



Standard Specification for Quality Assurance Requirements for Carbon and Alloy Steel Wire, Rods, and Bars for Mechanical Fasteners¹

This standard is issued under the fixed designation F 2282; 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.

1. Scope

1.1 This specification establishes quality assurance requirements for the physical, mechanical, and metallurgical requirements for carbon and alloy steel wire, rods, and bars in coils intended for the manufacture of mechanical fasteners which includes: bolts, nuts, rivets, screws, washers, and special parts manufactured cold.

NOTE 1—The Steel Industry uses the term “quality” to designate characteristics of a material which make it particularly well suited to a specific fabrication and/or application and does not imply “quality” in the usual sense.

1.2 Wire size range includes 0.062 to 1.375 in.

1.3 Rod size range usually includes $\frac{7}{32}$ in. (0.219) to $\frac{47}{64}$ in. (0.734) and generally offered in $\frac{1}{64}$ increments (0.0156).

1.4 Bar size range includes $\frac{3}{8}$ in. (0.375) to 1 $\frac{1}{2}$ in. (1.500).

1.5 Sizes for wire, rod and bar outside the ranges of paragraphs 1.2-1.4 may be ordered by agreement between purchaser and supplier.

1.6 Material is furnished in many application variations. The purchaser should advise the supplier regarding the manufacturing process and finished product application as appropriate. Five application variations are:

- Cold Heading
- Recessed Head
- Socket Head
- Scrapless Nut
- Tubular Rivet

1.6.1 Wire is furnished for all five application variations.

1.6.2 Rod and bar are furnished to the single application variation; Cold Heading.

2. Referenced Documents

2.1 *ASTM Standards:*

A 29/A 29M Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, and Cold-Finished, General Requirements²

A 370 Test Methods and Definitions for Mechanical Testing of Steel Products²

¹ This specification is under the jurisdiction of ASTM Committee F16 on Fasteners and is the direct responsibility of Subcommittee F16.93 on Quality Assurance Provisions for Fasteners.

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² *Annual Book of ASTM Standards*, Vol 01.05.

A 700 Practices for Packaging, Marking and Loading Methods for Steel Products for Domestic Shipment²

A 751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products²

E 4 Practices for Force Verification of Testing Machines³

E 10 Test Method for Brinell Hardness of Metallic Materials³

E 29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications⁴

E 112 Test Methods for Determining Average Grain Size³

E 381 Method of Macroetch Testing Steel Bars, Billets, Blooms, and Forgings³

E 407 Practice for Microetching Metals and Alloys³

E 1077 Test Methods for Estimating the Depth of Decarburization of Steel Specimens³

F 1470 Guide for Fastener Sampling for Specified Mechanical Properties and Performance Inspection⁵

F 1789 Terminology of F16 Mechanical Fasteners⁵

2.2 *AIAG Standard:*

B-5 Primary Metals Tag Application Standard⁶

2.3 *IFI Standard:*

IFI-140 Carbon and Alloy Steel Wire, Rods, and Bars for Mechanical Fasteners⁷

2.4 *SAE Standards:*

J403 Chemical Compositions of SAE Carbon Steels⁸

J404 Chemical Compositions of SAE Alloy Steels⁸

J406 Methods of Determining Hardenability of Steels⁸

J415 Definitions of Heat Treating Terms⁸

3. Terminology

3.1 *Definitions:*

3.1.1 *annealing*—a process of heating to and holding steel at a given temperature for a given time and then cooling at a given rate, used to soften or produce changes, or both, in the microstructure of the steel to enhance formability and reduce tensile strength.

³ *Annual Book of ASTM Standards*, Vol 03.01.

⁴ *Annual Book of ASTM Standards*, Vol 14.02.

⁵ *Annual Book of ASTM Standards*, Vol 01.08.

⁶ Available from AIAG, 26200 Lahser Road, Suite 200, Southfield, MI 48034.

⁷ Available from IFI, 1717 E. 9th St., Suite 1105, Cleveland, OH 44114-2879.

⁸ Available from Society of Automotive Engineers (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001.

3.1.2 *bars*—produced from hot rolled or cast billets or blooms rolled single strand into coils. Bars have a greater precision in cross section than rods. Size tolerances are in Table 1. Bars are finished as-rolled, annealed or spheroidize annealed, and in sizes included in 1.4.

3.1.3 *lap*—a longitudinal surface discontinuity extending into rod, bar, or wire caused by doubling over of metal during hot rolling.

3.1.4 *lot*—a quantity of raw material of one size and heat number submitted for testing at one time.

3.1.5 *rods*—produced from hot rolled or cast billets, usually rolled in a multiple strand mill to a round cross section then coiled into one continuous length to size tolerances shown in Table 2. Rods are furnished as-rolled, annealed, or spheroidize annealed in sizes found in 1.3.

3.1.6 *seam*—a longitudinal discontinuity extending radially into wire, rod, or bar. Seams in raw material used for the manufacture of fasteners or formed parts may lead to the formation of bursts.

3.1.7 *spheroidizing*—a form of annealing, involves prolonged heating at temperatures near the lower critical temperature, followed by slow cooling, with the object of forming spheroidal metallic carbides that allow a higher degree of formability.

3.1.8 *void*—a shallow pocket or hollow on the surface of the material.

3.1.9 *wire*—produced from hot rolled or annealed rods or bars by cold drawing for the purpose of obtaining desired size, dimensional accuracy, surface finish, and mechanical properties. Wire is furnished in the following conditions: direct drawn (DD); drawn from annealed rod or bar (DFAR or DFAB); drawn from spheroidized annealed rod or bar (DFSR or DFSB); drawn to size and spheroidized (SAFS); drawn, annealed in process, and finally lightly drawn to size (AIP); and drawn, spheroidize annealed in process, and finally lightly drawn to size (SAIP). Wire size tolerances are shown in Table 3. Sizes include those specified in 1.2.

3.1.9.1 *Discussion*—Spheroidize annealed-at-finish size wire (SAFS) is wire that has been spheroidize annealed after final cold reduction. One or more annealing treatments may precede the final cold reduction.

3.1.9.2 *Discussion*—Annealed-in-Process (AIP) or Spheroidize Annealed-in-Process (SAIP) wire is produced as drawn carbon or alloy steel wire. In producing AIP and SAIP wire, rods or bars are drawn to wire and thermal treatment (followed by a separate cleaning and coating operation) is done prior to final drawing to produce a softer and more ductile wire for applications in which direct drawn wire would be too hard.

TABLE 1 Bar Size Tolerances

Fractional Diameter, in.	Diameter ± Tolerance, in.	Out of Round max, in.
7/16 to 5/8	0.006	0.009
>5/8 to 7/8	0.007	0.011
>7/8 to 1	0.008	0.012
>1 to 1 1/8	0.009	0.014
>1 1/8 to 1 1/4	0.010	0.015
>1 1/4 to 1 3/8	0.011	0.017
>1 3/8 to 1 1/2	0.013	0.020

TABLE 2 Rod Size Tolerances

Diameter, in.	Diameter ± Tolerance, in.	Out of Round max, in.
7/32 to 47/64 (0.219 to 0.734)	0.012	0.018

TABLE 3 Wire Size Tolerances and Out of Round

Diameter, in.	Diameter ± Tolerance, in.	Out of Round max, in.
< 0.076	0.0010	0.0010
0.076 < 0.500	0.0015	0.0015
≥ 0.500	0.0020	0.0020

Thermal treatment may also be employed when controlled mechanical properties are required for a specific application.

3.2 Heat treating terms not defined in this standard are included in Terminology F 1789 or SAE J415.

4. Ordering Information

4.1 Wire orders shall state the following:

4.1.1 Quantity,

4.1.2 Specification number and issue date,

4.1.3 Diameter,

4.1.4 Steel grade,

4.1.5 Deoxidation practice and grain size or refinement practice (coarse or fine); see 5.3.1-5.3.5,

4.1.6 Application variation per 1.6,

4.1.7 Thermal treatment; see 5.5,

4.1.8 Surface coating,

4.1.9 Coil weight and dimensions as required,

4.1.10 Packaging,

4.1.11 Tagging,

4.1.12 Mill certification as required,

4.1.13 Special requirements, for example, steel making method and practice, specific hardenability, special shipping instructions, single heat, etc., and

4.1.14 *Example*—40 000 lb, ASTM F 2282, 0.250 in., carbon steel wire, IFI-1022A, silicon killed coarse grain, Recessed Head, spheroidize annealed-in-process, phosphate and lube, 1500 lb coils, 28 in. coil i.d., on 18 in. tubular carriers, three bands per carrier, one metal tag per coil, mill certification, do not ship Fridays.

