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INTERNATIONAL
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SURFACE VEHICLE RECOMMENDED PRACTICE

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

1. ***Scope—***Zinc and zinc-alloy coated steel is used to enhance a structure's protection against corrosion degradation. For the purpose of this SAE Recommended Practice, a galvanized coating is defined as a zinc or zinc-alloy metallic coating. The selection of the optimum galvanized steel sheet product depends on many factors, the most important being: desired corrosion protection, formability, weldability, surface characteristics, and paintability. The trade-offs of these product characteristics are more complex than is the case with uncoated steel sheet products.

1.1 **Purpose—**This document defines preferred product characteristics. It also explains the various manufacturing processes, presents the advantages and disadvantages of the resulting product characteristics, and discusses the trade-offs between corrosion protection properties and fabricating, assembling, and finish-coating process.

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 version of SAE publications shall apply.

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

SAE J1392 JUN84—Steel, High Strength, Hot Rolled Sheet and Strip, Cold Rolled Sheet, and Coated Sheet
SAE J2329 MAY97—Categorization and Properties of Low-Carbon Automotive Sheet Steels
SAE J2340 OCT1999—Categorization and Properties of Dent Resistant, High Strength, and Ultra High Strength Automotive Sheet Steel

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

ASTM A90—Test Method for Weight (Mass) of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings
ASTM A653/A653M—Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process
ASTM A754—Test Method for Coating Thickness by X-Ray Fluorescence
ASTM A879-96—Specification for Steel Sheet, Zinc Coated by the Electrolytic Process for Applications Requiring Designation of the Coating Mass on Each Surface

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3. ***The Galvanizing Process—***Two generic processes for metallic coated steels are currently used in the automotive industry: (1) hot-dipped coating and (2) electrolytic coating. Coating line conditions can be adjusted to produce a variety of coating masses and coating compositions.

3.1 **The Hot-Dip Process—**The uncoated coil product is usually annealed in-line or in a separate furnace. The steel is then passed continuously through a molten metal bath. Upon emergence from the bath, the molten metal coating mass is controlled by air (or other gas) knives or mechanical wipers before the coating solidifies. This produces the commonly used two-side zinc-coated sheet.

3.2 **The Electrodeposition Process—**Electrolytic coating is done in a continuous coating process using cells in which the metals are electrodeposited on pre-annealed steel. Coating mass is controlled by the electrodeposition rate in the plating cells. This product is available in one or two side coated sheet.

4. ***The Galvanized Coating—***The galvanized coating is applied to the steel sheet prior to delivery to the fabricating plant. The coating remains substantially intact through subsequent forming, and painting operations. The coating provides both barrier and sacrificial protection.

4.1 **Composition of Coatings**

4.1.1 TYPES OF COATINGS[1]—Types of commercially produced coatings include: (1) zinc, (2) zinc-iron (<20% iron) alloys, (3) aluminum-zinc silicon (55, 43, and 2 weight percent respectively) alloy, (4) zinc-aluminum (5% aluminum) alloy, and (5) zinc-nickel (<20% nickel) alloy. Coatings (1) and (2) can be applied by either electroplating or hot-dip coating. Coatings (3) and (4) are applied by hot-dip coating while coating (5) is applied by electroplating.

4.1.2 ZINC COATINGS—Coatings that are considered essentially pure zinc coatings are typically referred to as hot-dip galvanized or electrogalvanized. Hot-dip galvanized coatings may contain small amounts of aluminum, lead, and antimony which are added to enhance coating properties. Electrogalvanized coatings are typically high-purity zinc and control only trace amounts of other elements.

4.1.3 ALLOY COATINGS—The most common alloy coatings are zinc-iron alloys. They are used to enhance spot welding and certain aspects of paintability. Zinc-iron coatings can be produced by the electroplating process in which zinc and iron are codeposited onto the steel sheet surface. The iron content of the coating is controlled by adjustment of electrolytic solution and plating current.

