Designation: A 800/A 800M – 01 (Reapproved 2006)

# Standard Practice for Steel Casting, Austenitic Alloy, Estimating Ferrite Content Thereof[1]

This standard is issued under the fixed designation A 800/A 800M; 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 practice covers procedures and definitions for estimating ferrite content in certain grades of austenitic iron-chromium-nickel alloy castings that have compositions balanced to create the formation of ferrite as a second phase in amounts controlled to be within specified limits. Methods are described for estimating ferrite content by chemical, magnetic, and metallographic means.

1.2 The grades covered by this practice are: CF-3, CF-3A, CF-8, CF-8A, CF-3M, CF-3MA, CF-8M, CF-8C, CG-8M, and CH-10.

1.3 The values stated in either inch-pound units or SI units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the practice.

1.4 *This standard does not purport to address 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. Referenced Documents

2.1 *ASTM Standards:* [2]

A 351/A 351M Specification for Castings, Austenitic, for Pressure-Containing Parts

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

A 799/A 799M Practice for Steel Castings, Stainless, Instrument Calibration, for Estimating Ferrite Content

A 941 Terminology Relating to Steel, Stainless Steel, Related Alloys, and Ferroalloys

E 38 Methods for Chemical Analysis of Nickel-Chromium and Nickel-Chromium-Iron Alloys

E 353 Test Methods for Chemical Analysis of Stainless, Heat-Resisting, Maraging, and Other Similar Chromium-Nickel-Iron Alloys

E 562 Test Method for Determining Volume Fraction by Systematic Manual Point Count

2.2 *Constitution Diagrams:*

Schoefer Diagram for Estimating Ferrite Content of Stainless Steel Castings (1980 revision)[3]

Schaeffler Diagram for Estimating Ferrite Content of Stainless Steel Weld Metal [4]

DeLong Diagram for Estimating Ferrite Content of Stainless Steel Weld Metal [5]

2.3 *American Welding Society Specification:*

AWS A 4.2, Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal[6]

## 3. Terminology

3.1 *Definitions:*

3.1.1 *ferrite*—the ferromagnetic, body-centered, cubic-microstructural constituent of variable chemical composition in iron-chromium-nickel alloys. This may be formed upon solidification from the molten metal (delta ferrite) or by transformation from austenite or sigma phase on cooling in the solid state (alpha ferrite).

3.1.2 *ferrite content*—the proportion of total volume of an iron-chromium-nickel alloy present as the ferrite phase.

3.1.3 *ferrite number*—the ferrite content expressed as an arbitrary number based on the magnetic response of the alloy in a weld deposit.

3.1.4 *ferrite percentage*—the ferrite content expressed as a volume percent.

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[1] This practice is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel, and Related Alloys and is the direct responsibility of Subcommittee A01.18 on Castings.

Current edition approved March 1, 2006. Published April 2006. Originally approved in 1982. Last previous edition approved in 2001 as A 800/A 800M – 01.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Appendix of this practice.

[4] *Metal Progress Data Book*, American Society for Metals, Mid June 1977, p. 161.

[5] *Welding Journal*, American Welding Society, Vol 38, No. 7, July 1973, p. 293–s.

[6] Available from American Welding Society (AWS), 550 NW LeJeune Rd., Miami, FL 33126.

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3.1.5 *heat treatment*—the definitions in Terminology A 941 are applicable to this practice.

## 4. Significance and Use

4.1 The tensile and impact properties, the weldability, and the corrosion resistance of iron-chromium-nickel alloy castings may be influenced beneficially or detrimentally by the ratio of the amount of ferrite to the amount of austenite in the microstructure. The ferrite content may be limited by purchase order requirements or by the design construction codes governing the equipment in which the castings will be used. The quantity of ferrite in the structure is fundamentally a function of the chemical composition of the alloy and its thermal history. Because of segregation, the chemical composition, and, therefore, the ferrite content, may differ from point to point on a casting. Determination of the ferrite content by *any* of the procedures described in the following practice is subject to varying degrees of imprecision which must be recognized in setting realistic limits on the range of ferrite content specified. Sources of error include the following:

4.1.1 *In Determinations from Chemical Composition*—Deviations from the actual quantity of each element present in an alloy because of chemical analysis variance, although possibly minor in each case, can result in substantial difference in the ratio of total ferrite-promoting to total austenite-promoting elements. Therefore, the precision of the ferrite content estimated from chemical composition depends on the accuracy of the chemical analysis procedure.