4.2 Rod orders shall state the following:

4.2.1 Quantity,

4.2.2 Specification number and issue date,

4.2.3 Diameter,

4.2.4 Steel grade,

4.2.5 Deoxidation practice and grain size or refinement practice (coarse or fine),

4.2.6 Cold Heading,

4.2.7 Thermal treatment,

4.2.8 Surface coating,

4.2.9 Coil weight and dimensions as required,

4.2.10 Packaging,

4.2.11 Tagging,

4.2.12 Mill certifications as required,

4.2.13 Special requirements, for example, descaling practice, steelmaking method and practice, specific hardenability, special shipping instructions, etc., and

4.2.14 *Example*—200 000 lb, ASTM F 2282, ²/₆₄ in., carbon steel rod, IFI-1022B, silicon killed fine grain, Cold Heading, spheroidize annealed, pickled and limed, 3000 lb coils, 48 in. coil i.d., compacted and unitized in packages of two, banded with three steel straps per coil, two metal tags per coil attached to lead end on inside of bundle, put separators between coils.

4.3 Bar orders shall state the following:

- 4.3.1 Quantity,
- 4.3.2 Specification number and issue date,
- 4.3.3 Diameter,
- 4.3.4 Steel grade,
- 4.3.5 Deoxidation practice and grain size or refinement practice (coarse or fine),
- 4.3.6 Cold Heading,
- 4.3.7 Thermal treatment,
- 4.3.8 Surface coating,
- 4.3.9 Coil weight and dimensions as required,
- 4.3.10 Packaging,
- 4.3.11 Tagging,
- 4.3.12 Mill certification as required,
- 4.3.13 Special requirements, for example, steelmaking method and practice, specific hardenability, special shipping instructions, single heat, etc., and

4.3.14 *Example*—90 000 lb, ASTM F 2282, 0. 610 in., carbon steel bars, IFI-1038, silicon killed coarse grain, spheroidize annealed, Cold Heading, phosphate and lime, 5400 lb coils, 54 in. coil i.d., three bands per coil, one metal tag per coil, lead end of each coil paint red.

5. Manufacture

5.1 *Melting Practice*—The steel shall be melted in a basic oxygen or electric furnace process.

5.2 *Casting Practice*—Steel shall be ingot cast, or continuous cast with controlled procedures to meet the requirements of this specification.

5.3 *Deoxidation Practice and Grain Size*—The material shall be furnished in one of the deoxidation and grain size

practices included in 5.3.1-5.3.5, as specified by the purchaser. When not specified, the practice shall be at the option of the manufacturer.

5.3.1 Silicon killed fine grain shall be produced with aluminum for grain refinement. The material purchaser’s approval shall be obtained for the use of vanadium or columbium for grain refinement.

5.3.2 Silicon killed coarse grain practice.

5.3.3 Silicon killed fine grain practice.

5.3.4 Aluminum killed fine grain practice.

5.3.5 Rimmed (grain size not specified).

5.4 *Hardenability*:

5.4.1 Hardenability for steels with a specified minimum carbon content of 0. 20 % or greater shall be determined for each heat and the results furnished to the purchaser when requested on the purchase order. SAE J406, Appendix A shall be used for referee purposes in the event of dispute.

5.5 *Thermal Treatments*:

5.5.1 The purchaser shall specify one of the following options for thermal treatment on the purchase order:

5.5.1.1 No thermal treatment.

5.5.1.2 Annealed.

5.5.1.3 Spheroidized.

5.5.1.4 Drawn from annealed rod or bar.

5.5.1.5 Drawn from spheroidize annealed rod or bar.

5.5.1.6 Spheroidized at finished size wire.

5.5.1.7 Annealed-in-process wire.

5.5.1.8 Spheroidized annealed-in-process wire.

6. Chemical Requirements

6.1 The material shall have a chemical composition conforming to the requirements specified in Tables 4-8 for the applicable IFI grade specified by the material purchaser.

NOTE 2—The chemical compositions have been developed in a joint producer/user effort and are particularly appropriate to the cold forging industry process. The chemical composition ranges of these IFI grades may not be identical to those of SAE J403, SAE J404, or AISI.

TABLE 4 Carbon Steels, Chemical Ranges and Limits, %

Conditions Furnished	IFI Steel Grade Designation	Carbon		Manganese		Phosphorous Max	Sulfur Max	Silicon
		Min	Max	Min	Max			
R, AIK	IFI-1006	. . .	0.08	0.25	0.40	0.020	0.020	See Table 6
R, AIK, SiFg, SiCg	IFI-1008	. . .	0.10	0.30	0.50	0.020	0.020	See Table 6
R, AIK, SiFg, SiCg	IFI-1010	0.08	0.13	0.30	0.60	0.020	0.020	See Table 6
AIK, SiFg, SiCg	IFI-1018	0.15	0.19	0.65	0.85	0.020	0.020	See Table 6
AIK, SiFg	IFI-10B21	0.19	0.23	0.80	1.10	0.020	0.020	See Table 6
AIK, SiFg, SiCg	IFI-1022/A	0.18	0.21	0.80	1.00	0.020	0.020	See Table 6
AIK, SiFg, SiCg	IFI-1022/B	0.20	0.23	0.90	1.10	0.020	0.020	See Table 6
AIK	IFI-1033	0.31	0.36	0.70	0.90	0.020	0.020	See Table 6
AIK, SiFg, SiCg	IFI-1035	0.33	0.38	0.70	0.90	0.020	0.020	See Table 6
AIK, SiFg, SiCg	IFI-1038	0.35	0.42	0.70	0.90	0.020	0.020	See Table 6
SiFg	IFI-10B38	0.35	0.42	0.70	1.00	0.020	0.020	See Table 6
SiFg	IFI-1541/A	0.36	0.41	1.35	1.60	0.020	0.020	See Table 6
SiFg, SiCg, CgP	IFI-1541/B	0.38	0.43	1.35	1.60	0.020	0.020	See Table 6

NOTE—Carbon steels which have added boron use a B designation between the first and last two digits of the grade designation. A boron steel has a minimum boron content of 0.0008 % and a maximum of 0.003 % together with a minimum titanium content of 0.01 %.

AIK = Aluminum killed

R = Rimmed

SiFg = Silicon killed fine grain

SiCg = Silicon killed coarse grain

CgP = Coarse grain practice

TABLE 5 Permissible Variations from Specified Chemical Ranges, and Limits for Carbon Steel, %

Element	Limit or Max of Specified Range, %	Variation % Over Max Limit or Under Min Limit
Carbon	To 0.25 incl	0.02
	Over 0.25 to 0.55 incl	0.03
Manganese	To 0.90 incl	0.03
	Over 0.90 to 1.65 incl	0.06
Phosphorus	Over max only	0.008
Sulfur	Over max only	0.008
Silicon	To 0.30 incl	0.02
Copper	Over max only	0.03
Tin	Over max only	0.01
Nickel	Over max only	0.03
Chromium	Over max only	0.03
Molybdenum	Over max only	0.01
Vanadium	Over max only	0.01
Boron		N/A ^A

^A Unless misapplication is indicated.

TABLE 6 Silicon Limits for Four Deoxidation Practices, %

	Deoxidation Practice					
	Silicon Killed		Silicon Killed		Aluminum Killed	
	Fine Grain	Max	Course Grain and Course Grain Practice		Fine Grain	Rimmed Max
			Min	Max		
IFI-1006	...	...	...	...	0.10	0.02
IFI-1008	0.10	0.20	0.10	0.25	0.10	0.02
IFI-1010	0.10	0.20	0.10	0.25	0.10	0.02
Boron Grades	0.10	0.30	N/A	N/A	N/A	N/A
All Other Grades	0.15	0.30	0.15	0.30	0.10	N/A

NOTE 1—Fine Grain—Normally Si/Al killed or aluminum killed. Vanadium or Columbium (niobium) can be used upon agreement between raw material supplier and user (purchaser). See Supplementary Requirement S.2.

NOTE 2—The values listed in this table are designed to provide optimum headability and tool life in the cold forming process. Modifications to these limits require agreement between producer and purchaser.