When processed on a hot-dip coating line, the zinc-iron coating is called Galvannealed and is produced using a thermal process after hot dipping. This process promotes diffusion of iron from the steel base into the coating which typically contains an average of 8 to 12% iron.

Aluminum-zinc-silicon and zinc-aluminum hot-dip alloyed coatings are produced by conventional hot-dip coating processes. The molten coating bath contains approximately the same composition as the coating on the steel.

Zinc-nickel (<20% nickel) alloy electroplated coatings are produced by conventional electroplating techniques. The plating electrolyte contains zinc and nickel ions that are codeposited as an alloy mixture.

4.2 **Coating Mass—**This document addresses the needs of automotive engineering by identifying the coating masses most commonly used in component design and by expressing the coating mass measurements as a minimum and maximum single-spot test for a given side. For example, 70 g/m^2 is the minimum coating mass on a single-spot test for the designated side of coating Category 70. The maximum coating mass for this Category is 100 g/m^2 for hot-dip galvanized products, or 90 g/m^2 for electroplated products.

1. All coating compositions included in t his section are approximate values in mass percent.

This definition of coating mass represents a departure from the practice described in ASTM methods A653 and A653M for hot-dipped galvanized steel sheet, and ASTM method A879-93, except for Table 1, for electrolytic zinc-coated steel sheet. The ASTM Standard Specifications have been the principal public standards prior to the publication of this document.

The thickness of the coating is not an acceptable practice for specifying the quantity of coating to be deposited on the base steel.

4.3 Coating Designation—This document uses a nine-character designation that identifies the coating process, coating mass, and coating composition of each side, and the intended use of the coated steel with regard to the surface appearance quality required, i.e., exposed and unexposed. The terms “exposed” and “unexposed” are not related to corrosion requirements. The coating designation shall be stated using the following procedure:

a. 1st and 2nd Character—represent the coating process where HD = hot dip galvanized, and EG = electrogalvanized
b. 3rd and 4th Character—The numbers shown in the “Coating Mass Category” column of Table 1 indicates the coating mass of the unexposed side
c. 5th Character—Coating composition of the unexposed side where G = zinc coating, A = zinc-iron coating, N = zinc-nickel coating, X = other than G, A, or N
d. 6th and 7th Character—The numbers shown in the “Coating Mass Category” column of Table 1 indicates the coating mass of the other side (exposed side, if applicable)
e. 8th Character—Coating composition of the other side (exposed side, if applicable) where G = zinc coating, A = zinc-iron coating, X = other than G, A, or N
f. 9th Character—Intended use where E = exposed, U = unexposed, and Z = semi-exposed

TABLE 1—RECOMMENDED COATING MASS FOR GALVANIZED STEEL SHEET

Coating mass Category	Coating Mass Per Side Single Spot Test Hot Dipped and Electroplated min g/m^2	Coating Mass Per Side Single Spot Test Hot Dipped max g/m^2	Coating mass Per Side Single Spot Test Electroplated max g/m^2
00	00	NA	00
20	20	50	30
30	30	60	45
40	40	70	55
45	45	75	60
50	50	80	70
55	55	85	75
60	60	90	80
70	70	100	90
90	90	120	110
98	98	130	130

NOTE: For approximate conversion from mass to thickness, use:
microns = g/m^2 x 0.14
mils = g/m^2 x 0.006

Examples of the more commonly used galvanized steels expressed in terms of Table 1 are:

EG70G70GE = 70 g/m^2 minimum of zinc coating on each side for an exposed application.
HD70G20AE = 70 g/m^2 minimum of zinc coating on the unexposed side and 20 g/m^2 minimum of zinc-iron coating on the exposed side for an exposed application.
HD90G90GU = 90 g/m^2 minimum of zinc coating on each side for an unexposed application.
HD45A45AU = 45 g/m^2 minimum of zinc-iron coating on each side for an unexposed application.
EG30N30NE = 30 g/m^2 minimum of zinc-nickel coating on each side for an exposed application.
EG70G00XE = 70 g/m^2 minimum of zinc coating on the unexposed side and no coating on the exposed side ("one-side") for an exposed application.