4.1.2 *In Determinations from Magnetic Response*—Phases other than ferrite and austenite may be formed at certain temperatures and persist at room temperature. These may so alter the magnetic response of the alloy that the indicated ferrite content is quite different from that of the same chemical composition that has undergone different thermal treatment. Also, because the magnets or probes of the various measuring instruments are small, different degrees of surface roughness or surface curvature will vary the magnetic linkage with the material being measured.

4.1.3 *In Determinations from Metallographic Examination*—Metallographic point count estimates of ferrite percentage may vary with the etching technique used for identification of the ferrite phase and with the number of grid points chosen for the examination, as explained in Test Method E 562.

4.2 The estimation of ferrite percent by chemical composition offers the most useful and most common method of ferrite control during melting of the metal.

4.3 For most accurate estimate of ferrite percent, a quantitative metallographic method should be used.

## 5. Ordering Information

5.1 Orders for material to this practice should include the following as required:

5.1.1 Applicable ASTM product specification or other document covering product requirements,

5.1.2 Alloy grade,

5.1.3 Required ferrite content range, in volume percent, of the castings after final heat treatment. Also, if desired by the purchaser, required ferrite content range, in ferrite number, for weld deposits (Note 1) as deposited, and

5.1.4 Supplementary requirements, if any, desired.

NOTE 1—There may be a substantial decrease in the ferrite content of weld deposits after solution heat treatment in comparison with the as-deposited value.

## 6. General Caution

6.1 In specifying ferrite content as required in 5.1.3, the purchaser should not set limits that conflict with applicable material specification requirements: for example, a maximum limit of 10 % ferrite for Grade CF-3A in Specification A 351/A 351M for which the minimum tensile strength requirement is 77 ksi [530 MPa].

6.2 When Supplementary Requirement S1 is specified, the purchaser should set ferrite content limits that are compatible with the measuring instrument to be used.

## 7. Estimation of Ferrite Content

7.1 Estimation in the base metal of the casting by chemical composition in accordance with the Schoefer diagram (see Appendix X1):

7.1.1 A chemical analysis of the heat from which the castings are poured shall include the following elements whether or not required by the chemical requirements of the product specification: carbon, manganese, silicon, chromium, nickel, molybdenum, columbium, and nitrogen.

7.1.1.1 Upon written agreement between the purchaser and the producer, an estimated nitrogen content may be reported instead of an amount determined by analysis of the specific heat if actual chemical analyses have been made for nitrogen in a sufficient number of heats of the same alloy type, produced by the same melting practice, to establish the average nitrogen content to be expected.

7.1.2 The ferrite content of the casting shall be estimated from the central line of the diagram at the composition ratio of "chromium equivalent" ($Cr_e$) to "nickel equivalent" ($Ni_e$) determined from the following formula:

$$(Cr(\%) + 1.5Si(\%) + 1.4Mo(\%) + Cb(\%) - 4.99)/(Ni(\%) + 30C(\%) + 0.5Mn(\%) + 26(N - 0.02\%) + 2.77) = (Cr_e)/(Ni_e)$$

7.1.3 When a product analysis is made by the purchaser, it shall include the elements listed in 7.1.1. If a comparison is made of ferrite content estimated from a product analysis performed by the purchaser, with that estimated from the heat analysis (see 7.1.1), the reproducibility data in the precision statements of Test Methods E 353 shall be used as a guide.

7.1.3.1 Methods E 38 or Test Methods E 353, as applicable, shall be used as referee chemical analysis methods.

7.2 Estimation in weld deposits by chemical composition in accordance with the Schaeffler or DeLong diagrams:

7.2.1 The ferrite content shall be estimated (*a*) from the deposit chemical analysis included on the electrode manufacturer's certified material test report, or (*b*) from chemical analysis of a weld deposit pad made by the casting manufacturer.



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7.3 Estimation of ferrite content in heat, product, or weld metal may be made by the magnetic response or metallographic methods by imposition of Supplementary Requirements S1 or S2, respectively.

