Standard Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement[1]

This standard is issued under the fixed designation A 143; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This practice covers procedures that can be followed to safeguard against the possible embrittlement of steel hot-dip galvanized after fabrication, and outlines test procedures for detecting embrittlement. Conditions of fabrication may induce a susceptibility to embrittlement in certain steels which can be accelerated by galvanizing. Embrittlement is not a common occurrence, however, and this discussion does not imply that galvanizing increases embrittlement where good fabricating and galvanizing procedures are employed. Where history has shown that for specific steels, processes and galvanizing procedures have been satisfactory, this history will serve as an indication that no embrittlement problem is to be expected for those steels, processes, and galvanizing procedures.

1.2 The values stated in inch-pound units are to be regarded as the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Terminology

2.1 *Definition*:

2.1.1 *embrittlement*—the loss or partial loss of ductility in a steel. An embrittled product characteristically fails by fracture without appreciable deformation. Types of embrittlement usually encountered in galvanized steel are related to aging phenomena, cold working, and absorption of hydrogen.

3. Factors in Embrittlement

3.1 Embrittlement or loss of ductility in steel is often associated with strain-aging. Strain-aging refers to the delayed increase in hardness and strength, and loss of ductility and impact resistance which occur in susceptible steels as a result of the strains induced by cold working. The aging changes proceed slowly at room temperature, but proceed at an accelerated rate as the aging temperature is raised and may occur rapidly at the galvanizing temperature of approximately 850°F (455°C).

3.2 Hydrogen embrittlement may also occur due to the possibility of atomic hydrogen being absorbed by the steel. The susceptibility to hydrogen embrittlement is influenced by the type of steel, its previous heat treatment, and degree of previous cold work. In the case of galvanized steel, the acid pickling reaction prior to galvanizing presents a potential source of hydrogen. However, the heat of the galvanizing bath partially expels hydrogen which may have been absorbed. In practice hydrogen embrittlement of galvanized steel is usually of concern only if the steel exceeds approximately 150 ksi (1100 MPa) in ultimate tensile strength, or if it has been severely cold worked prior to pickling.

3.3 Loss of ductility of cold-worked steels is dependent on many factors including the type of steel (strength level, aging characteristics), thickness of steel, and degree of cold work, and is accentuated by areas of stress concentration such as caused by notches, holes, fillets of small radii, sharp bends, etc.

3.4 Low temperatures increase the risk of brittle failure of all plain carbon steels including steel that has been galvanized. The rate at which this temperature loss of ductility occurs varies for different steels. The expected service temperature should thus be taken into account when selecting the steel.

4. Steels

4.1 Open-hearth, basic-oxygen, and electric-furnace steels shall be used for galvanizing.

5. Cold Working and Thermal Treatment

5.1 For intermediate and heavy shapes, plates, and hardware, cold bend radii should not be less than that which is

[1] This practice is under the jurisdiction of ASTM Committee A-5 on Metallic Coated Iron and Steel Productsand is the direct responsibility of Subcommittee A05.13 on Structural Shapes and Hardware Specifications.

Prepared by Subcommittee A05.10 on Embrittlement Investigation of Committee A-5 on Corrosion of Iron and Steel and based on an investigation made by Battelle Memorial Institute under American Society for Testing and Materials' sponsorship. See *Proceedings*, Am. Soc. Testing Mats., Vol 31, Part I, 1931, p. 211; also paper by Samuel Epstein, "Embrittlement of Hot-Galvanized Structural Steel," see *Proceedings*, Am. Soc. Testing Mats., Vol 32, Part II, 1932, p. 293.

Current edition approved Nov. 4, 1974. Published January 1975. Originally published as A 143 – 32 T. Last previous edition A 143 – 72.

proven satisfactory by practice or by the recommendations of the steel manufacturer. These criteria generally depend on the direction of grain, strength, and type of steel. A cold bending radius of three times (3×) the section thickness, or as recommended in *AISC Manual of Steel Construction*,[2] will ordinarily ensure satisfactory properties in the final product. Although sharper bending on thin sections can usually be tolerated, embrittlement may occur if cold bending is especially severe. If the design requires sharper bending than discussed herein, the bending should be done hot, or if done cold the material should be subsequently annealed or stress relieved as noted in 5.3.