4.4 Coating Mass Determination—The coating mass requirements in Table 1 refer to any single spot test per side.

There are several methods of determining coating mass. Modern galvanizing lines use X-ray fluorescence techniques described in ASTM method A754 to continuously monitor coating mass throughout the coil during the galvanizing process. The referee method is the "weigh-strip-weigh" method as described in ASTM method A 90 except, coating on each side must be measured separately.

4.4.1 MINIMUM COATING MASS—If the initial testing produces a value less than the minimum shown in Table 1, two additional test specimens shall be taken from the same lift of blanks or cut lengths or coil, except that no portion of the retest specimen may be any closer than 25 mm to the edge of the as-received steel. Both retests must conform to the minimum value of Table 1 for the Coating Mass Category specified; otherwise, the lift of blanks or cut lengths or coil can be considered unacceptable.

4.4.2 MAXIMUM COATING MASS—If the initial testing produces a value more than the maximum shown in Table 1, three additional test specimens shall be taken from the same lift of blanks or cut lengths or coil, except that no portion of the retest specimen may be any closer than 25 mm to the edge of the as-received steel. The average of the three retest specimens must conform to the maximum value of Table 1 for the Coating Mass Category specified, and no retest specimen may exceed the maximum in Table 1 by more than 30%. Otherwise, the lift of blanks or cut lengths or coil can be considered unacceptable.

4.5 Coated Surface Finish and Conditions—The user of galvanized steel should specify either exposed (E), semi-exposed (Z), or unexposed (U), surface quality as required (see 4.3). The steel supplier's responsibility is to supply a galvanized surface finish suitable for the application.

The following coated surfaces and conditions are available. References to spangle conditions do not apply to zinc-iron or electrodeposited coatings since these coatings do not develop spangles. Unexposed (U) hot-dip applications should be supplied with a minimized spangle surface finish.

4.5.1 REGULAR SPANGLE (HOT-DIPPED ONLY)—A commonly seen type of coating in non-automotive markets is regular spangle, typified by the flower-like or snowflake-like design (spangle pattern) that results from an uneven topographical relief, which shows prominently through most primer/paint systems used in the automotive industry. Regular spangle coatings are not considered acceptable for automotive applications.

4.5.2 MINIMIZED SPANGLE (HOT-DIPPED ONLY)—By application of various processing techniques during the transition period when the zinc coating freezes, the size and texture of the developing spangle can be altered (refined) substantially. The intent of these processing techniques is to produce very small spangles, and thereby, decrease the surface roughness associated with relief of the spangles normally formed. The surface finish of minimized spangle may be suitable for some less visible exposed applications. When the spangle is minimized to the extent that it is not visible to the unaided eye, the finish is termed spangle-free. Product intended for "U," Unexposed applications.

4.5.3 EXTRA SMOOTH (HOT-DIPPED ONLY)—Following the galvanizing operation, rolling processes can be used to improve the smoothness of the zinc-coated steel. The most frequently used rolling process is called temper rolling (skin passing). This additional processing step is used to produce a very uniform matte surface that is readily painted. Usually, the extra smooth product is produced by temper rolling minimized spangle product. Product intended for "Z," Semi-exposed applications.

In addition to enhancing the painted surface quality, extra smooth processing minimizes or eliminates the objectionable appearance of fluting or stretcher strains.

4.5.4 EXTRA SMOOTH SPANGLE FREE (HOT-DIPPED ONLY)—This product is produced by temper rolling a spangle free coating. Product intended for "E," Exposed application.

4.5.5 PHOSPHATE-TREATED—Hot-dipped and electrogalvanized sheets for automotive applications can be treated with either a crystaline-phosphate coating, applied by spray or dipping, or an amorphous phosphate coating, applied by roll coating. The phosphate coating is applied between 0.5 to 1.5 g/m^2 followed by oiling. The treatment has been found to enhance the formability of galvanized (chiefly zinc-iron alloy and electrogalvanized) sheet, and eliminates the need for draw die lubrication at the press line.

