction, chemical composition, and microstructure. Table A4 lists those ratios which should be used as minimums for 90 degree bends in actual shop practice. It recognizes that “hard way” bending (bend axis parallel to rolling direction) is common in production and presupposes that reasonably good forming practices will be employed. Where design permits, users are encouraged to employ large radii that are shown in Table A4 for improved performance. Where the bend axis can be designed across the width (“easy way”) of the sheet, or bends less than 90 degrees, slightly tighter radii can be employed. As the cold forming becomes progressively more difficult, that is, from a straight bend to a curved or offset bend to stretching or drawing, it is advisable that the producer and user consult to determine the special material, design, and tooling requirements of the application. The fabricator should be aware that steel may crack to some degree when bent on a sheared or burned edge. This is not to be considered to be the fault of the steel, but rather a function of the induced cold work or heat affected zone (HAZ).

## 8. **Nomenclature and Suggested Ordering Practice**

- 8.1 Specifying sheet steel on the engineering drawing under this document should include the following information to adequately describe the desired material:
- a. Name of material being specified; such as electro-galvanized bake-hardenable steel.
  - b. SAE Recommended Practice number (SAE J2340).
  - c. Base metal type, hot rolled (HR) or cold reduced (CR).
  - d. Grade (four character identification which includes minimum yield strength and sheet steel product type).
  - e. Coating type and coating weight, if any. Indicate hot-dip or electro-galvanized zinc coating and coating weight. See SAE J1562 for detailed nomenclature.
  - f. Surface condition. Indicate exposed, E, unexposed, U; or semi exposed, Z, matte, or dull finish will be supplied unless otherwise specified.
  - g. Part thickness plus the tolerance.
- 8.2 Suggested ordering practice should include the specification from the engineering drawing plus the following additional information.
- a. Application (show part identification and description).
  - b. Dimensions (thickness, tolerance, width, and length for cut lengths).
  - c. Condition (specify pickled if required, specify oiled or not oiled as required, specify chemical treatment for coated product if required).
  - d. Edges (must be specified for hot-rolled sheet and strip, that is, mill edge or cut edge).

- e. Coil size and weight requirements (must include inside diameter, outside diameter, and maximum weight).
- f. Cut length weight restrictions, that is, maximum weight of individual bundle.
- g. Heat or cast analysis and mechanical property report (if required).

**8.3** Typical specification and ordering descriptions are as follows:

- a. Hot-dip galvanized dent resistant steel per SAE J2340 CR 180A HD70G70GZ, 1.00 mm min. +0.08 thick. Cold-reduced hot-dip galvanized dent resistant sheet for a semi-exposed application, cut edge, 1625 mm wide x coil.
- b. Electro-galvanized bake-hardenable steel per SAE J2340 CR 250B EG70G70GE, 0.80 mm min. + 0.08 thick. Cold-reduced electro-galvanized bake-hardenable sheet for an exposed application, 1500 mm wide X 2540 mm.
- c. High strength low alloy steel per SAE J2340 HR 340XU, 2.50 mm min +0.30 thick. Hot-rolled high strength low alloy sheet steel, pickled and oiled, unexposed surface, 1400 mm wide X coil.
- d. Ultra high strength sheet steel per SAE J2340 CR 1300M, 1.20 mm min + 0.10 thick. Cold-reduced ultra high strength sheet steel, 1220 mm wide x coil.

**9. Thickness Tolerances**—Tolerances for dimensions are shown in SAE J1058.

**10. Tensile Samples**

**10.1 Method**

- 10.1.1 Samples should be flat and free of defects such as scores, wrinkles, die marks, etc.
- 10.1.2 For standard testing, one longitudinal 0 degree coupon is needed.
- 10.1.3 For r-Bar ( $r_m$ ) testing, one longitudinal 0 degree, one diagonal 45 degrees and one transverse 90 degrees samples are required. r Bar ( $r_m$ ) is a calculated number from individual r value tests.
- 10.1.4 Care should be taken to insure that the samples be cut exactly at 0 degree, 45 degrees, or 90 degrees to the coil rolling direction.
- 10.1.5 Tensile test shall be made with coating on.

**10.2 Preparation of Samples**

10.2.1 Method (ASTM E 8, E 517, E 646)

- 10.2.1.1 Samples must have all oils, lubricants, or dry films removed prior to measurement.
- 10.2.1.2 If base metal hardness is a desired value for correlation information, all coating must be removed from samples prior to testing.
- 10.2.1.3 Samples should be EDM (electrical discharge machining) cut if possible. If specimens are milled, preparation must be such that minimal cold work is imparted to the edges of the reduced section.

10.2.2 DIMENSIONS

- 10.2.2.1 *Gage Length*—50 mm  $\pm$  0.10 mm.
- 10.2.2.2 *Width*—12.50 mm  $\pm$  0.25 mm.

10.2.2.3 *Parallelism*

- a. Standard Testing—Reduced section must be parallel to  $\pm 0.025$  mm.
- b. *r* value Testing—Reduced section must be parallel to  $\pm 0.013$  mm.