6.2 Compositions other than those designated in this standard may be applicable when specified by the purchaser.

6.3 *Cast or Heat Analysis*—An analysis of each cast or heat shall be made by the producer to determine the percentage of the elements specified. The analysis shall be made from a test sample(s) taken during the pouring of the cast or heat. The chemical composition shall be reported, if required, to the purchaser or his representative.

6.4 *Product Analysis:*

6.4.1 Product analysis may be made on the finished material from each heat. The composition thus determined shall conform to the requirements in Table 4, Table 6, or Table 7 for the specified grade subject to the permissible variations for product analyses in Table 5 or Table 8, as applicable.

NOTE 3—A product analysis is optional. The analysis is not used for a duplicate analysis to confirm a previous result. The purpose of the product analysis is to verify that the chemical composition is within specified limits for each element, including applicable permissible variations in product analysis. The results of analyses taken from different pieces of a heat may differ within permissible limits from each other and from the heat or cast analysis. The results of the product analysis obtained shall not vary both above and below the specified range.

6.4.2 Rimmed or capped steels are characterized by a lack of uniformity in their chemical composition, especially for the elements carbon, phosphorus, and sulfur, and for this reason product analysis is not technologically appropriate unless misapplication is clearly indicated.

6.4.3 Test Methods A 751 shall be used.

6.5 *Residual Element Limits*—Material grades defined in this standard shall conform to the residual element limits in Table 9.

7. Metallurgical Structure

7.1 *Coarse Austenitic Grain Size:*

7.1.1 When a coarse grain size is specified, the steel shall have a grain size number of 1 to 5 inclusive.

7.1.2 Conformance to this grain size of 70 % of the grains in the area examined shall constitute the basis of acceptance.

7.2 *Fine Austenitic Grain Size:*

7.2.1 When a fine grain size is specified, the steel shall have a grain size number greater than five, as determined in accordance with Test Methods E 112.

7.2.2 Conformance to this grain size of 70 % of the grains in the area examined shall constitute the basis of acceptance.

7.2.3 When aluminum is used as the grain refining element, the fine austenitic grain size requirement shall be deemed to be fulfilled if, on heat analysis, the total aluminum content is not less than 0.020 % total aluminum or, alternately, 0.015 % acid soluble aluminum. The aluminum content shall be reported. The grain size test specified in 7.2.1 shall be the referee test.

7.2.4 If columbium or vanadium or both are to be used, Supplementary Requirement S.2 shall be specified.

7.2.5 If specified on the order, one grain size test per heat shall be made and the austenitic grain size of the steel, as represented by the test, shall be number 6 or higher.

7.3 *Spheroidized Annealed Materials:*

7.3.1 Spheroidize annealed material shall meet a minimum test rating of G2 or L2 in the IFI spheroidization rating—Plate 1 (see Fig. 1).

7.3.2 Optimum spheroidization is equal to or greater than 90 %. The spheroidization rating shall be performed on a polished transverse sample etched with a 2 % Nital solution in accordance with Practice E 407. The examination area for spheroidization shall be at or near the center of the material. The resulting structure shall be compared at 1000× magnification to Plate 1. The following descriptions may be used to better compare to Plate 1.

Spheroidization Rating Descriptions for Plate 1

% Spheroidization	Description
100	Spheroidal carbides are homogeneously distributed in a matrix of ferrite.
80 G1/L1	All carbides are spheroidal with a good distribution. Grain boundaries are not so obvious.
60 G2/L2	Most of the carbides are spheroidal with an average distribution. Some lamellar carbides and grain boundaries are present.
40 G3/L3	Approximately ½ of the carbides have been spheroidized. All carbides are in prior pearlitic colonies; grain boundaries are prevalent.
20 G4/L4	A very slight breakup of the lamellar carbides; mainly pearlite and ferrite.
0 G5/L5	The entire microstructure consists of pearlite and ferrite.

TABLE 7 Chemical Ranges and Limits for Alloy Steels, %

IFI Steel Grade Designation	Carbon		Manganese		Nickel		Chromium		Molybdenum		Phosphorous	Sulfur
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Max	Max
IFI-1335	0.33	0.38	1.60	1.90	...	...	...	...	...	...	0.020	0.020
IFI-4037 ^A	0.35	0.40	0.70	0.90	...	...	...	...	0.20	0.30	0.020	0.020
IFI-4042	0.40	0.45	0.70	0.90	...	...	...	...	0.20	0.30	0.020	0.020
IFI-4118	0.18	0.23	0.70	0.90	...	...	0.40	0.60	0.08	0.15	0.020	0.020
IFI-4140	0.38	0.43	0.75	1.00	...	...	0.80	1.10	0.15	0.25	0.020	0.020
IFI-5140	0.38	0.43	0.70	0.90	...	...	0.70	0.90	...	...	0.020	0.020
IFI-8637	0.35	0.40	0.75	1.00	0.40	0.70	0.40	0.60	0.15	0.25	0.020	0.020

^A Furnished in AIK or SiFg or SiCg or CgP. All other grades in SiFg-Fg only.

TABLE 8 Permissible Variation from Specified Chemical Ranges and Limits for Alloy Steels, %

Element	Limit or Max of Specified Range, %	Variation, %, Over Max Limit or Under Min Limit
Carbon	To 0.30 incl	0.01
	Over 0.30 to 0.75 incl	0.02
Manganese	To 0.90 incl	0.03
	Over 0.90	0.04
Phosphorus	Over Max only	0.005
Sulfur	Over Max only	0.005
Silicon	To 0.40 incl	0.02
Nickel	To 1.00 incl	0.03
Chromium	To 0.90 incl	0.03
	Over 0.90	0.05
Molybdenum	To 0.20 incl	0.01
	Over 0.20 to 0.40 incl	0.02
Vanadium	Over Max only	0.01
Copper	Over Max only	0.03

TABLE 9 Residual Element Limits^A

Element	Residual Limit ^B max, %
Copper	0.20
Nickel	0.10
Chromium	0.10 ^C
Molybdenum	0.04 ^C
Tin	0.02
Nitrogen	0.009
Boron	0.0007 ^D

^A Residual limits for a given element do not apply to alloy steel if that element has a specified range.

^B Controlling residual limits provides optimum formability and tool life during cold forming operations.

^C See Supplementary Requirements.

^D Not applicable to boron steels (see Table 4). Titanium shall not exceed 0.01 % for steels which do not have an intentional addition of boron and titanium.

8. Decarburization

8.1 The entire periphery of a sample prepared of the rod, wire, or bar for killed steels having carbon content exceeding 0.15 % shall be examined for decarburization at a magnification of 100 diameters. Free ferrite shall not exceed the maximum depth as specified in Table 10. The worst location shall be used to draw perpendicular bisectors, and the depth of decarb at the points where the bisectors intersect the circumference, shall be measured and the four (4) readings averaged as defined in the example identified as Fig. 2.

8.2 That average shall not exceed the limits for total average affected depth (TAAD) as specified in Table 10. The depth (D) of the worst location shall not exceed the maximum allowed in Table 10.

9. Mechanical Properties

9.1 Bars, rod, and wire furnished in the conditions below shall conform to the tensile strength and reduction in area requirements specified in Table 11.

9.1.1 Annealed or spheroidize annealed rod and bar.

9.1.2 Spheroidize annealed at finish size wire.

9.1.3 Annealed-in-process or spheroidize annealed-in-process wire.

9.2 Percent reduction in area is determined by the test methods of Test Methods A 370. Values for minimum percentages which shall apply are included in Table 11.

9.3 No individual test value shall be out of specification, and for steels with a maximum specified carbon content over 0.30 %, the maximum range shall not exceed the minimum by more than 10 % in any lot; for example:

$$\frac{(80 \text{ KSI} - 74 \text{ KSI})}{74 \text{ KSI}} = 8.1 \% \text{ accept}$$

9.4 Tensile/reduction in area equipment shall be calibrated and verified in accordance with Practices E 4, and operated by personnel with documented qualifications.

9.5 Conformance of all test data shall be determined in accordance with Practice E 29.

10. Dimensional Size Tolerances

10.1 Wire tolerances are shown in Table 3.

10.2 Rod tolerances are shown in Table 2.

NOTE 4—Inherent mill design of rod mills does not permit the same control of size as bar mills. Reducing diameter variability increases control of both the physical and mechanical properties during the forming process. Less variability permits engineering for reduced tool wear and consistent product quality.

10.3 Bar tolerances are shown in Table 1.

11. Mill Scale/Surface Condition

11.1 Mill scale (surface oxides) on hot rolled material shall be readily removable by an acid pickling or mechanical descaling process.

