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Properties of Galvanized Low Carbon Sheet Steels and Their Relation to Formability

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SAE The Engineering Society For Advancing Mobility Land Sea Air and Space
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MATERIALS REPORT

SAE J1852

Issued Sept. 1987

PROPERTIES OF GALVANIZED LOW CARBON SHEET STEELS AND THEIR RELATION TO FORMABILITY

1. SCOPE: The purpose of this SAE Information Report is to describe those properties of galvanized low carbon sheet steel which relate to its formability; that is, its ability to be formed with the structural, dimensional and surface integrity to fulfill the design intent.

2. CITATION: The American Iron and Steel Institute has published a guide to The Forming of Galvanized Sheet Steels, (AISI Document SG-539). This SAE Information Report reproduces those sections of the AISI document specifically devoted to the properties of the galvanized sheet steels.

   Copies of the complete publication can be obtained from: American Iron and Steel Institute, 1000 16th Street, Washington, DC 20036.

3. INTRODUCTION: The need of the automotive industry to improve the corrosion resistance of vehicles has resulted in a greater use of coated steel sheets in place of the traditional uncoated cold rolled steel sheets for automobile bodies.

   Compared with uncoated steel sheets, coated steels have different characteristics that can be expected to affect automotive manufacturing operations such as stamping, welding and painting. The purpose of this publication is to characterize the features of coated steel sheets and to indicate how these features (especially where they differ from uncoated sheets) influence formability in stamping operations.

   Two material related factors greatly influence the formability of coated sheets - the steel substrate and the coating.

   - The steel substrate is more important than the coating because 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). Thus, just as mechanical properties are very important to the formability of uncoated cold rolled steel, so too are they important to the formability of coated sheets.

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3. (Continued):

- The characteristics of the coating, 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.

Both these factors, the substrate and the coating, are influenced markedly by the method used by the steel manufacturer to produce the coated sheet. Because there are a variety of production methods, different mechanical properties and coatings can exist. These combinations of properties and coating types offer the steel user a broad range of product performance features.

4. FORMABILITY OF THE STEEL SUBSTRATE: Because of the large number of automotive parts produced from steel sheets, formability requirements range from simple to complex. To accommodate these requirements, the steel industry offers coated sheets with different levels of formability and, accordingly, cost. Consequently, it is possible to make a most cost-effective selection of a coated sheet for any part configuration.

As it is with uncoated cold rolled sheets, the formability of coated sheets is influenced by steel composition, microcleanliness, thermomechanical processing conditions used in hot rolling, cold rolling and annealing, and by the amount of temper rolling or leveling.

4.1 Coating Processes and Their Impact on Substrate Formability: Before categorizing coated sheets according to the formability of their steel substrates, it should be recognized that the coating method can affect the metallurgical structure of the substrate which, in turn, can affect the formability of the coated sheet as follows:

4.1.1 Hot Dipped Galvanizing: In the most common method for continuous hot dipped galvanizing, the sheet reaches one of two different temperature regions depending on the nature of the process and metallurgical properties required.

- Low Temperatures of about 455° to 480°C (850° to 900°F) are attained when a cooler, flux-cleaned strip enters the hotter zinc pot or when preheating is done to ensure that the sheet is at the same temperature as the molten zinc bath. These lowline temperatures are usually used when the cold rolled steel has been pre-box annealed to obtain a soft, ductile structure that exhibits good formability.

- High Temperatures of about 675° to 900°C (1250° to 1650°F) are employed to achieve in-line annealing and replace pre-box annealing. Because the in-line annealing is of short duration and higher temperature, compared with box annealing, different metallurgical reactions occur. For conventional carbon steels (0.015 to 0.15% carbon), the heating during the hot dipped galvanizing, and the associated rapid cooling, causes excess carbon to remain in solution in the steel. This carbon tends to reduce the formability of the steel compared with box annealing. For this reason, post heat treating at 260° to 290°C (500° to 550°F) is often practiced to precipitate carbon and hence restore some of the formability. Alternatively, when extra low carbon

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4.1.1 (Continued):

(<0.01% carbon) interstitial-free steels are used, post heat treating is not necessary because the carbon is combined (stabilized) by alloying elements such as columbium and titanium, and excellent formability is obtained.

4.1.2 Electrogalvanizing: The electrogalvanizing process is conducted slightly above normal room temperature. Consequently, the mechanical properties of electrogalvanized sheet are almost identical to box annealed cold rolled sheet, although some minor effects may occur because of in-line tension or bending.