10.2.2.4 Reduced section should be approximately 75 mm.

10.2.2.5 Overall length should be approximately 200 mm.

**10.3 Measurements**

10.3.1 EQUIPMENT

10.3.1.1 Use a digital measuring device capable of resolving to at least 0.013 mm.

10.3.1.2 Measuring device should be verified and documented with a test block or pin daily, before measurements are made.

10.3.1.3 Measuring device should be zeroed after each set of tests. If it does not return to zero, reset the device and re-measure the previous set of samples.

10.3.2 MEASUREMENT METHOD

10.3.2.1 *Standard Testing*—Measure narrowest width and thickness within the 50 mm gage marks.

10.3.2.2 *r Value Testing*—Measure at least three equally spaced width and thickness measurements across the 50 mm gage length. Average these for the initial dimensions. End gage mark must be at least 25 mm from grips.

**10.4 Testing**

10.4.1 TENSILE MACHINE OPERATING PARAMETERS—See Table 9.

**TABLE 9—TENSILE MACHINE OPERATING PARAMETERS**

	Crosshead Speed	Strain Rate
Ramp rate 1 <sup>(1)</sup>	3.0 mm/min	1.5 mm/min
Ramp rate 2 <sup>(2)</sup> to determine <i>r</i> value	12.5 mm/min	6.2 mm/min
Ramp rate 2 for all standard tensile tests	25.0 mm/min	12.5 mm/min

- 1. Ramp rate 1 is prior to and through yield or YPE.
- 2. Ramp rate 2 is after yield or YPE (yield point elongation). Either crosshead speed control or strain rate control can be used; the method must be noted in test report results. Speed of testing greatly affects stress values, making uniformity critical.

10.4.2 Machine grips should cover at least 2/3 of the gripped section of the sample.

10.4.3 Stopping point for *r* value test measurement is 17% elongation.

10.4.4 *n*-value determination range is 10% to 20% elongation, or 10% - ultimate load if uniform elongation is less than 20%. Minimum 5 data pairs. Calculation per ASTM E 646 Part 10.

10.4.5 Tensile machine repeatability and reproducibility must be performed, and results documented as defined by the quality control procedures of the testing laboratory.

## 10.5 Calculation methods

- 10.5.1 Elongation can be determined by either the piece-fit method or computer generated through the extensometer. Whatever method is used must be stated in the lab report, because piece-fit elongation is generally higher than extensometer elongation. Elongation value is invalid if the specimen breaks within 6 mm of, or outside the gage marks.
- 10.5.2 Uniform elongation is defined as the elongation value measured at peak stress.
- 10.5.3 0.2% offset yield strength will be used for all samples without YPE. For samples with YPE, the yield strength at the lowest point of discontinuous yielding shall be reported, along with the percentage of YPE.
- 10.5.4  $r$  Bar ( $r_m$ ) Value =  $(r_{90^\circ} r_{0^\circ} + 2r_{45^\circ})/4$
- 10.5.5 Earing Tendency ( $\Delta r$ ) =  $(r_{90^\circ} + r_{0^\circ} - 2r_{45^\circ})/2$

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

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## APPENDIX A

**DENT RESISTANT STEELS**  
**DATA ARE SHOWN IN THE APPENDIX FOR INFORMATION ONLY.**

**A.1 Dent Resistant Steels**—See Table A1.**TABLE A1—TYPICAL MECHANICAL PROPERTIES<sup>(1)</sup> OF DENT RESISTANT COLD-REDUCED SHEET STEEL**

SAE J2340 Grade and Type	As Received Properties Yield Strength <sup>(2)</sup> MPa	As Received Properties Tensile Strength MPa	As Received Properties Total Elongation %	As Received Properties n Value <sup>(3)</sup>	As Received Properties r <sub>m</sub> Value <sup>(4)</sup>	Yield Strength after 2% Strain MPa	Upper Yield Strength After 2% Strain and Bake MPa <sup>(5)</sup>
180 A	200	350	40	0.22	1.7	235	
180 B	200	330	39	0.21	1.6		265
210 A	230	375	38	0.21	1.7	265	
210 B	230	350	37	0.19	1.5		295
250 A	270	400	36	0.20	1.5	305	
250 B	270	370	35	0.18	1.4		335
280 A	300	430	36	0.18	1.4	335	
280 B	300	410	35	0.17	1.1		365

1. The mechanical property requirements shall be determined in longitudinal direction unless otherwise specified and shall be performed per Section 10.
2. Yield Strength is 0.2% offset or, in the presence of yield point elongation, lower yield point.
3. n value shall be calculated, per ASTM E 646, from 10 to 20% strain or to the end of uniform elongation when uniform elongation is less than 20%.
4. r value shall be calculated, per ASTM E 517, at 17% strain, r<sub>m</sub> calculation by  $(r_0 + r_{90} + 2r_{45})/4$ . The r<sub>m</sub> value can be up to 0.2 lower for thickness greater than 1.4 mm and/or galvaneal products.
5. 2% tensile prestrain and baking at 175 °C for 30 min at temperature.