## 8. Acceptance Standards

8.1 Conformance with the required ferrite content range specified in 5.1.3 as indicated by the estimation procedure of 7.1 and 7.2 shall be the basis for acceptance of material supplied under this practice unless other methods of estimation are ordered as supplementary requirements, in which case the supplementary requirement shall be the basis of acceptance.

8.2 If lack of conformance with the ferrite content range specified in 5.1.3 is indicated by a product analysis made by the purchaser (7.1.3) and by a referee analysis as provided in 7.1.3.1, rejection of material shall be subject to the tests of 7.3 as established by written agreement between the manufacturer and the purchaser.

## 9. Certification

9.1 The manufacturer's certification shall be furnished to the purchaser stating that the material was sampled and tested in accordance with the specification (including year date) and was found to meet the requirements.

9.2 The test report shall contain the results of the actual chemical analyses required by 7.1.1 and 7.2.1 and the indicated ferrite content range. The estimates of ferrite content from magnetic measurements (S1) or from point counts (S2), or both, if ordered by the purchaser, also shall be reported.

9.3 The test report shall be signed by an authorized agent of the manufacturer.

9.4 The test report shall be furnished within five working days of shipment of the castings.

## 10. Keywords

10.1 austenite; austenitic stainless steel; ferrite; Schoefer Diagram; steel castings

## SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements are for use when desired by the purchaser. They shall not apply unless specified in the order, in which event the specified methods of ferrite content estimation shall be employed by the manufacturer before shipment of the castings.

## S1. Estimation of Ferrite Content by Measurement of Magnetic Response

S1.1 The ferrite content of the heat from which the castings are poured shall be estimated from measurements made by primary or secondary instruments calibrated in accordance with the requirements of Practice A 799/A 799M. All measurements shall be made on material after the solution heat treatment required by the applicable product specification, or, if any subsequent solution heat treatment is employed, then after the final solution heat treatment.

S1.1.1 *Location of measurements—base metal:*

S1.1.1.1 Measurements shall be made on the unstrained ends of tension test specimens from the same heat as the castings represented. Measurements may be made either before or after performance of the tension test. If a tension test is not required by the applicable product specification, measurements may be made on a specimen cut from a keel block of a design in Fig. 3 of Test Methods and Definitions A 370.

S1.1.1.2 When further specified, measurements shall be made on the base metal of the castings, or a specified sample of castings (*not* on weld repairs or other weld deposits), in locations designated on the design drawing or as otherwise agreed in writing between the purchaser and the manufacturer.

S1.2 The ferrite content of weld deposits shall be estimated from measurements made by primary or secondary instruments calibrated in accordance with the requirements of Specification AWS A4.2. All measurements shall be made on weld deposits as deposited.

S1.2.1 *Location of measurements—weld deposits:*

S1.2.1.1 Measurements shall be made on a weld pad deposited in accordance with the electrode specification.

S1.2.1.2 When further specified, measurements shall be made on repair or fabrication welds on castings in locations as agreed in writing between the purchaser and manufacturer.

S1.3 *Number of Measurements*—Six measurements shall be made at random in each designated location. For instruments having probes making two contacts with the surface being measured, a "measurement" shall consist of a pair of readings taken with the probe oriented on perpendicular axes.

S1.4 *Surface Condition:*

S1.4.1 The instrument magnet or probe and the surface to be measured shall be dry and cleaned prior to testing to remove any scale, grease, lint, or dirt that could affect the accuracy of measurement.

S1.4.2 Measurements shall be made more than 0.25 in. [6.350 mm] from the edge of a surface. When measurements are made on a curved surface the radius of curvature must be greater than 0.375 in. [9.525 mm].

S1.5 *Acceptance Criteria:*

S1.5.1 The average of the ferrite contents estimated from measurements in each designated location shall be within the limits stated in the order, and not more than two individual measurements shall indicate ferrite contents less than or in excess of these limits.

S1.5.1.1 If ferrite contents are estimated with an instrument that indicates for each measurement a value between an upper and a lower limit, more than one-half of all measurements shall be within the limits stated in the order.

S1.5.2 Should the requirements of S1.5.1 not be met, a referee estimation of ferrite content may be made by the metallographic method of Supplementary Requirement S2 that shall take precedence over the magnetic method.



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## S2. Estimation of Ferrite Content by Metallographic Examination

S2.1 The locations of specimens to be examined shall be specified on the drawing radiographic shooting sketch, or otherwise in writing by the purchaser.

