Literature Review

Ferrite Measurement in Austenitic and Duplex Stainless Steel Castings

Submitted to:
SFSA/CMC/DOE

August 1999

Submitted by:
C. D. Lundin
W. Ruprecht
G. Zhou

Materials Joining Research Group
Department of Materials Science and Engineering
The University of Tennessee, Knoxville

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1.0 PROGRAM INTRODUCTION

Ferrite measurement techniques evolved after the realization that austenitic stainless steel weld metals, containing a moderate amount of ferrite, were free of hot cracking related weld defects. Ferrite measurement was immediately identified as a method by which engineers could quantify the amount of weld metal ferrite and ensure that their fabrications would be free from hot cracking. The advent of duplex stainless steels further re-emphasized the need for adequate ferrite measurement techniques as a suitable ferrite/austenite phase balance provides adequate mechanical properties and improved corrosion performance. In order to qualify their cast products, reliable means to measure ferrite were developed to assure compliance with industrial practices and customer requirements.

The Ferrite Measurement program was conceived with the ideology that an increased database, with regard to current ferrite measurement techniques, will benefit producers and users of stainless steel castings. Utilizing available instrumentation, a series of “round-robin” tests have been implemented to study lab-to-lab variation in traditional magnetic and modern electronic ferrite measurement techniques. Since the implementation of this program (February 1998), the Materials Joining Research Group (University of Tennessee – Knoxville) conducted a survey of literature and initiated studies into the characterization of castings. Studies involving ferrite content measurement as a function of surface roughness were designed. Efforts to characterize ferrite content as a function of depth from the surface of a casting were implemented.

Additionally, this research effort has moved toward the development of a practice to manufacture cast secondary standards, which are required for the calibration of electronic ferrite measurement equipment.

This increased knowledge base has a direct impact upon industrial corporations that manufacture duplex stainless steel castings. Analysis of ferrite typically requires a more time consuming and possibly destructive analysis in which castings are sectioned for metallographic analysis or resized to complement an instrument. With the validation of improved techniques, the amount of expended labor and energy usage can decrease while productivity can improve. It is the desire of this research effort that a marked reduction in energy usage and associated material and labor costs shall result from an increased understanding of new ferrite determination techniques and their applicability to industry.

2.0 PROJECT GOALS

The following project goals have been defined for this program:

- Comparison of metallographic, magnetic and electronic permeability methods of ferrite measurement and assessment of statistical repeatability for each method.
- Examination of variations in ferrite content by performing surface-to-core depth profile measurements on castings.
- Examination of the effect of surface finish on measurement capability.
- Development of standard ferrite measurement procedures.
- Development of a methodology for the production of Cast Secondary Standards.
- Publication of research and guidance in ferrite measurement.

3.0 LITERATURE REVIEW

3.1 Introduction

A critical review of published literature has been conducted to define methods of ferrite measurement and means of round-robin testing for measurement validation. Special attention has been paid to relevant technical specifications (AWS A4.2) as well as research articles. This review is primarily concentrated on applicable ferrite measurement techniques and their inherent capability and accuracy. The following section, "Importance to Industry", describes the desire of industrial producers and users of stainless steel castings to obtain repeatable and cost effective methods of ferrite determinations for their finished products.

3.1.1 Importance to Industry

Producers and users of stainless steel castings have recognized the need to accurately quantify the microstructure of their finished product. With increasing demand being placed upon quality and reliability by institutions like the International Standardization Organization (ISO 9000 / ISO 9001), engineers have recently become concerned with their ability to accurately quantify the ferrite content in a casting, and thus to verify the capability of their manufacturing processes. Additionally, efforts to

eliminate destructive evaluation, as a method to qualify castings, have yielded to new developments in ferrite measurement techniques.

With the advent of new technology for non-destructive evaluations of ferrite content, new options have been introduced to foundries, consumers and engineers. Prior to examining current techniques, a review of “Advances in Ferrite Measurement” was compiled from a series of Adam’s Lectures presented at the American Welding Society’s annual meetings and then subsequently published in the Welding Journal.