5.2 Smaller shapes, including thicknesses up to ¼ in. (6.35 mm) may be cold worked by punching without subsequent annealing or stress-relieving. Shapes 5⁄16 to 11⁄16 in. (7.94 to 17.46 mm) in thickness are not seriously affected as to serviceability by cold punching or if the punching is done under good shop practice. The heavier shapes ¾ in. (19.05 mm) and over shall be reamed by at least 1⁄16 in. (1.59 mm) of metal removed from the periphery of the hole after punching, or shall be drilled, or thermally treated prior to galvanizing as noted in 5.3.

5.3 Fabrication in accordance with the principles outlined in 5.1 and 5.2 will normally obviate the need for thermal treatment. However, if required, proper thermal treatment shall precede galvanizing of the steel. For heavy cold deformation exemplified by cold rolling, sheared edges, punched holes, or cold-formed rods and bolts, subcritical annealing at temperatures from 1200 to 1300°F (650 to 705°C) should be employed. For less severe cold deformation typified by cold bending, roll forming, etc., it is advisable to limit the thermal treatment to stress relieving at a maximum of 1100°F (595°C) to avoid excessive grain growth or alternatively to fully normalize the steel at temperatures from 1600 to 1700°F (870 to 925°C). The time at temperature should be approximately 1 h/in. (25.4 mm) of section thickness.

6. Preparation for Galvanizing

6.1 Hydrogen can be absorbed during pickling and in some instances, as noted in 3.2, may contribute to embrittlement of the galvanized product. The likelihood of this, or of surface cracking occurring, is increased by excessive pickling temperature, prolonged pickling time, and poor inhibition of the pickling acid. Heating to 300°F (150°C) after pickling and before galvanizing in most cases results in expulsion of the hydrogen absorbed during pickling.

6.2 Abrasive blast cleaning followed by flash pickling may also be employed when over-pickling is of concern.

7. Responsibility for Avoiding Embrittlement

7.1 Design of the product and selection of the proper steel for its suitability to be fabricated and to withstand normal galvanizing operations without embrittlement is the responsibility of the designer and fabricator. The galvanizer shall employ proper pickling and galvanizing procedures.

[2] Available from American Institute of Steel Construction, 400 N. Michigan Ave., 8th floor, Chicago, IL 60611. See p. 4-166 of the eighth edition.

8. Testing for Embrittlement of Steel Shapes, Steel Castings, Threaded Articles, and Hardware Items

8.1 Subject to base material and dimensional limitations, the tests given in 8.2, 8.3, and 8.4 shall apply. If one test specimen should be found embrittled by these tests, two additional specimens should be tested. Failure of either the second or the third specimen shall be cause for rejection of the lot (see Note 1) that the samples represent.

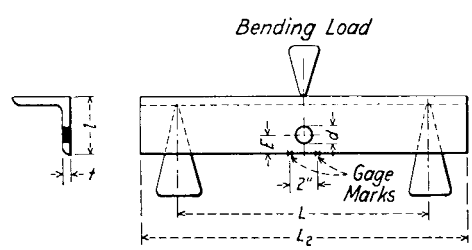
NOTE 1—A lot is a unit of production from which a sample may be taken for testing. Unless otherwise agreed upon by the manufacturer and the purchaser, or established within this specification, the lot shall be as follows: For test at a manufacturer's facility, a lot is one or more articles of the same type and size comprising a single order or a single delivery load, whichever is the smaller, or a smaller number of articles identified as a lot by the manufacturer, when these have been galvanized within a single production shift. For test by purchaser after delivery, the lot consists of the single order or the single delivery load, whichever is the smaller, unless the lot identity, established in accordance with the above, is maintained and clearly indicated in the shipment by the manufacturer.