11.2 The surface shall be free from excessive dirt contaminants or rust which would impede pickling or descaling, or contaminate an acid pickle bath.

12. Coatings

12.1 The supplied coatings shall be specified for all materials by the purchaser based upon the individual requirements of the purchaser. Adequate care should be taken during handling and transit to maintain the integrity of the coating.

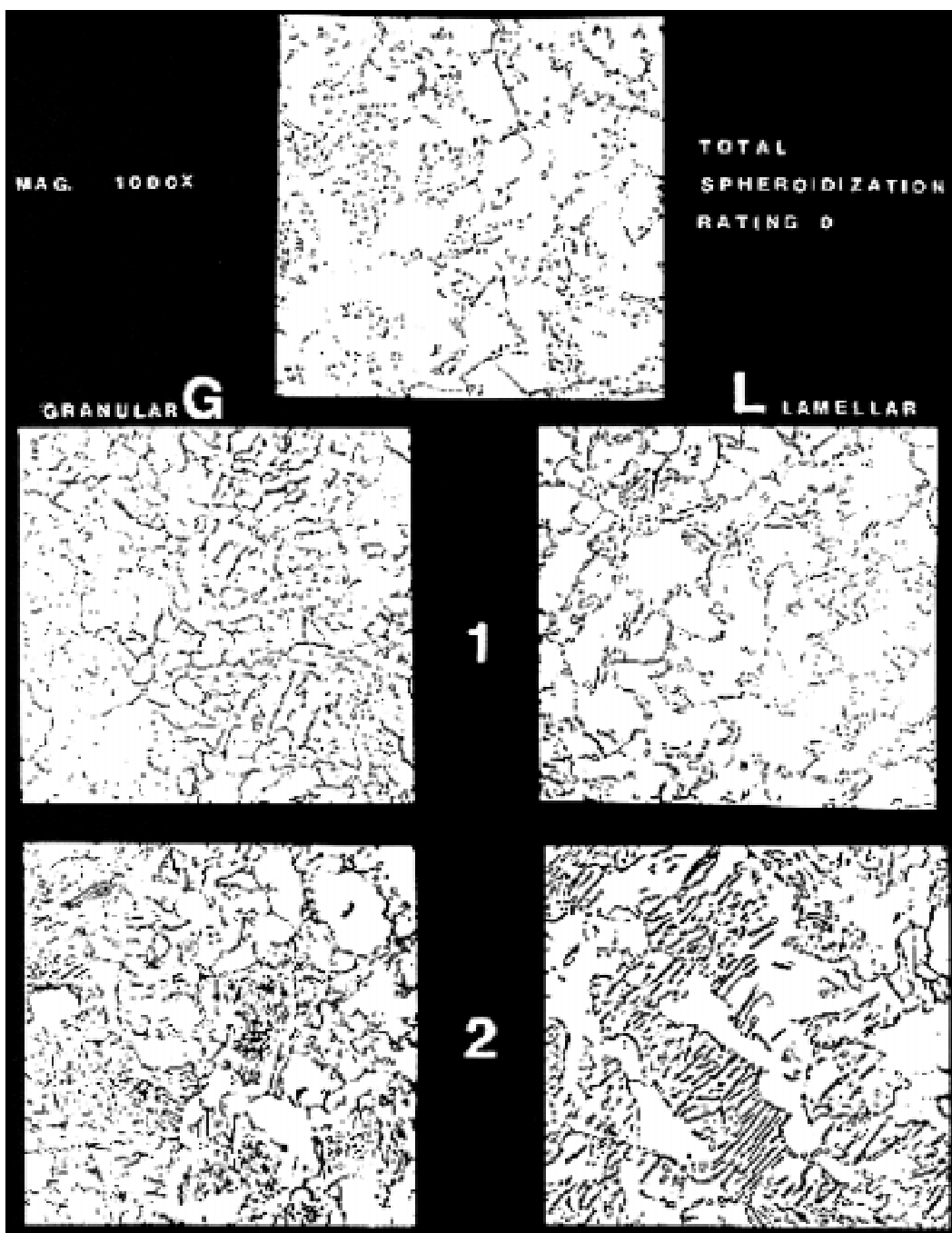


FIG. 1 Plate 1—IFI Spheroidization Rating

Extreme variations in temperature and humidity may adversely affect the applied coatings.

12.2 Coatings for hot rolled bars, wire rods, and wire which are thermally treated at finished size include the following:

12.2.1 Pickle and lime dip,

12.2.2 Zinc phosphate and lime dip,

12.2.3 Zinc phosphate and reactive or nonreactive lube dip, and

12.2.4 Alternate coatings, including polymer, may be used upon agreement between purchaser and producer.

12.3 In addition, if cold drawing is the final operation, a drawing compound will also be applied through the die

drawing process. There are, however, no batch coatings applied after drawing when cold drawing is the final operation.

13. Workmanship, Finish and Appearance

13.1 Bar, rod, and wire shall be free from detrimental surface imperfections including seams, voids, pits, scratches, and laps. Material, suitably thermally treated when appropriate, which bursts or splits when upset or formed, and having imperfections deeper than the greater of 0.003 in. or 0.5 % of D (where D is finished diameter in inches of material) shall be subject to rejection. Samples requiring assessment of such surface imperfections shall be prepared by metallographic

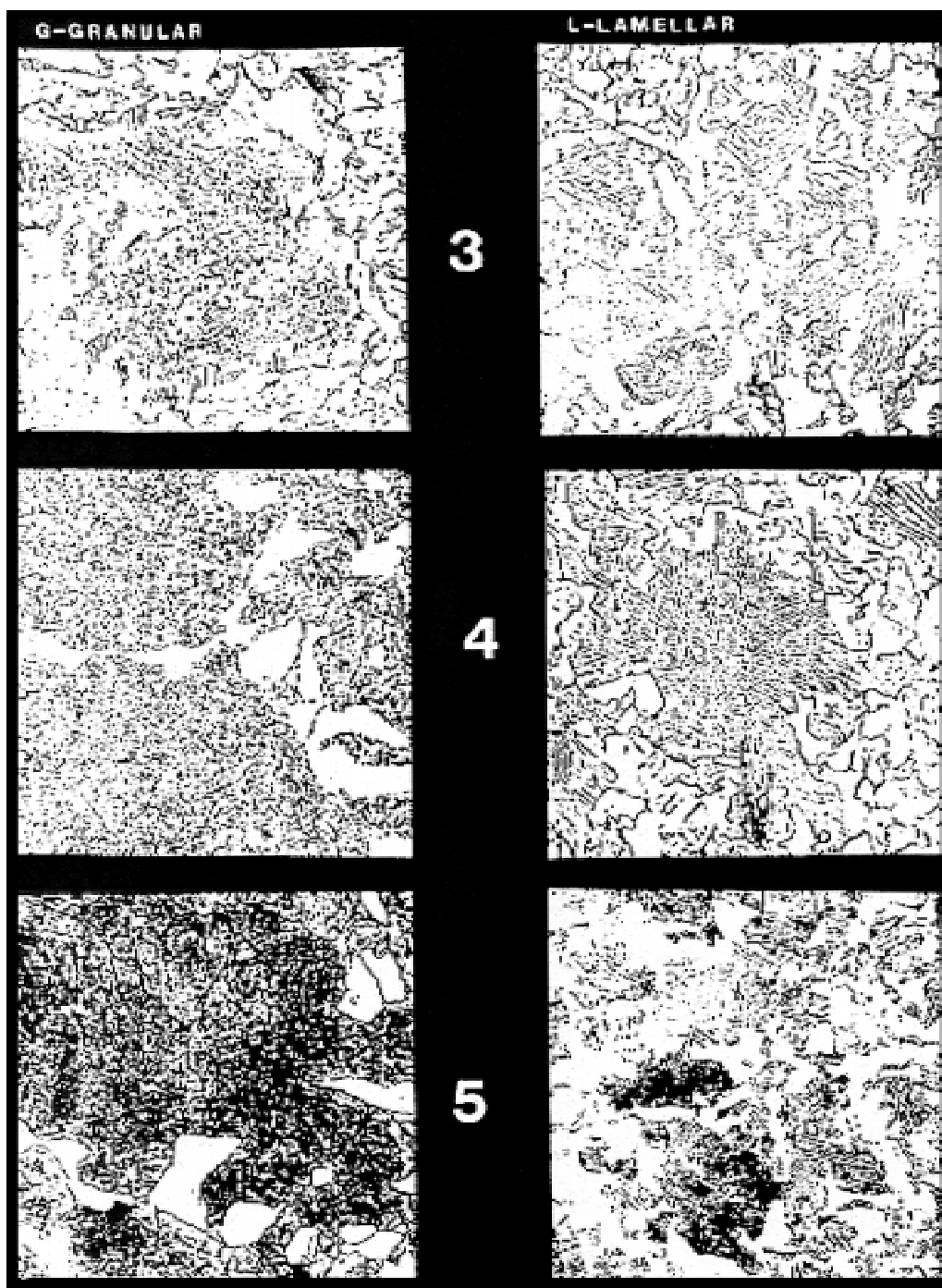


FIG. 1 Plate 1—IFI Spheroidization Rating (continued)

technique, suitably etched and the depth of imperfection measured radially from the surface at a magnification of 100 \times .