3.1.2 Advances in Ferrite Measurement

In his 1974 Adams Lecture, W.T. DeLong summarized the subject of ferrite measurement for the 55th annual American Welding Society (AWS) Meeting. During his lecture, DeLong recounted the characteristics of ferrite and its importance in the field of welding. Dating his lecture material prior to World War II, DeLong was able to characterize early observations of the effect of ferrite on cracking, fissuring, mechanical properties and corrosion performance of weldments.¹

As a part of his lecture, DeLong recounted methods of ferrite measurement including calculation of ferrite from chemistry, metallography, magnetic measurement, x-ray diffraction and magnetic permeability. His critique of each available method, as applied to weld metal substrates consisting of austenitic stainless steels, revealed the following observations:²

- Ferrite determination from chemistry had been evaluated and was considered a statistically viable option for ferrite prediction through the application of

appropriate constitution diagrams. The Schaeffler and DeLong diagrams were the only applicable diagrams which incorporated alloy chemistry into ferrite content prediction.

- The statistical accuracy of metallographic measurements (point counting) was highly influenced by the ferrite colony size, and the introduction of automated techniques had done little to improve upon operator variances. It was also observed that changes in ferrite content within the same substrate made quantification representative of the entire sample difficult.
- Magnetic measurements, using commercially available instruments, were defined to be a suitable method of quantifying ferrite content. Such devices are discussed further in this review.
- The use of x-ray diffraction as a ferrite measurement technique was applicable. However, diffraction patterns were diffuse in nature and subject to interpretation. It was concluded that sufficient accuracy was unattainable using this technique.
- Magnetic permeability measurements had not yet been accurately researched. Although proposals had been submitted on this subject, insufficient research had been conducted to validate such a technique.*

*Note: Future developments would later validate this method of ferrite measurement.

Incorporating these techniques into a world-wide round-robin test series, the International Institute of Welding (IIW), Subcommittee IIC and the Advisory

Subcommittee of the High Alloys Committee of the Welding Research Council (WRC), initiated two doctrines in 1974. They are presented as follows:

- 1) Based upon the round-robin test series, the WRC Advisory Subcommittee proposed that the term “Ferrite Number” (FN) replace conventional “percent ferrite” as a method to quantify ferrite content. The lack of appropriate universal calibration procedures and reference standards had produced significant lack of agreement between laboratories. At that time, FN was meant to directly replace “percent ferrite” on a 1:1 basis.³

Note: Future research would reveal that the 1:1 correlation of FN to “volume percent ferrite” is only acceptable for low ferrite contents (0-10 FN), such as that present in the majority of austenitic stainless steel weld metals. The application of ferrite measurement techniques to duplex stainless steels would require further testing to define appropriate correlations.

- 2) The lack of standardized testing methods produced significant variability in the data acquired from IIW round-robin testing. Furthermore, measurements between laboratories suggested that further work was required to institute a universal system of ferrite measurement.⁴

Data from IIW round-robin testing enabled the WRC to establish a standard practice for quantifying ferrite content using available techniques. The publication of AWS A4.2, “Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal”, was the among the first steps to provide a universal calibration procedure for magnetic instrumentation.

Developments in ferrite measurement techniques continued for the next 20 years before another review of applicable techniques was performed. In that time, the FN

system was explored through a series of round robin test series and AWS A4.2 undertook a series of revisions to incorporate newly developed techniques.

Dr. D. J. Kotecki revisited the topic of ferrite measurement in his 1997 article entitled, “Ferrite Determination in Stainless Steel Welds – Advances since 1974” (Reference 23). Describing the revisions to AWS A4.2 and recounting research efforts encompassing the previous 20 years, the following items were highlighted:

- Extension of the Ferrite Number (FN) System:

With the advent of new stainless steel alloys (duplex), the need to characterize materials, whose ferrite content exceeded 28 FN, was established.⁵ The FN system was studied with various modifications, including extrapolation, calibration with new coating thickness standards and the development of cast secondary standards.*

**Note: Coating thickness standards (primary standards) and cast secondary standards will be examined in following sections of this review.

- Ferrite Number vs. Ferrite Percent:

The relationship between ferrite number and ferrite percent was explored utilizing weld metal samples. However, it was determined that the morphology and distribution of weld metal ferrite promoted unwanted effects during metallographic characterization. Such effects included a lack of agreement between laboratories, utilizing metallographic techniques, due to the fineness and irregular morphology of weld metal ferrite.