4.5.6 CHEMICALLY TREATED—Chromium compound chemical treatments can be applied in-line on galvanizing lines to provide protection against wet storage straining. However, these chemical treatments are not used for automotive applications since they adversely affect automotive cleaning, phosphating, and painting processes.

4.5.7 MILL OILS—Special oil is applied by the manufacturing facility after the base metal is coated. The purpose of this oil is to provide protection from oxidation staining during shipment to the buyer's facility and for a reasonable storage period.

4.5.8 PRELUBRICATED—Galvanized steel sheet can be processed with special lubricants that are applied by the steel mills to replace both mill oils (used for rust prevention) and drawing compounds applied at stamping plants.

5. Characteristics of Galvanized Steel Sheet

5.1 Thickness Definition—The thickness of galvanized steel sheet is determined by measuring as a single unit the combination of the base metal and all galvanized coatings.

5.2 Formability—For a given forming process, the steel sheet is only one element in the system. Forming is also influenced by such factors as the nature of the press, die design, blank/part shape, and lubrication. Since manufacturing conditions may vary, it is recommended that the producer and user consult regarding the features involved in specific applications.

The majority of hot-dip galvanized steel is produced on in-line annealing lines. For conventional steel compositions and standard processing, the relatively short annealing cycles plus exposure to a pot temperature in the vicinity of 460 °C, result in formability properties different from batch annealed cold-rolled steel. Recent technical developments can minimize these differences. Through the use of special extra low carbon steels, interstitial-free steels, or with extra processing of conventional grades, it is now possible to obtain in-line annealed and out-of-line annealed hot-dip galvanized steel with mechanical properties equivalent to cold-rolled steel sheet.

In contrast to the hot-dip process, electrolytic zinc coatings are applied in an environment near room temperature and the coating process does not significantly affect the mechanical properties of the incoming steel. These steels can, therefore, be designed for specific properties by various compositional and thermomechanical treatments prior to coating with the assurance that the properties will not be altered by the coating process.

5.3 Coating Adhesion—Coated steels are susceptible to flaking and powdering during forming which can result in die-pickup. Additional die cleaning and maintenance is usually required in stamping plants when forming galvanized steel parts as compared to uncoated steel parts.

Pure zinc coatings are soft and malleable with good coating adhesion. The soft nature of the zinc coating relative to the steel requires that more attention be paid to handling damage and scratches during forming operations. The zinc-alloy coatings are harder and more brittle, making them more susceptible to flaking and powdering.

5.3.1 BEND TESTING—Test specimens of coated sheet shall be capable of being bent through 180 degrees in any direction without flaking of the coating on the outside bend only. The coating bend test inside diameter shall have a relation to the thickness of the specimen as shown in ASTM method A653/A653M.

5.3.2 POWDERING AND FLAKING TESTS—Alloy coated sheet products which tend to powder and/or flake, are evaluated by numerous test methods, therefore customers should be contacted for their specific test method requirements and acceptance criteria. The more common test methods used in the automotive industry are: (1) double reverse olsen cup adhesion test, (2) draw bead test, and (3) 60 and 90 degrees reverse bend test.

5.4 Base Metal Quality—Galvanized steel sheet is available in the chemical compositions and mechanical properties normally produced for uncoated steel sheet. Base metal quality is dependent upon user requirements. This is normally expressed by a grade designation with reference to specific forming properties (see SAEJ2329 MAY97) for low-carbon steels, or (see SAE J1392 JUN84 and J2340 OCT1999) high-strength steels.

5.5 Weldability—The welding of zinc-coated steels is more difficult than uncoated steels. This is true whether the coating is applied electrolytically or by hot-dip processing. The major drawbacks in resistance welding of zinc-coated steels are a reduction in useful electrode life, and an increase in the required welding currents and times. Once these problems are properly addressed, however, zinc-coated steels can be satisfactorily welded. The following general comments apply: Lighter coatings and less variation generally improve welding performance. Zinc-iron coatings are generally more readily welded than zinc coatings. The behavior of differentially coated (including one side coated materials) depends upon the orientation of the coating with regard to the welding electrodes.