S2.2 Specimens shall be prepared so that metallographic examination may be made on three orthogonal planes.

S2.3 The volume fraction of ferrite shall be estimated from the specimens by the point count practice recommended in Test Method E 562.

## APPENDIX

**(Nonmandatory Information)**

## X1. NOTES TO SCHOEFER DIAGRAM

X1.1 Fig. X1.1 is applicable to alloys containing elements in the following ranges:

| | Weight, % |
|---|---|
| Carbon | 0.20 max |
| Manganese | 2.00 max |
| Silicon | 2.00 max |
| Chromium | 17.0 to 28.0 |
| Nickel | 4.0 to 13.0 |
| Molybdenum | 4.00 max |
| Columbium | 1.00 max |
| Nitrogen | 0.20 max |

X1.2 The $Cr_e/Ni_e$ Composition Ratio necessary to produce alloy castings within a specified ferrite content range may be read from the diagram at the intersection of the central line with the desired ferrite percentage, or may be obtained from Table X1.1. *Example:* For a ferrite content of 12 % the composition ratio should be 1.234.

X1.3 The estimated average ferrite content of castings may be read from the diagram at the intersection of the central line with the composition ratio calculated from the chemical composition of the heat from which they were poured. Because of errors in chemical analyses, the calculated ratio may differ

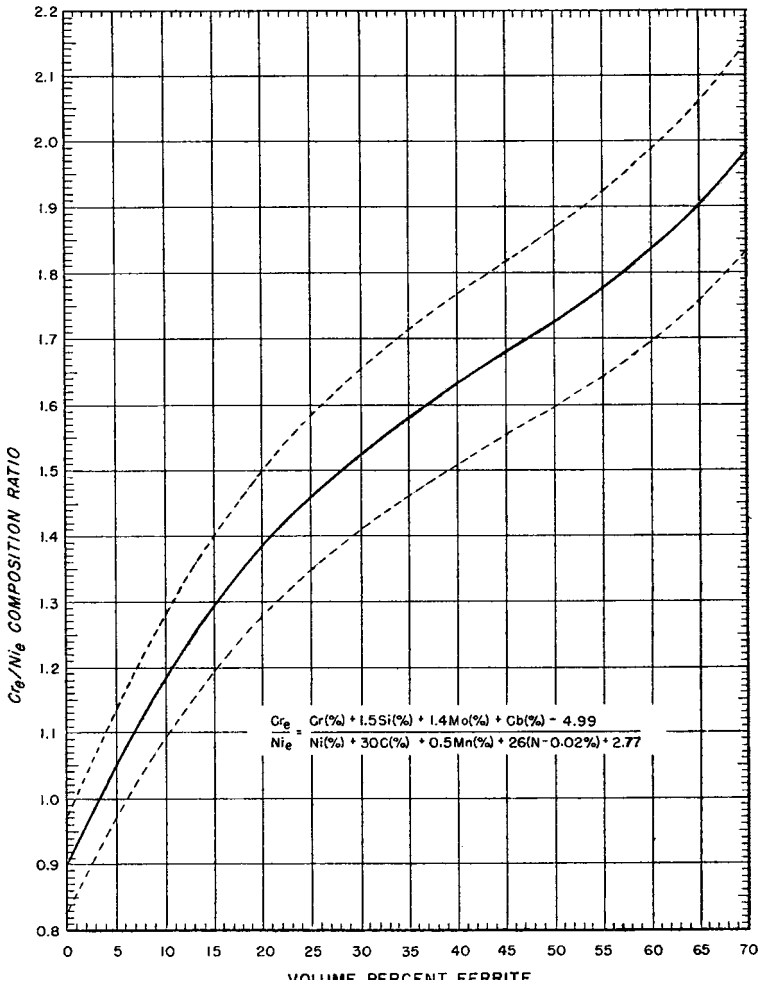


**FIG. X1.1 Schoefer Diagram for Estimating the Average Ferrite Content in Austenitic Iron-Chromium-Nickel Alloy Castings**