However, such adverse morphologies were not present in cast materials. In general, the ferrite size was significantly coarser and more regularly shaped than weld

metal ferrite. A comparison of point counting and magnetic measurements revealed that the ratio of ferrite number to ferrite percent was not uniform over the entire FN scale. It was established that the correlation was roughly 1:1 for FN values of 0-28. However, above 28 FN the correlation deviated. Examinations, during experimental trials, suggested that this correlation could be approximated using a ferrite number to ferrite percent ratio of 1.4:1. However, a lack of agreement between laboratories left this issue in dispute among researchers.⁶

- Future Work:

Dr. Kotecki suggested that the issue of “ferrite number vs. ferrite percent” needed further study. However, his suggestions indicated that the lack of agreement between laboratories, to establish a firm correlation, did not preclude the successful use of the FN system.

It was apparent that the only universal baseline to evaluate castings and weldments was a direct determination of the amount of ferrite present. This further necessitated the need for a correlation between ferrite number and ferrite volume percent. It was also suggested that current ferrite measurement techniques were not applicable for the characterization of heat-affected zones in comparison to the unaffected base metal or weld metal. Due to the relatively narrow width of the heat-affected zone, no available technique had been able to adequately characterize this region. Although specifications required a destructive metallographic examination to determine the ferrite content of the heat-affected zone, this specification was not accepted due to a lack of reproducibility within the same weldment. It was concluded that a new breed of technology of ferrite

measurement techniques needed to be developed to combat this situation. Finally, the constitution diagrams commonly used to predict the ferrite content based upon alloy chemistry required further development to allow for additional alloying elements and variations in cooling rate due to different joining processes.⁷

Having clearly defined the past, present and future research efforts regarding ferrite measurement techniques, it was evident that this area had undergone a significant amount of change and investigation since its conception in the 1940's. The current review concentrates on defining each appropriate ferrite measurement technique, paying careful attention to evaluate its efficacy.

3.2 Review of Measurement Techniques

A variety of techniques have been developed to determine the amount of ferrite present in a substrate. Ferrite measurement has been performed using the following techniques:

- Metallographic Point Counting
- Constitution Diagrams
- Magnetic Attraction
- X-Ray Diffraction
- Mössbauer Effect
- Magnetic Permeability
- Magnetic Saturation

Among the above techniques, x-ray diffraction and the Mössbauer effect have been applied to only laboratory experimentation. The principles governing x-ray diffraction and interpretation of diffraction spectra have long been characterized, however, the Mössbauer effect suggested interesting new principles.

L. J. Schwartzendruber discussed the Mössbauer effect in 1974 in a Welding Journal Research Supplement article entitled “Mössbauer – Effect Examination of Ferrite in Stainless Steel Welds and Castings”.⁸ When applied to alloy systems, it was found that different phases within a metal yield differing Mössbauer spectra. It was also found that the relative areas contained within the spectra were directly proportional to the amount of each phase present.⁹ In comparing this techniques with others, Schwartzendruber commented that the Mössbauer technique was a valid method to conduct ferrite measurement. However, its application was limited to laboratory testing and cannot be readily utilized in the field.

Measurement by magnetic saturation involved saturating a given interaction volume with a magnetic field and measuring the associated magnetic response. K. Bungart (et al.) discovered that such measurements were highly influenced by alloy chemistry and the chemical composition of the ferrite. It was found that the saturation magnetism of the ferrite was governed by its chemistry.¹⁰ Therefore, accurate ferrite measurements could only be obtained if the saturation magnetism of ferrite was established as a function of chemical composition. This technique has not been developed for commercial use. These principles were also examined as a part of Schwartzendruber’s examination of the Mössbauer effect.

Having defined the less common ferrite measurement techniques, emphasis is now placed upon the use of metallographic point counting, constitution diagrams and magnetic instrumentation as viable methods of ferrite measurement.

3.2.1 Metallographic Point Counting

ASTM E562 is the “Standard Practice for Determining Volume Fraction by Systematic Manual Point Count.” This specification may be applied to any microconstituent or phase which is metallographically identifiable. The principles governing this method are clearly defined in the specification. A two-dimensional metallographic sample is prepared and examined at an appropriate magnification. A grid is then superimposed over the image and the operator counts the number of points which fall within the desired phase or microconstituent. Statistical analysis reveals the fraction of points which fall within the desired phase and the volume fraction is then calculated.¹¹ When correctly implemented, this technique is an excellent method for determining the volume fraction of a desired phase or microconstituent. However, accuracy is often influenced by many factors, including the following:

- Homogeneity
- Quality of Sample Preparation
- Grid Density
- Magnification of the Substrate
- Operator Interpretation of the Microstructure

Attempts to mechanize this technique, using computer software, often decreased analysis time but still required the use of a trained technician. Although accurate, this technique requires a significant amount of preparation and analysis time. Preparation includes metallographic polishing to a 0.05 micron finish and the application of a suitable etching technique. Etching techniques are tailored to a specific microconstituent. Additionally, this technique is destructive in nature, requiring that a sample be extracted from the component or substrate. It was also limited to the number of fields examined and the location of the removed sample.