13.2 Wire shall not be kinked or tangled, and for wire drawn last, shall be properly cast. No welds are permitted, unless otherwise specified.

14. Number of Tests and Retests

14.1 *Metallurgical:*

14.1.1 Austenitic grain size shall be based on one test per heat in accordance with 7.2.4.

14.1.2 Each spheroidize annealed lot shall be tested once and shall meet minimum rating requirements of G2 or L2 (see 7.3.1).

14.1.3 For each lot of wire, rod, or bar, a single sample shall be tested for decarburization in accordance with Section 8 of this standard.

14.2 *Mechanical:*

14.2.1 Rods, bars, and wire shall be tested one sample per coil/bundle on at least 20 % of randomly selected coils/bundles in the lot with at least two tests for maximum tensile strength.

TABLE 10 Decarburization Limits for Killed Steels With Carbon Content Exceeding 0.15 %

Diameter, in.	Free Ferrite Depth max, in.	Total Average Affected Depth (TAAD) max, in.	Worst Location Depth, max, in.
through $\frac{25}{64}$	0.001	0.005	0.008
over $\frac{25}{64}$	0.001	0.006	0.009
through $\frac{5}{8}$	0.001	0.007	0.011
over $\frac{5}{8}$	0.001	0.008	0.012
through 1	0.001	0.010	0.015
over 1			
through $1\frac{1}{2}$			

NOTE—Test conducted in accordance with Section 8 of this standard.

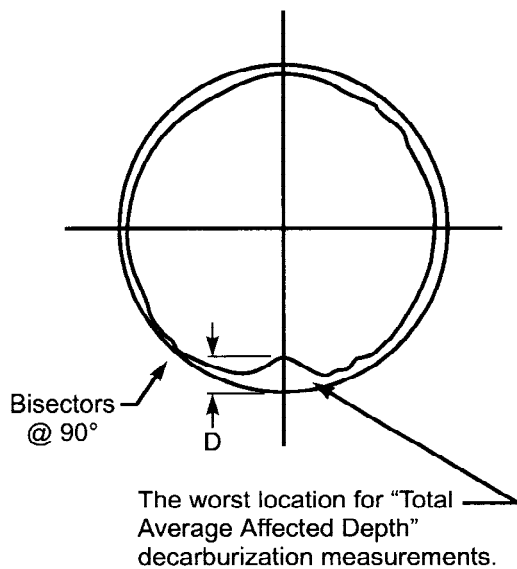


FIG. 2

14.2.2 Rods, bars, and wire shall be tested one sample per coil/bundle on at least 20 % of randomly selected coils/bundles in the lot with at least two tests for percent reduction in area.

14.2.3 Yield strength, percent elongation, and hardness tests are included in supplementary requirements of this standard.

15. Test Methods

15.1 *Maximum Tensile Strength:*

15.1.1 Maximum tensile strength shall be determined in accordance with the test methods of Test Methods A 370.

15.2 *Reduction of Area:*

15.2.1 Reduction of area is determined by test methods included within Test Methods A 370.

15.3 *Calibration:*

15.3.1 Tensile/reduction in area equipment shall be calibrated in accordance with Practices E 4.

15.4 *Hardenability:*

15.4.1 Hardenability shall be determined in accordance with SAE J406, Appendix A or B.

15.5 *Grain Size:*

15.5.1 Grain Size shall be determined in accordance with Test Method E 112.

15.6 *Decarburization:*

15.6.1 Decarburization shall be determined using the test method Test Methods E 1077.

15.7 *Control of Measuring and Testing Equipment:*

15.7.1 Unless otherwise specified, control shall conform to Guide F 1470.

16. Disposition of Nonconforming Lots

16.1 A recommended procedure for disposition of nonconforming lots may be found in Guide F 1470.

17. Identification/Tagging

17.1 A tag(s) shall be attached to each coil or banding as specified by the purchaser and shall include as a minimum the following information:

17.1.1 Supplier’s name or trademark,

17.1.2 Grade of steel,

17.1.3 Heat number or traceable code, and

17.1.4 Diameter.

17.2 When specified, the following may be added:

17.2.1 Purchaser’s name,

17.2.2 Purchase order number,

17.2.3 Mill order number,

17.2.4 Secondary process description and source if applicable, and

17.2.5 Bar coding (optional). It is suggested that bar coding in accordance with AIAG B-5 be used.

18. Packaging and Loading

18.1 Unless otherwise specified, rod coils shall be wound counterclockwise which provides a right hand pitch to facilitate handling and uncoiling. Winding of bar coils varies and the direction of winding should be specified. The nature of compacting, banding, and protection, shall be specified by purchaser.

18.2 The purchaser shall specify the method of packaging and loading for shipment. A recommended procedure for packaging and loading for shipment is found in Practices A 700.

19. Certification and Test Reports

19.1 When specified in the purchase order, a producer’s certification shall be furnished to the purchaser that the material was manufactured, sampled, tested, and inspected in accordance with this specification and has been found to meet the requirements as specified. Test results shall be retained by the producer in accordance with his quality assurance procedures. If requested by the purchaser, a test report shall be furnished which will meet the consumer’s requirements for chemical analysis of the mill heat including the identification and the results of the chemical analysis of the primary steel melter and austenitic grain size, if required.

19.2 Traceability shall include the mill order and steel heat number with all specified mechanical data on mill test certification.

20. Keywords

20.1 carbon and alloy steel; mechanical fasteners; quality assurance; wire, rods, and bars

TABLE 11 Mechanical Properties Carbon and Alloy Steels

Steel Grade	Rod/Bar Properties				Spheroidize Annealed at Finished Size Wire Properties		Annealed in Process and Spheroidized Annealed in Process Finished Wire Properties			
	Annealed		Spheroidize Annealed		SAFS		AIP		SAIP	
	Max Tensile ^A	Min R/A	Max Tensile ^A	Min R/A	Max Tensile ^A	Min R/A	Max Tensile ^A	Min R/A	Max Tensile ^A	Min R/A
	KSI	%	KSI	%	KSI	%	KSI	%	KSI	%
Carbon										
IFI-1006	55	62	53	65	51	70	62	60	60	62
IFI-1008	56	62	54	65	52	70	63	60	61	62
IFI-1010	58	62	55	65	54	70	65	60	62	62
IFI-1018	68	62	65	65	63	68	76	60	68	62
IFI-1022/A	72	62	67	65	65	68	81	60	72	62
IFI-1022/B	73	62	69	65	67	68	82	60	73	62
IFI-1033	80	58	74	60	72	64	89	56	82	58
IFI-1035	81	58	75	60	73	64	90	56	83	58
IFI-1038	82	58	76	60	74	64	91	56	84	58
IFI-1541A	92	53	85	57	82	61	98	51	92	55
IFI-1541B	93	53	86	57	83	61	99	51	93	55
Boron										
IFI-10B21	75	62	71	64	69	68	84	60	75	62
IFI-10B38	88	56	82	58	80	62	97	52	90	56
Alloy										
IFI-1335	93	53	85	55	82	59	100	51	92	53
IFI-4037	86	55	80	57	78	60	95	53	85	55
IFI-4042	88	55	82	57	80	60	97	53	87	55
IFI-4118	76	60	71	61	68	64	84	58	76	59
IFI-4140	92	55	85	57	82	59	102	53	90	55
IFI-5140	92	55	85	57	82	59	102	53	90	55
IFI-8637	92	53	85	55	82	57	102	51	92	53

^A For aluminum killed steel, subtract 3 KSI and add 1 % R/A.

For rimmed steel, subtract 5 KSI and add 2 % R/A.