For the above reasons, substrate formability of electrogalvanized sheet closely approximates that of cold rolled sheet.

4.2 Steel Substrates: Specific combinations of steel composition and processing conditions result in four principal categories of steel substrates for coated sheets.

4.2.1 Commercial Quality (CQ) Steel Sheets: These coated sheets are produced from either ingot cast rimmed and capped steels or from ingot or continuous cast aluminum-killed steels. Aluminum-killed steels are usually less sensitive to strain aging at room temperature than rimmed and capped steels.

Typical[1] properties of the steel substrates after being processed by hot dipped galvanized or electrogalvanizing are shown in Table 1.

4.2.2 Drawing Quality (DQ) Steel Sheets: These sheets are also produced from either ingot cast, rimmed/capped and aluminum-killed steels or from continuous cast aluminum-killed steels. The DQ steels are made to compositions and processing conditions more restrictive than those used for CQ steels. As a result, they exhibit somewhat better formability than CQ steels.

Typical properties of the steel substrates of DQ steels are shown in Table 2.

4.2.3 Drawing Quality Special-Killed or Aluminum-Killed (DQSK or DQAK) Steel Sheets: The highly formable aluminum-killed steel sheets can be divided into subcategories according to the carbon content of the steels and the processing conditions as follows:

- DQSK - Low Carbon Steels (LC) - These steels usually contain 0.015 to 0.15% carbon (and for the most part 0.04 to 0.06% carbon). For hot dip galvanized products, they are either in-line annealed or pre-box annealed and post heat treated (box annealed). Typical properties are shown in Table 3.

[1]The mechanical properties listed in Tables 1 to 5 are typical of the specific steel category and are not meant to represent averages or median values.

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4.2.3 (Continued):

- DQSK - Extra Low Carbon Steels (ELC) - These steels are produced by special steelmaking practices to achieve very low carbon contents (0.002 to 0.015% carbon) and excellent microcleanliness. There are two types:

  - Stabilized (Interstitial-Free) Steels - in which the low residual carbon content is combined (or fully stabilized) with alloying additions such as columbium or titanium. For hot dipped products, these steels can be in-line annealed or pre-box annealed. (No post annealing is necessary for these steels because the carbon is fully stabilized by the alloying elements present.) Electrogalvanized interstitial-free steels have substrate properties (formability) as good as their box annealed counterparts.

  - Nonstabilized Steels - contain no strong carbide-forming alloying elements (Cb, Ti, etc.) and, hence, are unlike interstitial-free steels. For this reason, nonstabilized steels require a pre-box anneal plus post annealing to develop the maximum level of formability.

  Table 4 lists the representative properties of DQSK extra low carbon steels.

4.2.4 <u>High Strength Steels</u>: These steels usually contain special strengthening agents (such as phosphorus, manganese, columbium, vanadium or titanium). By judicious combinations of the steel composition and processing practice, a number of strength levels can be obtained. Typical mechanical properties are shown in Table 5.

5. <u>EFFECTS OF GALVANIZED COATINGS ON FORMABILITY</u>: The formability of the zinc coated steels depends both upon the properties of the substrate and the characteristics of the coating. To some extent, the variety of substrate properties from different steel manufacturers has contributed to confusion in the substitution of galvanized steels for cold rolled steels. Recent changes in steelmaking practices have improved the mechanical properties of some of the hot dipped galvanized products to the point where their formability is about equivalent to that of the uncoated cold rolled product.

In general, experience has shown that the substrate properties are more important than those of the galvanized coatings. There are, of course, exceptions to this and there are applications where the surface characteristics of the galvanized coatings become very important. These surface characteristics can change the frictional behavior during the forming process. This is especially true for prototype or soft tool programs where results have shown that galvanized sheets behave differently from cold rolled sheets, even when the substrate properties are similar. For example, it has been established that one of the primary reasons for the poorer performance of the galvannealed steels during tooling development is because there is an interaction between the galvannealed surface and the soft prototype tooling. This produces high frictional forces that adversely affect formability.

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5. (Continued):

It must be recognized that sheet metal forming is a complex process involving interactions among the material being formed, the tooling and the lubricants. While all are important, under certain circumstances one may overshadow the others. What may be found to work well for one material under one set of conditions may not work well for that same material on another part. For example, because of the material-tool-lubricant interactions, comparison between galvannealed and bare steel on soft prototype tooling using the same lubricant may result in the galvannealed steel exhibiting poorer forming performance than would be expected for hard production tooling. For such cases, the soft prototype tool trials may be misleading. It is suggested that different lubricants may be required for soft prototype tool and hard production tool conditions. Furthermore, because of these interactions, it may be more fruitful to use a different type of steel and/or coating for the prototype tool trials than will be used under production conditions.