Zinc-coated steels can also readily be welded by any of the arc welding processes or by high energy techniques (laser, electron beam, for example). The primary problem is usually associated with zinc fumes and their possible health hazards. These can usually be negated with proper venting.

The cosmetic appearance of spot welds on galvanized steel sheet is different from spot welds used on uncoated steel sheet.

5.6 Adhesive Bonding—Adhesive bond strength is a function of the type of coated steel.

5.7 Paintability—Parts fabricated from galvanized steel sheet are readily primed and top coated. As in all cases, the components to be painted should be thoroughly cleaned prior to the application of pretreatments, primers, and top coats. Of particular note is that pretreatments are different for galvanized steel than those used for uncoated steel.

6. Corrosion—Corrosion is primarily an electrochemical phenomenon that degrades appearance and structural integrity. Physical design, chemical, and mechanical factors are often involved in the corrosion process.

In galvanized steel sheet, zinc protects the base metal through two mechanisms. The first is its action as a simple barrier which prevents contact to the base metal with the corrosive environment. The second is by acting as a sacrificial anode, commonly referred to as “galvanic protection.” This mechanism serves to protect the base metal even if the zinc coating is locally damaged. Some corrosion protection is even offered to the

uncoated cut edge of galvanized sheet.

Unpainted galvanized sheet generally offers protection from corrosion of the base metal in direct proportion to the coating weight. Painted galvanized sheet enhances protection compared to unpainted galvanized, but in varying degrees that are dependent upon the metal preparation prior to painting, the type of organic coating, and the thickness of the organic coating.

7. Marking and Identification—It is recommended that the seller and buyer agree to marking and identification requirements prior to placing orders for galvanized steel sheet. A review of these requirements will help reduce the potential for misapplication of material due to the variety of coating masses and compositions used in many manufacturing facilities. The marking should be made at the seller's facility directly on the coated steel surface, preferably in a continuous process. This allows blanks and cut lengths to be identified throughout fabrication up to the point of painting or a subsequent application of a coating.

In determining the type and location of markings, the following conditions should be considered:

a. Exposed side versus unexposed side (marking the exposed side should be avoided, if possible)
b. Differential coating masses, e.g., Coating Mass Category 90 on one side and Coating Mass Category 70 on the other side
c. Differential Coating Compositions, e.g, zinc on one side and zinc-iron on the other side

Identification markings should include:

a. Name or commonly recognized mark, e.g., logo, that identifies manufacturer
b. Coating designation (see 4.3), e.g, EG70G70GE, HD45A45AU, EG98G00XE

Other identification markings and special locations of the markings should be discussed with the seller to determine the capability of performing. Such markings could include the manufacturers location (mill), date coated, specification number, heat number, and coil number.

8. Recommended Ordering Information—When galvanized steel sheet is ordered, the following information should be considered so that adequate description of the required material is communicated to the producer.

a. Product name (hot-dip galvanized sheet or electrodeposited galvanized steel sheet or galvanized steel sheet which permits the producer to apply either coating process)
b. Base metal quality (low-carbon automotive grade, high strength, public, and proprietary specification)
c. Coating designation (see 4.3)
d. State whether or not chemical treatment is required
e. State whether oiled or not-oiled is required
f. Coated surface finish and condition (specify only if hot-dip coating, and application requires other than extra smooth or extra smooth-spangle free for exposed application, or other than minimized spangle for unexposed application)
g. phosphate treated (if required)
h. Mill lube treated (if required - state specific name of lubricant)
i. Dimensions (thickness, width, length, if cut length)
j. Coil size requirements (ID, OD, maximum weight) if required
k. Application (part name)
l. Part number
m. Special requirements not identified by any of the preceding