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**TABLE X1.1 Composition Ratio Required for a Desired Ferrite Content**

| Volume Percent Ferrite | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.900 | 0.933 | 0.966 | 0.997 | 1.027 | 1.056 | 1.084 | 1.111 | 1.138 | 1.163 |
| 10 | 1.187 | 1.211 | 1.234 | 1.256 | 1.277 | 1.297 | 1.317 | 1.336 | 1.354 | 1.371 |
| 20 | 1.388 | 1.405 | 1.420 | 1.436 | 1.450 | 1.464 | 1.478 | 1.491 | 1.504 | 1.516 |
| 30 | 1.528 | 1.540 | 1.551 | 1.562 | 1.573 | 1.584 | 1.594 | 1.604 | 1.614 | 1.623 |
| 40 | 1.633 | 1.643 | 1.652 | 1.661 | 1.671 | 1.680 | 1.689 | 1.699 | 1.708 | 1.718 |
| 50 | 1.728 | 1.737 | 1.747 | 1.758 | 1.768 | 1.779 | 1.790 | 1.801 | 1.813 | 1.825 |
| 60 | 1.837 | 1.850 | 1.863 | 1.877 | 1.891 | 1.906 | 1.921 | 1.937 | 1.953 | 1.970 |
| 70 | 1.988 | | | | | | | | | |

from the actual composition ratio and, as a result, the ferrite content may be higher or lower than indicated by the central line. Accordingly, if additional estimates of ferrite content are made by magnetic or metallographic methods, they can be expected to differ from the diagram value. The possible extent of this difference is shown by the broken lines. *Example:* If the composition ratio is 1.234, the indicated ferrite content is 12 % with a probable maximum range from 8 to 17 %. Similar information is available in Table X1.2.

X1.4 The ferrite content ranges are related to the upper and lower bounds of the composition ratio that are determined from the ratios $1.04Cr_e/0.96Ni_e$ and $0.96Cr_e/1.04Ni_e$. These correspond approximately to ±1 σ deviations in all the ferrite promoting elements and ±1 σ deviations in all the austenite promoting elements (based on standard deviations of individual elements as derived in a round-robin test project of the Steel Founders' Society of America).

X1.5 Values of composition ratio (*CR*) for a given ferrite content (*F*), or vice versa, may be determined mathematically from the equation of the central line:

$$CR = 0.9 + 3.38883 \times 10^{-2}F - 5.58175 \times 10^{-4}F^{2} + 4.22861 \times 10^{-6}F^{3}$$