For AIP and SAIP wire under 0.200 in., add 50 psi for every 0.001 in. under 0.200 in.

NOTE—The values in this table have been designed to provide optimum headability and tool life in the cold forming process. The reduction of area test is not applicable to wire sizes less than 0.092 in.

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the contract or order.

S1. Residual Element Limits

S1.1 The residual limit for Cr shall be to 0.20 max if specified by the purchaser. The residual element limit for Mo may be to 0.06 max if so specified by the purchaser. Reduced residual element limits below those specified in Table 9 shall be based upon agreement between supplier and purchaser.

S2. Grain Refiners

S2.1 Use of columbium (Cb) or vanadium (v), or both, instead of or with aluminum shall be based on the requirements of Specification A 29/A 29M, paragraphs 5.1.2.2 and 5.1.2.3. For the convenience of the users of this standard, they are reprinted as follows:

“ASTM A 29/A 29M-99^{e1}

5.1.2.2 By agreement between purchaser and supplier, columbium or vanadium or both may be used for grain refining instead of or with aluminum. When columbium or vanadium is used as a grain refining element, the fine austenitic grain size requirement shall be deemed to be fulfilled if, on heat analysis,

the columbium or vanadium content is as follows (the content of the elements shall be reported with the heat analysis):

Steels having 0.25 % carbon or less:

Cb 0.025 min

V 0.05 min

Steels having over 0.25 % carbon:

Cb 0.015 min

V 0.02 min

The maximum contents shall be:

Cb 0.05 max

V 0.08 max

Cb + V 0.06 max

5.1.2.3 When provisions of 5.1.2.1 or 5.1.2.2 are exercised, a grain size test is not required unless specified by the purchaser. Unless otherwise specified, fine austenitic grain size shall be certified using the analysis of grain refining element(s).”

S3. Yield Strength/Percent Elongation

S3.1 Yield strength/percent elongation may be used for special applications when agreed upon between purchaser and

manufacturer. Method of determination shall be in accordance with Test Methods A 370.

S4. Hardness

S4.1 Hardness may be used as an option when agreed to between producer and purchaser in lieu of tensile/reduction of area testing of wire or bar over 1 in. in diameter. Test method shall be in accordance with Test Method E 10.

S5. Mac-etch Test

S5.1 Mac-etch test may be used for bars when specified by the purchaser at the time of order. The test method shall be in accordance with Practice E 407 or Method E 381.

APPENDIXES

(Nonmandatory Information)

X1. HISTORY

X1.1 This ASTM standard is based on IFI-140, which was developed by the IFI Raw Materials Study Committee which is a joint effort of cooperation between the fastener manufacturer, the raw material manufacturer, and other important fastener industry suppliers.

X1.2 Following IFI approvals and subsequent publication, and in its traditional role of issuing IFI standards, it was intended that IFI-140 be introduced into the National Consensus Standards process of ASTM.

X2. MATERIALS AND PROCESSING

X2.1 Forming is the primary manufacturing operation in the fastener industry and the term includes heading, upsetting, extruding, and forging. These formed parts are produced at very high speeds by metal flow due to machine-applied pressure. The primary forming operation self-inspects the quality of the raw material and imperfections such as seams, laps, and internal pipe which may not be visible are revealed when the material is upset. The absence of bursts, forging cracks, and open seams is strong evidence that the quality of material selected was that intended for the severe upsets of today's fastener manufacturing.

X2.2 Rods and Bars:

X2.2.1 While standard steel grades for rods and bars have been in existence for many years, and have, with modifications or restrictions of one or more elements, long been used for cold forming, this ASTM standard presents a distinct selected series of twenty steel grades for cold forming. These have been jointly developed by steel producers and cold heading and forging users under the aegis of the Industrial Fasteners Institute. These twenty grades are designated IFI steel grades and the ranges and limits for the thirteen carbon steel grades for carbon, manganese, phosphorus, and sulfur are shown in Table 4. Maximum residual limits for copper, nickel, chromium, molybdenum, and tin are specified in 6.5. Silicon ranges and limits are shown in Table 6. The chemical limits for the seven alloy steel grades are shown in Table 7.

X2.2.2 A significant area of improvement is in the decarburization control and measurement for cold heading rods and bars. A method to measure based upon the location of the worst decarburization position is described in Section 8 and shown in Fig. 2. The average total affected depth which may not be

exceeded is found in Table 10. Free ferrite should not exceed the maximum depth of free ferrite at the worst location.

X2.2.3 To prepare a material for cold forming it is often spheroidized, which is an annealing treatment that transforms the microstructure of steel to its softest condition with maximum formability. In the hot rolled or normalized condition, steels containing less than 0.80 % carbon consist of the microconstituents pearlite and ferrite. Pearlite, the harder of the two constituents, causes the steels to resist deformation. The harder pearlite is comprised of alternating thin layers or shells of ferrite and cementite (iron carbide), a very hard substance. In spheroidize annealing, the cementite layers are caused by time and temperature to collapse into spheroids or globules of cementite. This globular form of cementite tends to facilitate cold deformation in such processes as cold heading, cold rolling, forming, and bending.

X2.2.4 Plate 1, Fig. 1 displays variations in the transformation of pearlite to spheroidized cementite. Temperature variations within a charge or inadvertent heating either slightly below or slightly above the optimum temperature may produce a departure from the ideally spheroidized structure. Plate 1 displays material treated at a lower than ideal temperature exhibiting a granular structure and is shown as G1 through G5. Material treated at a higher than ideal temperature will exhibit a lamellar structure and is shown as L1 through L5. Latent energy from cold work will allow drawn wire to transform more readily to a higher degree of spheroidization than will hot rolled rod or bar. The degree of spheroidization is normally evaluated at 1000× magnification.

X2.2.5 When spheroidize annealed, Cold Heading Rods or Cold Heading Bars shall meet a maximum rating of G-2 or L-2 in Plate 1.

X2.2.6 While a fully spheroidized microstructure is desired for forming, material is rarely used in the “as spheroidized annealed” condition. Such material can cause processing difficulties because of its poor coil configuration, the formation of a “shear lip” during shearing, or result in undesirable bending of the fastener shank during cold heading. For these reasons almost all material is given a light wire drawing reduction after the thermal treatment either by the wire producer or in front of the fastener heading operation. Spheroidized structures are also known to retard austenization during short cycle heating, such as induction heating, in a subsequent hardening operation. Additional time may be required to dissolve the spheroidized cementite into the austenite at the heating temperature.

X2.2.7 The tolerances for rod and bar are reduced for IFI grades, reflecting the committee consensus that this feature would significantly improve control of cold working. Out-of-round material may cause localized die wear showing up as wear rings in the drawing die. The elliptical material cross section produces nonuniform cold work stresses around the circumference of the drawn cross section which contributes to distortion of the product and causes hardness variation across the section. Thus, serious efforts are anticipated now and in the future to bring about reasonable economic tolerance improvement.

X2.2.8 Rods and bars are subject to mill testing and inspection to provide material soundness and freedom from detrimental surface imperfections. These features are required to assure satisfactory performance of the wire produced from rods and bars. Thermal treatment as a part of wire mill processing is very important in the higher carbon grades of steel. Wire “direct drawn” from low carbon and medium low carbon steel wire rods is sometimes successfully used for simple two-blow upsets or for standard trimmed hexagon head cap screws.

X2.2.9 As upsetting becomes progressively more demanding, wire drawn from annealed or spheroidize annealed rods is more appropriate. For demanding applications, annealed-in-process or spheroidize annealed-in-process wire is required. For thermally treated in-process wire, the final drawing operation may be performed by the wire supplier or incorporated into the cold heading operation by drawing in tandem with that operation.

X2.2.10 Cold Heading Rods and Bars will not necessarily result in successful production of recess head and socket head quality wire. Wire mills desiring to produce recess head and socket head wire should consult steel manufacturers to secure material with additional restrictive requirements.

X2.2.11 In the production of rods for heading, forging or cold extrusion in killed steels over 0.13 % carbon, both austenitic grain size and decarburization are important features. Such steels can be produced either “fine” or “coarse” austenitic grain as required depending upon the type of heat treatment and application. Table 10 shows decarburization limits for the maximum permissible depth of free ferrite and the average total affected depth of decarburization. The examination is conducted as outlined in Section 8 of this standard. If decarburization limits closer than those shown in Table 10 are required in a given manufactured product, it is sometimes

appropriate for the purchaser to incorporate means for carbon restoration in his manufacturing process.