An area of considerable research today is the study of the interaction between galvanized surfaces and forming lubricants. The coating surface topography will determine to a great extent the ability of that coating to carry lubricant into the die forming operation.

6. EFFECTS OF SURFACE CHARACTERISTICS ON FORMABILITY: It is recognized that different finishing techniques affect the surface characteristics of galvanized coatings, and in turn, these surface characteristics have an effect on the formability of galvanized steel.

In addition, tooling materials and tooling surface treatments have a significant effect on formability.

Quantitative data in this area is limited and further research is needed.

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TABLE 1 - TYPICAL SUBSTRATE MECHANICAL PROPERTIES OF CQ STEELS

Type of Steel	Yield Strength MPa (ksi)	Ultimate Tensile Strength MPa (ksi)	Percent Total Elongation 51 mm (2 in)	r_m*	$\bar{n}$**
Hot-Dipped Galvanized (all Coatings, including Two Sides, One Side, Fully Alloyed Zinc-Iron, Differentially Coated)	276 (40)	352 (51)	34	1.1	0.18
Electrogalvanized (all Coatings, including Two Sides, One Side, Fully Alloyed Zinc-Iron, Differentially Coated)	234 (34)	331 (48)	38	1.2	0.20
Uncoated Cold Rolled (for comparison)	234 (34)	331 (48)	38	1.2	0.20

*r_m (average normal plastic anisotropy) = $(r_l + 2r_{45} + r_t)/4$

**$\bar{n}$ (average strain hardening exponent) = $(n_l + 2n_{45} + n_t)/4$

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TABLE 2 - TYPICAL SUBSTRATE MECHANICAL PROPERTIES OF DQ STEELS

Type of Steel	Yield Strength MPa (ksi)	Ultimate Tensile Strength MPa (ksi)	Percent Total Elongation 51 mm (2 in)	r_m	$\overline{n}$
Hot-Dipped Galvanized (all coatings included)	255 (37)	345 (50)	37	1.1	0.20
Electrogalvanized (all coatings included)	207 (30)	324 (47)	39	1.2	0.21
Uncoated Cold Rolled (for comparison)	207 (30)	324 (47)	39	1.2	0.21

TABLE 3 - TYPICAL SUBSTRATE MECHANICAL PROPERTIES OF DQSK (Low Carbon) STEELS

Type of Steel	Yield Strength MPa (ksi)	Ultimate Tensile Strength MPa (ksi)	Percent Total Elongation 51 mm (2 in)	r_m	$\overline{n}$
Hot-Dipped Galvanized (all coatings included)					
Conventional In-Line Anneal Plus Post Heat Treat	228 (33)	338 (49)	39	1.2	0.20
Pre-Box Anneal Plus Post Heat Treat	207 (30)	317 (46)	41	1.6	0.21
Electrogalvanized (all coatings included)	187 (27)	303 (44)	43	1.6	0.22
Uncoated Cold Rolled (for comparison)	187 (27)	303 (44)	43	1.6	0.22
Zincrometal (for comparison)	193 (28)	310 (45)	41	1.6	0.21

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TABLE 4 - TYPICAL SUBSTRATE MECHANICAL PROPERTIES OF DQSK (Extra Low Carbon) STEELS

Type of Steel	Yield Strength MPa (ksi)	Ultimate Tensile Strength MPa (ksi)	Percent Total Elongation 51 mm (2 in)	r_m	$\bar{n}$
Hot-Dipped Galvanized (all coatings included)					
Extra Low Carbon - Stabilized (Interstitial Free)					
In-Line Annealed	193 (28)	331 (48)	42	1.6	0.21
Pre-Box Annealed	172 (25)	331 (48)	46	2.0	0.24
Extra Low Carbon - Nonstabilized					
In-Line Annealed plus Post Anneal	187 (27)	297 (43)	44	1.3	0.24
Pre-Box Annealed plus Post Anneal	179 (26)	290 (42)	44	1.6	0.24
Electrogalvanized (all coatings included)					
Interstitial Free	172 (25)	331 (48)	44	2.0	0.23
Uncoated Cold Rolled (for comparison)					
Interstitial Free	165 (24)	331 (48)	47	2.0	0.24
Zincrometal (for comparison)					
Interstitial Free	179 (26)	338 (49)	45	2.0	0.23

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