Because metallographic point counting is a destructive test and requires extensive preparation and analysis time, significant effort is placed upon the development of techniques which were non-destructive and labor efficient. Scientists and engineers next placed their focus on the effect of alloy chemistry on the amount of ferrite present.

3.2.2 Constitution Diagrams

Schaeffler, DeLong and WRC constitution diagrams introduced a non-destructive method to relate alloy composition to the amount of ferrite present in an alloy. The development of such a technique eliminated the need to destructively analyze a component, given that an accurate chemical analysis could be performed.

3.2.2.1 Schaeffler Diagram

The introduction of the Schaeffler diagram (1949) provided the first method to calculate ferrite percent in a non-destructive manner. Schaeffler mathematically correlated chromium and nickel equivalents, which were readily calculated based upon the alloy chemistry, to the amount of ferrite present. Based upon the amount of nickel, carbon, manganese, chromium, molybdenum, silicon and niobium (columbium) present, a brief reference to this diagram quickly estimated the amount of ferrite present (Figure 1).¹³

C. J. Long and W. T. DeLong cited the inherent problem of nitrogen additions during welding in their 1973 article entitled “The Ferrite Content of Austenitic Stainless Steel Weld Metal” (Reference 35). Although DeLong had published his own constitution diagram, accounting for nitrogen levels in weld metal, he identified an inherent problem associated with Schaeffler’s diagram. Ferrite content varied with the amount of nitrogen present. As Schaeffler had not addressed this issue, nitrogen levels became a source of experimental error to be addressed in the next generation of constitution diagrams.¹⁴

3.2.2.2 DeLong Diagram

W. T. DeLong (et. al.)¹⁵ revised the Schaeffler diagram in 1956 by adding the effect of nitrogen to the nickel equivalent. Citing a weighting factor of 30 for the effect of nitrogen, DeLong proposed a significant relationship between nitrogen concentration and ferrite formation (Figure 2).

Figure 1. Schaeffler Diagram

From ASM Specialty Handbook® on Stainless Steels, edited by J. R.

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Figure 2. DeLong Diagram

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The major advantage of the DeLong diagram was its introduction of nitrogen as a significant factor in ferrite formation. Nitrogen, an austenitizer, retards the formation of ferrite. DeLong postulated that variations in welding technique and atmospheric conditions could affect the nitrogen content in weld metal, thus affecting the amount of ferrite formed during solidification of the weld pool. His work increased the accuracy of the Schaeffler diagram and revealed that his estimations predicted increased ferrite over that of Schaeffler, for a given chemistry.¹⁶

3.2.2.3 WRC 1988 Diagram

In 1988, T. A. Siewert, C. N. McCowan and D. L. Olson published the WRC 1988 constitution diagram (Reference 49). This diagram accounted for the following flaws in the Schaeffler and DeLong diagrams:

- The DeLong diagram is essentially a finely tuned subset of the Schaeffer range, designed specifically for the 300-series stainless steel welds containing small amounts of ferrite.¹⁷ The refined nature of the DeLong diagram forced engineers to reference the Schaeffler diagrams for alloys containing more than 15% ferrite. As previously defined, the Schaeffler diagram did not have the improved degree of accuracy or accountability for nitrogen that the DeLong diagram developed.
- The effect of manganese on ferrite formation had been incorrectly established. An improved database revealed that the original 0.5 weighting factor should have been changed to unity (1), based upon work performed by E. R. Szumachowski and D. J. Kotecki.¹⁸