X2.2.12 In cases of disagreement in the testing for decarburization, it is customary to make heat treatment tests of the finished product to determine suitability for the particular application.

X2.2.13 Rods and bars should be reasonably free from detrimental surface imperfections including seams, voids, pits, scratches, and laps. Material suitably thermally treated when appropriate, which bursts or splits when upset or formed, and having imperfections deeper than the greater of 0.003 in. or 0.5 % of D (where D is the finished diameter in inches of material), is normally rejectable.

X2.2.14 Samples requiring assessment of such surface imperfections shall be prepared by careful metallographic technique, suitably etched, and the depth of imperfection measured radially from the surface at a magnification of 100×.

X2.2.15 Mechanical properties for thermally treated rods and bars are shown in Table 11.

X2.2.16 Rod size tolerances are shown in Table 2.

X2.2.17 Bar size tolerances are shown in Table 1.

X2.2.18 A selected series of steel grades has been developed for carbon steel rods and bars for cold heading and cold forging. See Table 4.

X2.3 Wire:

X2.3.1 Wire for cold heading and forging is produced from bars or rods featuring closer than normal control of chemical composition, size tolerances, decarburization limits, freedom from detrimental surface imperfections, and when appropriate, specified mechanical properties for thermally treated material, see Table 11; and when spheroidized, a maximum rating G2 or L2, see Plate 1.

X2.3.2 Thermal treatment of wire involves heating and cooling the steel in such a manner to achieve desired properties or structures.

X2.3.3 *Annealing* is the general term applied to a variety of thermal treatments for the purpose of softening the wire. Annealing commonly involves heating the material to temperature near or below the critical temperature. A number of processes are employed which influence the surface finish obtained. If a particular finish is required on wire annealed at final size, the producer should be consulted.

X2.3.4 *Regular Annealing*, sometimes called pot annealing, is performed by heating coils of wire in a furnace followed by slow cooling without an attempt to produce a specific microstructure or a specific surface finish.

X2.3.5 *Spheroidize Annealing* involves prolonged heating at a temperature near or slightly below the lower critical temperature, followed by slow cooling, with the object of producing a globular (spheroidal) condition of the carbide to obtain maximum softness.

X2.3.6 *Annealed in Process Wire* is a term normally associated with cold heading wire. The product is manufactured by drawing rod or bar to a size larger than the finished diameter wire, and regular annealing to relieve the stresses of cold work and obtain softening. This is followed by cleaning, coating with a suitable lubricant, and redrawing to finished size, usually with an area reduction of between 7 % to 20 %

depending upon wire size and application. See Table 11 for expected tensile strengths.

X2.3.7 *Spheroidize Annealed in Process Wire* is another term normally associated with cold heading wire. The product is manufactured by drawing rod to a size larger than the finished diameter wire, followed by spheroidize annealing to obtain maximum softness and to create a spheroidal structure as shown in Plate 1. The wire is then cleaned, coated with a suitable lubricant, and redrawn to finished size, usually with an area reduction of between 7 % to 20 % depending upon wire size and application.

X2.3.8 *Decarburization Tests* are made by the microscopic method described in Section 8. Table 10 shows the decarburization limits for the maximum depth of free ferrite and the maximum average total affected depth. The limits shown apply to wire made from killed steel over 0.13 % carbon. When closer limits are required, it is sometimes appropriate for the purchaser to incorporate means for carbon restoration in its finished product.

X2.3.9 Finishes or coatings are designed to provide proper lubrication for the header dies. With modern developments in cold heading technique, the role of wire finishes has assumed much greater importance. In addition to performing the required upset in the dies, the cold heading operations may now include single or double extrusion, slotting, punching, trimming, pointing, etc. The wire coatings or finishes must have both the necessary lubricating quality and adherence to prevent galling or undesirable die wear. This necessitates special control of the various types of lubricants that are used and the correct amount of coatings for the type of heading operation involved.

X2.3.10 While lime-soap finishes are widely employed, phosphate finishes are frequently used for the more demanding forming applications.

X2.3.11 Phosphate coated wire finishes are produced from material which has been chemically cleaned, coated with zinc phosphate, and suitably neutralized. The stock may be coated with lime or borax as a carrier if the lubricant is to be applied in the die box. The wire lubricant may be applied by immersing the phosphate coated coils in a dilute soluble soap bath, by pickup of a dry lubricant in the drawing die box, or by a combination of both methods. The drawn finish so produced is particularly beneficial in many severe cold working applications, especially those involving backward extrusion.

X2.3.12 Thermally treated wire can also be supplied cleaned and lime coated or cleaned and phosphate coated at ordered size. Wire phosphate coated at ordered size can be furnished with or without suitable lubricant coatings for subsequent drawing into smaller sizes or for direct use in cold formers. A drawn phosphate finish as discussed in the preceding paragraph, provides a more effective lubrication during cold forming than phosphate coated at finished size.

X2.3.13 Solid die heading machines, especially those used for extrusion heading, require a coating of special consistency, whereas with open or split die heading machines a light coating will perform satisfactorily. Cold heading finishes are varied considerably even for the same type of heading, in order to meet individual cold heading requirements. Those coatings are

individual in character and involve manufacturing techniques that differ markedly from conventional wire mill practice where the only consideration is the provision of lubrication essential for the wire drawing operation.

X2.3.14 Size tolerances for wire for cold heading and cold forging are shown in Table 3.

X2.3.15 Mechanical properties for selected steel grades of wire for cold heading and cold forging when thermally treated are shown in Table 11. Whereas it is appropriate to establish mechanical properties for selected compositions of thermally treated carbon steel rods and bars, mechanical properties of wire drawn directly from rods or bars are substantially influenced by the amount of reduction in drawing the wire. The reduction is dependent on the incremental availability of nominal rod and bar sizes as well as the influence of size tolerances. Accordingly no values are included in Table 11 for wire drawn from annealed or spheroidize annealed rods or bars. Certain steel grades are available with differences in deoxidation practices. Suitable allowances for aluminum killed steel and rimmed steel are incorporated in the footnote to Table 11. The amount of reduction prior to thermal treatment, the size tolerance of the intermediate thermally treated wire, and the required percent reduction to final size which progressively increases as the final wire size decreases, influence the mechanical properties. An appropriate adjustment in values for annealed in process and spheroidize annealed in process wire as a function of size is included in the footnote to Table 11.

X2.3.16 Chemical compositions particularly suited to wire for cold heading and cold forging have been developed. For carbon steels these are included in Table 4 and for alloy steels in Table 7.

X2.3.17 Cold Heading and Cold Forging Wire have five application variations as follows:

- X2.3.17.1 Cold Heading,
- X2.3.17.2 Recessed Head,
- X2.3.17.3 Socket Head,
- X2.3.17.4 Scrapless Nut, and
- X2.3.17.5 Tubular Rivet.

X2.3.18 Each of these variations is intended to be well suited to the fabrication of a particular fastener type and fastener manufacturing method.

X2.3.19 Fastener fabrication includes a wide variety of methods and complexity of machines and tooling. The simplest is a single die, single blow machine, common to the nail machines, but also used for simple shapes such as certain rivets. Single die, two blow machines which first gather stock, then rotate the punch, and strike again, are widely used for larger headed rivets and most machine screws and tapping screws. By partitioning the cold work in two separate die cavities, progressively and selectively deforming the raw material, it is thus possible to produce larger overall deformations or upsets, of more complex shapes, without fracture.

X2.3.20 Two die three blow machines permit extruding of the shank, thereby utilizing a larger diameter starting raw material, accommodating the production of larger heads without as much upsetting; or permitting the use of hard drawn wire where annealed material would otherwise have been required. Progressive headers can include six or more stations permitting

the cold forged production of very complex configurations which otherwise would require machining or a combination of forming and machining for their manufacture. Accordingly, it is not appropriate to merely examine the geometry of a finished fastener to establish the appropriate raw material; for example, hard drawn, wire drawn from annealed rod or bar, or spheroidize annealed in process wire. The method of manufacture is also required information, as is the steel processing for a particular application. Communication between the steel supplier and the fastener producer is, therefore, of paramount importance to avoid the use of raw material which is unnecessarily costly on the one hand or inadequately processed on the other.

X2.3.21 *Cold Heading Wire* is produced by specially controlled manufacturing practices to provide satisfactory quality for heading, forging, and roll threading. The wire is subject to mill tests and inspection for internal soundness, control of chemical composition, and freedom from detrimental surface imperfections.