**TABLE X1.2 Volume Percent Ferrite Indicated by Composition Ratio**

| | Composition Ratio[A] | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *U* | | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 | 0.5 | 1.0 | 1.5 | 1.5 | 2.0 |
| | 0.80 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *L* | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| *U* | | 2.5 | 2.5 | 3.0 | 3.5 | 3.5 | 4.0 | 4.5 | 5.0 | 5.0 | 5.5 |
| | 0.90 | 0.0 | 0.5 | 0.5 | 1.0 | 1.0 | 1.5 | 2.0 | 2.0 | 2.5 | 3.0 |
| *L* | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.5 |
| *U* | | 6.0 | 6.5 | 7.0 | 7.0 | 7.5 | 8.0 | 8.5 | 9.0 | 9.5 | 9.5 |
| | 1.00 | 3.0 | 3.5 | 4.0 | 4.0 | 4.5 | 5.0 | 5.0 | 5.5 | 6.0 | 6.0 |
| *L* | | 0.5 | 1.0 | 1.5 | 1.5 | 2.0 | 2.0 | 2.5 | 2.5 | 3.0 | 3.0 |
| *U* | | 10.0 | 10.5 | 11.0 | 11.5 | 12.0 | 12.5 | 13.0 | 13.5 | 14.0 | 14.5 |
| | 1.10 | 6.5 | 7.0 | 7.5 | 7.5 | 8.0 | 8.5 | 9.0 | 9.5 | 9.5 | 10.0 |
| *L* | | 3.5 | 4.0 | 4.0 | 4.5 | 5.0 | 5.0 | 5.5 | 6.0 | 6.0 | 6.5 |
| *U* | | 15.0 | 15.5 | 16.5 | 17.0 | 17.5 | 18.0 | 18.5 | 19.5 | 20.0 | 20.5 |
| | 1.20 | 10.5 | 11.0 | 11.5 | 12.0 | 12.5 | 12.5 | 13.0 | 13.5 | 14.0 | 14.5 |
| *L* | | 7.0 | 7.0 | 7.5 | 8.0 | 8.5 | 8.5 | 9.0 | 9.5 | 10.0 | 10.0 |
| *U* | | 21.0 | 22.0 | 22.5 | 23.5 | 24.0 | 25.0 | 25.5 | 26.5 | 27.5 | 28.0 |
| | 1.30 | 15.0 | 15.5 | 16.0 | 16.5 | 17.0 | 18.0 | 18.5 | 19.0 | 19.5 | 20.0 |
| *L* | | 10.5 | 11.0 | 16.5 | 11.5 | 12.0 | 12.5 | 13.0 | 13.5 | 14.0 | 14.5 |
| *U* | | 29.0 | 30.0 | 31.0 | 32.0 | 33.0 | 34.0 | 35.0 | 36.0 | 37.0 | 38.0 |
| | 1.40 | 20.5 | 21.5 | 22.0 | 22.5 | 23.5 | 24.0 | 24.5 | 25.5 | 26.0 | 27.0 |
| *L* | | 15.0 | 15.0 | 15.5 | 16.0 | 16.5 | 17.0 | 17.5 | 18.0 | 18.5 | 19.0 |
| *U* | | 39.0 | 40.5 | 41.5 | 42.5 | 43.5 | 45.0 | 46.0 | 47.0 | 48.5 | 49.5 |
| | 1.50 | 27.5 | 28.5 | 29.5 | 30.0 | 31.0 | 32.0 | 33.0 | 33.5 | 34.5 | 35.5 |
| *L* | | 20.0 | 20.5 | 21.0 | 21.5 | 22.0 | 22.5 | 23.5 | 24.0 | 24.5 | 25.0 |
| *U* | | 50.5 | 51.5 | 52.5 | 54.0 | 55.0 | 56.0 | 56.5 | 57.5 | 58.5 | 59.5 |
| | 1.60 | 36.5 | 37.5 | 38.5 | 39.5 | 40.5 | 42.0 | 43.0 | 44.0 | 45.0 | 46.0 |
| *L* | | 26.0 | 26.5 | 27.5 | 28.0 | 29.0 | 29.5 | 30.5 | 31.0 | 32.0 | 33.0 |
| *U* | | 60.5 | 61.0 | 62.0 | 63.0 | 63.5 | 64.5 | 65.0 | 66.0 | 66.0 | 67.0 |
| | 1.70 | 47.0 | 48.0 | 49.0 | 50.0 | 51.5 | 52.0 | 53.0 | 54.0 | 55.0 | 56.0 |
| *L* | | 33.5 | 34.5 | 35.5 | 36.5 | 37.0 | 38.0 | 39.0 | 40.0 | 41.0 | 42.0 |



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**TABLE X1.2** *Continued*

| Composition Ratio[A] | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| *U* | 68.0 | 68.5 | 69.0 | 69.5 | 70.5 | >70 | | | | |
| 1.80 | 57.0 | 58.0 | 58.5 | 59.5 | 60.0 | 61.0 | 62.0 | 62.5 | 63.0 | 64.0 |
| *L* | 43.0 | 44.0 | 45.0 | 46.0 | 47.0 | 48.0 | 49.0 | 50.0 | 51.0 | 51.5 |
| *U* | >70 | | | | | | | | | |
| 1.90 | 64.5 | 65.5 | 66.0 | 66.5 | 67.0 | 68.0 | 68.5 | 69.0 | 69.5 | 70.0 |
| *L* | 52.5 | 53.5 | 54.5 | 55.0 | 56.0 | 57.0 | 57.5 | 58.5 | 59.0 | 60.0 |
| *U* | >70 | | | | | | | | | |
| 2.00 | >70 | | | | | | | | | |
| *L* | 61.0 | 61.5 | 62.0 | 63.0 | 63.5 | 64.0 | 64.5 | 65.5 | 66.0 | 66.5 |
| *U* | >70 | | | | | | | | | |
| 2.10 | >70 | | | | | | | | | |
| *L* | 67.0 | 67.5 | 68.0 | 69.0 | 69.5 | 70.0 | >70 | | | |

[A] For a given composition ratio the ferrite content estimate will be found at the intersection of the appropriate line and column. The figures immediately above and below on the lines *U* and *L* indicate the probable upper and lower bounds of the ferrite range that may be expected.

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