- A study by R. H. Espy revealed that the effect of nitrogen on ferrite formation resulted in a decreased value of the nitrogen coefficient in the nickel equivalent. Espy suggested that the nitrogen coefficient be lowered from 30 to 20.¹⁹
- The effect of silicon on weld metal ferrite had been examined by D. J. Kotecki. The results of his study revealed that the 1.5 silicon weighting factor used in both the Schaeffler and DeLong diagrams was inaccurate. Kotecki's work suggested that the weighting factor be reduced to 0.1.^{20,21} Kotecki conducted a similar study to investigate the effect of molybdenum and concluded that its coefficient be reduced from 1.0 to 0.7.²²

Siewert, McCowan and Olson concluded that, based upon the studies of elemental effects on ferrite formation, there was significant need to develop a new constitution diagram for the prediction of weld metal ferrite content. The WRC 1988 diagram (Figure 3) was then developed according to the following goals:²³

- Development of a database containing recent FN data and new compositions.
- Evaluation of the accuracy of the Schaeffler and DeLong diagrams.
- Determination of which elements were not properly incorporated in these diagrams.
- Development of an improved predictive diagram that was continuous over the range of 0-100 FN.

The development of the WRC 1988 diagram improved the applicable ferrite range, reestablished the appropriate manganese, molybdenum, nitrogen and silicon contents, improved accuracy over the DeLong and Schaeffler diagrams and included solidification boundaries that correspond to changes in FN response.²⁴

Figure 3. WRC 1988 Diagram

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3.2.2.4 WRC 1992 Diagram

Shortly after the submission of the WRC 1988 diagram, D. J. Kotecki and T. A. Siewert sought to include the effect of copper on the formation of ferrite in duplex stainless steels. While developing the WRC 1988 diagram, a copper coefficient was considered. However, research had not provided sufficient agreement on a universal value. Therefore, as the demand for duplex stainless steels increased, a need was recognized to modify the existing WRC diagram to include the effects of copper on the chromium equivalent.²⁵

The resulting WRC 1992 (Figure 4) constitution diagram presented increased accuracy and the ability to extend the chromium and nickel equivalencies to allow dilution calculations incorporating dissimilar base materials and electrode compositions.

As a result of the advent of this diagram, engineers were able to rely on increased accuracy in ferrite prediction for copper-bearing alloys. Alloys with residual copper contents were not adversely affected. Additionally, this diagram allowed for the accountability of dissimilar weld joint configurations, which was a luxury not afforded by previous constitution diagrams.²⁶

3.2.3 Magnetic Instrumentation

The use of x-ray diffraction, Mössbauer techniques and magnetic saturation as methods of ferrite measurement were previously described. Experimental

Figure 4. WRC 1992 Diagram

From ASM Specialty Handbook® on Stainless Steels, edited by J.

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trials revealed that these practices would not be readily applied to field engineering situations due to the use of laboratory confined equipment or variations in material response to each technique. However, as previously indicated, developments in magnetic instrumentation proved useful in creating reliable, reproducible and user-friendly ferrite measurement equipment. In the following sections, magnetic indicators, attractive force indicators and magnetic permeability instruments are introduced as viable methods for quantifying ferrite content.

The measurement of ferrite content yielding reproducible results was addressed separately by E. Stalmasek, E.W. Pickering, E.S. Robitz and D. M. Vandergriff. Stalmasek investigated the “Measurement of Ferrite Content in Austenitic Stainless Steel Weld Metal Giving Internationally Reproducible Results” (Reference 52) while Pickering, Robitz and Vandergriff concentrated on “Factors Influencing the Measurement of Ferrite Content in Austenitic Stainless Steel Weld Metal Using Magnetic Instruments” (Reference 39). Both articles are contained within Welding Research Council Bulletin 318 (Reference 53). WRC Bulletin 318 is addressed in the following paragraphs as individual magnetic measurement devices are described.

The following items were identified as significant to the development of new ferrite measurement devices by the above authors.²⁷

- Ferrite chemistry, distribution, particle shape/size, and degree of transformation were identified as factors which make precise and accurate ferrite measurement difficult.
- The utilization of different measuring techniques does not necessarily yield identical results.

- Sample size and shape must be considered such that its geometry does not affect ferrite measurement due to unwanted edge effects.
- Reproducibility between instruments required the institution of a standard calibration procedure to incorporate all techniques.
- The relationship between ferrite number and ferrite percent is non-linear.

For additional information describing the ferromagnetic properties of ferrite in a duplex microstructure, refer to reference 52.