X2.3.22 In many cases, the threads of bolts, screws, studs, etc., are cold formed by an operation known as roll threading. This consists of rolling the shank between rolling dies to provide the particular thread form required. Experience has shown that detrimental internal imperfections and detrimental surface imperfections in the wire will result in a crushed condition or imperfect thread which renders the product unfit for use. Therefore, particular care is required in the manufacture of the wire to provide freedom from detrimental imperfections. Precautions are also required of the fabricators in setting up and adjusting roll threading equipment. Faulty set up or adjustment can produce defective threads even when the wire is of proper quality.

X2.3.23 Hard drawn low carbon and medium low carbon steel wire is sometimes successfully used for simple two-blow upsets or for standard trimmed hexagon head cap screws. As upsetting becomes progressively more demanding, wire drawn from annealed or spheroidized annealed rods is more appropriate. For demanding applications, annealed in process or spheroidize annealed in process wire is required. For thermally treated in process wire, the final drawing operation may be performed by the wire supplier or incorporated into the cold heading operation by drawing in process in tandem with that operation. Cold Heading wire is not appropriate for recessed head or socket head application.

X2.3.24 *Recessed Head Wire* is employed when screw heads incorporate a recess configuration such as a crossed or square recess. This wire involves more exacting precautions and controls than Cold Heading wire, such as improved surface quality and special wire processing. Exacting precautions and controls are necessary in the selection and internal soundness

of the steel and in the preparation of billets for surface quality. Special attention to rod rolling and to inspection of the rods is essential. In order to provide wire that will be soft enough to withstand the very severe cold forming operations, wire for all types of recess head screws is generally spheroidize annealed in process or spheroidize annealed at finished size, with the final drawing incorporated into the heading operation by drawing in process in tandem with that operation. When spheroidize annealed at finish size wire is so employed, the fastener producer should ensure that the final reduction is not excessive.

X2.3.25 *Socket Head Wire* is similar to Recessed Head wire but is intended for the deep sockets attendant with hexagon and Torx[™] and similar internal drives, requiring still more exacting processing and controls to accommodate the substantially heavier deformation.

X2.3.26 *Scrapless Nut Wire* is produced by closely controlled manufacturing practices, and subjected to mill tests and inspection designed to provide internal soundness and freedom from detrimental surface imperfections, thus providing satisfactory cold heading, cold expanding, cold punching, and thread tapping characteristics.

X2.3.26.1 This wire is produced for the manufacture of various shaped nuts, which are made in continuous operation on heading machines. The cold heading operation in the production of scrapless nuts is very severe, and the wire is specially prepared for that purpose.

X2.3.27 Low and medium low carbon hard drawn wire or wire drawn from annealed rods or bars is employed, depending on the severity of deformation. Medium carbon wire is normally drawn from annealed or spheroidize bars or rods, or produced annealed in process. For nuts not requiring a final heat treatment, the attainment of minimum required nut proof loads is partially dependent on the raw material, the selection of an appropriate steel grade, and the amount of wire reduction.

X2.3.28 *Tubular Rivet Wire* is suitable for cold heading and backward extruding the hole in the shank during cold heading. In order to obtain the properties essential for the production of tubular rivets, the wire is spheroidize annealed in process but with a final redrawing operation somewhat heavier than normal to prevent buckling in the extruding operations. Accordingly, the mechanical properties shown in Table 11 may not always be appropriate for spheroidize annealed in process tubular rivet wire. Wire may also be furnished spheroidize annealed at finished size with the final drawing incorporated into the heading operation by drawing in tandem with that operation. Wire finish to accommodate the individual conditions of severe cold extruding and cold heading is an important consideration. Tubular Rivet wire is normally produced from low carbon aluminum killed steel.

X3. BORON CONTENT IN CARBON STEELS

X3.1 Boron is extremely effective as a hardening agent in carbon steels, contributing hardenability which generally exceeds the result of many commercial alloying elements. It does not adversely affect the formability or machinability (see Note X3.1) of plain carbon steels. Actually, the reverse is true since boron permits the use of lower carbon content which contributes to improved formability and machinability (see Note X3.1).

X3.2 In its early development, some unsatisfactory results produced product which did not have uniform hardness or toughness along with reduced ability to resist delayed fracture. However, many of these problems were overcome by exhaustive research which demonstrated that for boron to be effective as an alloying agent, it must be in solid solution in a composition range of 0.0005 % to 0.003 %. During deoxidation, failure to tie up the free nitrogen results in the formation of boron nitrides which will prevent the boron from being

available for hardening. Research also revealed boron content in excess of 0.003 % has a detrimental effect on impact strength because of the precipitation of excess boron as iron borocarbide in the grain boundaries.

X3.3 Many European steels contain higher boron levels than in North America. ISO 898-1 addresses this issue by the following statement: "Boron content can reach 0.005 % provided that noneffective boron is controlled by addition of titanium and/or aluminum." Boron content is not to be determined by product analysis; only the ladle analysis shall be used.

NOTE X3.1—When producing a boron steel, titanium and/or aluminum is added and the resulting product is subjected to thermal processing. These two additions are designed to tie up nitrogen to stop it from reacting with boron. The resulting free boron is available to provide excellent hardenability in steel. Both titanium and aluminum nitrides reduce the machinability of the steel, however, when the nitrogen becomes tied up, the formability of the steel is improved.

X4. SILICON AND ALUMINUM

X4.1 Silicon and aluminum act as somewhat similar elements with respect to their behavior when added during the steel making process. They both have a high affinity for oxygen and are, therefore, used to deoxidize or "kill" the steel. Deoxidation or "killing" is a process by which a strong deoxidizing element is added to the steel to react with the remaining oxygen in the bath to prevent any further reaction between carbon and oxygen. When carbon and oxygen react in the bath a violent boiling action occurs which removes carbon from the steel. When the bath or heat reaches the desired carbon content for the grade being produced, the carbon-oxygen reaction must be stopped quickly to prevent further elimination of carbon. This addition is accomplished by the addition of deoxidizers such as silicon and aluminum which have a greater affinity for oxygen than does carbon. This effectively removes oxygen, eliminating the "carbon boil" and killing the heat. Elements other than silicon and aluminum can be used, but these are the most common.

X4.2 Silicon and aluminum can be added together or individually. This is determined by the type of steel desired. If silicon only is added, that particular batch of steel is referred to as a silicon killed coarse grain practice grade because silicon acts as a deoxidizer without the formation of fine precipitates allowing the formation of large or coarse austenitic grains. Austenitic grain size is not usually a factor for consideration in cold forming, but has a significant effect in subsequent fastener heat treatment. Aluminum, on the other hand, not only deoxidizes the steel, but also refines the grain size. Like silicon, aluminum removes oxygen from the bath, effectively killing the heat. Aluminum also reacts with nitrogen in the steel to form aluminum nitride particles which precipitate both at the grain boundaries and within the austenitic grains thus restrict-

ing the size of the grains; even when the steel is reheated for carburizing or neutral hardening, hence the term fine grain. When aluminum only is added, the steel is referred to as aluminum killed, fine grain. A third group of steels are referred to as silicon killed, fine grain. In steels of this type, silicon is added as the deoxidizer followed by the addition of aluminum for grain size control.

X4.3 In the two types where silicon is added, the silicon content can have several ranges with the most common being 0.15 % to 0.30 %. When aluminum is added to these steels for grain size control, the aluminum content is generally in the 0.015 % to 0.030 % range. The aluminum content in fully aluminum killed steels is generally 0.015 % to 0.055 %, somewhat higher on average since the aluminum must both deoxidize and control grain size at the same time.

X4.4 In selecting the type of deoxidation practice for a particular carbon grade of steel to be used in fastener manufacturing, a number of factors should be considered, such as, heat treated property requirements, heat treat conditions, fastener size, and steel availability, to name a few. Silicon acts as a ferrite strengthener and, therefore, in the absence of aluminum, has somewhat greater hardenability. For the same carbon grade and heat treat conditions with and without aluminum, complete transformation of the fastener core during heat treatment can take place in a larger section using a coarse grain steel. The disadvantage of silicon killed steels can be reflected in reduced ductility and tool life during cold heading because of its ferrite strengthening characteristic. Aluminum killed steels are usually more formable and hence provide somewhat improved tool life but reduced heat treatment response during

heading, particularly in larger size fasteners. For this reason, the recommended maximum diameter for oil quenched aluminum killed carbon grades is typically 0.190 in.

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