**A.1.1 Determination of Strain-Hardening Index and Bake-Hardening Index**—Bake-hardening steel strength shall be determined in specimens that have been prestrained 2% and baked at 175 °C for 30 min. Standard test specimens will be taken from unstrained and unbaked material in the longitudinal (rolling) direction per ASTM A 370. Referring to Figure A1, both the bake-hardening index (BHI) and the strain-hardening index (SHI) of the material can be determined as follows in Equation 1:

$$\text{BHI} = C - B \quad (\text{Eq. A1})$$

where:

B = Flow stress at 2% prestrain

C = Yield strength (either upper or lower yield strength) after baking at 175 °C for 30 min.

$$\text{SHI} = B - A \quad (\text{Eq. A2})$$

where:

A = Initial 0.2% offset yield strength

B = Flow stress at 2% prestrain

The original specimen area is used in calculation of all engineering strengths in this test (A, B, and C). The total increase in strength from the test is reported as BHI (BHI<sub>U</sub> or BHI<sub>L</sub>) + SHI.

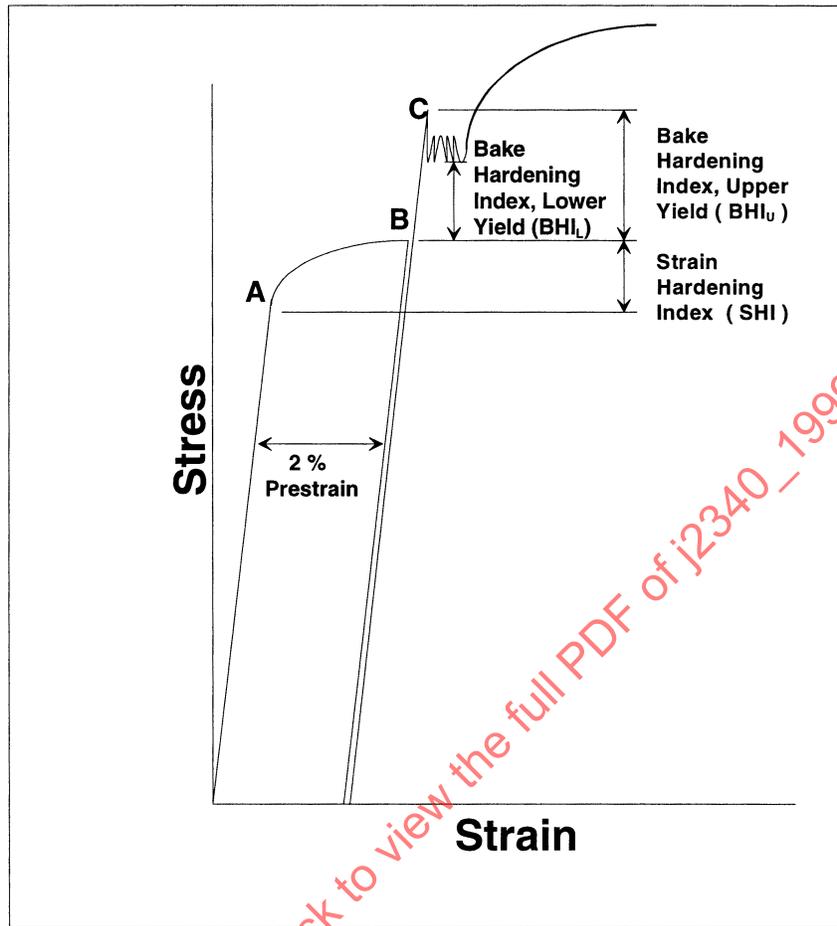


FIGURE A1—REPRESENTATION OF STRAIN-HARDENING AND BAKE-HARDENING INDEX

For the purpose of part design, it may be desirable to predict yield strength at various locations on the finished part. The yield strength for 180B, 210B, 250B, and 280B shown in Table 3 is attained by straining 2% during forming followed by a paint cycle of 30 min at 175 °C. Figure A2 approximates the changes from this yield strength with varying amounts of prestrain.

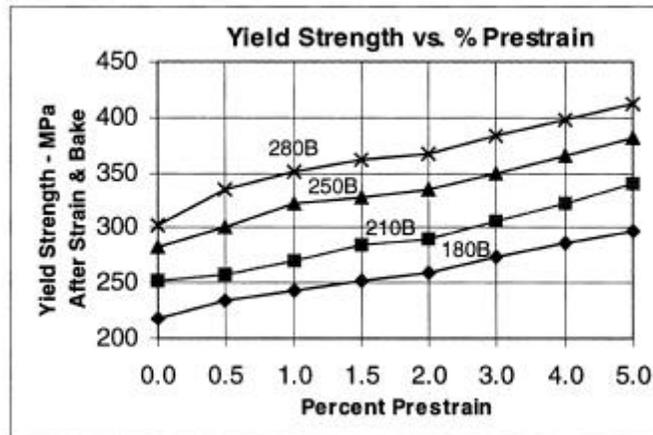


FIGURE A2—TYPICAL CHANGES TO YIELD STRENGTH WITH VARYING AMOUNTS OF PRESTRAIN