8.2 A convenient bend test for embrittlement of galvanized steel hardware such as bolts, pole and tower steps, braces, rods, reinforcing bars, etc., consists of bending the article and comparing the degree of bending to that which is obtained on a similar ungalvanized article. The article, before and after galvanizing, may be clamped in a vise and using a lever if necessary, bent until cracking of the base steel occurs, or to 90° whichever is less. In the case of previously bent articles such as reinforcing bars, the test shall be accomplished by reverse bending the previously bent section. The galvanized article should withstand a degree of bending substantially the same as the ungalvanized article. Flaking or spalling of the galvanized coating is not to be construed as an embrittlement failure. For threaded articles, the test shall be made on the unthreaded portion.

8.3 Small steel castings and steel hardware of such shape or size that do not permit bending may be struck a sharp blow with a 2-lb (1-kg) hammer and the results for both galvanized and ungalvanized samples compared. If the article withstands such a blow in the ungalvanized condition, but after galvanizing cracks under the blow, it shall be considered embrittled.

8.4 A test for embrittlement of galvanized steel angles is detailed as follows:

8.4.1 *Test Specimen*—A test specimen with a length determined by the table in 8.4.2.1 and by Fig. 1 shall be cut from the steel angle before galvanizing. A hole shall be made in the test specimen at its midlength, using the same procedure as will be employed in the fabricated material which the specimen



NOTE 1—2 in. = 50.8 mm.

FIG. 1 Specimen for Elongation after Fracture

represents, whether this be by punching, punching and reaming, or drilling. The dimensional values, diameter, and location of hole shall be not less than those employed in the structural details. Care should be taken not to place the hole near stamped or rolled-in identification marks. The specimen shall then be galvanized. For determining the elongation after fracture, a 2-in. (50.8-mm) gage length (Fig. 1) shall be prick-punched in the middle of the edge of the vertical leg of the galvanized angle along a line parallel to its length and centered directly under the hole. For specimens under ½ in. (12.7 mm) in thickness, or those in which the distance from the edge of the hole to the edge of the angle is less than ⅜ in. (9.52 mm), a 1-in. (25.4-mm) gage length shall be used.

8.4.2 *Procedure*:

8.4.2.1 The test shall be made in a universal testing machine, or by other means such as a press with the load applied slowly, until fracture of the galvanized test specimen occurs. The length of the test specimen and the distance between the supports are shown in the following table:

Leg of Angle, *l*, in. (mm) (see Fig. 1)	Length Between Supports, L_1, in. (mm)	Minimum Length, L_2, in. (mm)
Up to 4 (102), incl	14 (356)	18 (457)
Over 4 to 6 (102 to 152), incl	20 (508)	24 (610)
Over 6 to 8 (152 to 203), incl	30 (762)	36 (914)

8.4.2.2 After the test, the distance along the gage length from each punch mark to the corresponding edge of the fracture shall be measured to 0.01 in. (0.25 mm) with a flexible scale and the percentage of elongation calculated from the sum of these distances.

8.4.2.3 For determining the percentage reduction of thickness after fracture, the reduction shall be measured with a ball-point micrometer at the three locations indicated in Fig. 2: namely *a*, outer side of hole; *b*, inner side of hole; and *c*, middle of leg. The percentage reduction of thickness shall be calculated on the basis of the original thickness of the angle and the average of the three values at *a*, *b*, and *c*.

8.4.2.4 The test shall be made upon galvanized specimens having a temperature not below 60°F (16°C) and not over 90°F (32°C) when tested.

8.4.3 *Requirements*—The elongation measured in accordance with 8.4.2.2 shall be not less than 5 % with the following exception: when the specimen does not show 5 % elongation, the reduction in thickness shall be measured in accordance with 8.4.2.3. The sum of the percentage of elongation plus the average percentage reduction of thickness shall not be less than 10.

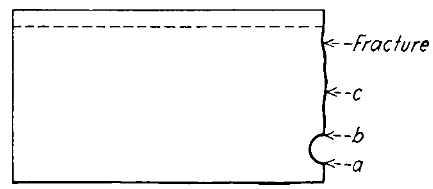


FIG. 2 Measurement of Reduction of Thickness after Fracture