3.2.3.1 Magnetic Indicators (e.g., Severn Gage)

Having identified ferrite as a ferromagnetic phase, the first efforts to construct a device to assess ferrite content included magnetic indicators. Utilizing a permanent bar magnet, suspended from a lever arm, the substrate ferrite content was compared to a reference magnet. The reference magnet was either a permanent magnet or electromagnet.

R. B. Gunia and G. A. Ratz reviewed the performance of such devices in WRC Research Bulletin 132 (August 1968). Gunia and Ratz differentiated between instruments utilizing a permanent reference magnet (Severn Gage, Tinsley Gage and Elcometer) and those using an electromagnetic reference magnet (Ferrite Tester, Magne-Probe, Magnetoscope and Permascope).²⁸

The advantage associated with such devices included ease of use and portability. With the inclusion of reference magnets of varying strength and associated ferrite

content, the user was able to quickly determine a range over which the ferrite content of the subject was contained. This technique eliminated the need for laborious metallography and time consuming analysis. However, the degree to which the ferrite content range could be characterized was governed by the reference magnets. Thus, this technique was only a “quick and dirty” estimation of the substrate ferrite content. No calibration of the instrument was required beyond establishing the ferrite content of the reference magnets.

3.2.3.2 Attractive Force (e.g., Magne Gage)

Building on the characteristics of the magnetic indicators, a device was sought which could directly correlate the force required to separate a magnet from a substrate (tear-off force) to the ferrite content of the substrate. The governing principle was that increasing ferrite content would promote a larger ferromagnetic response, which would result in increasing force required to separate a reference magnet from a substrate. However, no such device existed for that specific purpose.

While Schaeffler was developing his constitution diagram, a device had been constructed to measure the thickness of nonmagnetic coatings on magnetic materials. The principles governing the Magne Gage were easily defined. A permanent magnet, suspended from a lever arm, would be lowered until the magnet was in contact with the substrate. Using a calibrated dial, increasing torque was applied, through a helical spring, until the reference magnet separated from the substrate. The dial reading was recorded and compared to a calibration curve, which revealed the coating thickness or ferrite

content.²⁹ When properly calibrated, the Magne Gage proved to be a useful tool in assessing ferrite content.³⁰

The advantage of the Magne Gage was its capability of directly measuring the ferrite content based upon magnetic response. The operator was no longer limited to a range of possible ferrite contents, as described with the use of the Severn gage. Rather, calibration to coating thickness standards (primary standards) allowed the operator to directly assess the ferrite content as a function of ferrite number. Conversely, the Magne Gage was primarily a laboratory instrument and was sensitive to outside vibrations. The Magne Gage and the primary coating thickness standards are shown in subsequent figures.

Use of the Magne Gage was revised in 1982 by D. J. Kotecki when he proposed the extension of the WRC ferrite number system. Increasing use of duplex stainless steel alloys required that the existing ferrite number system be expanded to include ferrite contents above 28 FN. This new system covered the full range of duplex alloys up to fully ferritic material. The new extended ferrite number (EFN) system proved to be statistically viable, as compared to the original ferrite number system.³¹

The use of the Magne Gage increased in later years as scientists and engineers sought to determine the relationship between ferrite content and as-welded mechanical properties. Studies by D. J. Kotecki³² and D. L. Olson³³ further validated the Magne Gage as a useful tool in characterizing the ferrite content of austenitic and duplex alloys.

Increased use of Magne Gages spurred the implementation of the IIW 5th Round Robin of FN Measurements to assess interlaboratory variations in ferrite measurement. The results showed suitable repeatability with proper calibration.³⁴

3.2.3.3 Magnetic Permeability (e.g.: Feritscope®)

Magnetic permeability has been defined as the ratio of magnetic induction to magnetic field strength. Ferrite measurement, using this technique, required that a magnetic field be induced on a substrate and the resulting field strength be measured to establish the magnetic permeability.³⁵ This technique, provided by Gunia and Ratz, was later confirmed by E. Stalmasek in WRC Bulletin 318. Stalmasek further commented that *“the overall permeability of a two phase alloy containing one ferromagnetic and one nonferromagnetic phase, depends, at a given strength of the magnetizing field, upon the individual permeability, upon the content and upon demagnetization factor of the ferromagnetic phase”*.³⁶ In short, this established that the strength of the induced field varied with the amount of ferromagnetic phase present.

The Fischer Feritscope® was developed as a hand-held device which utilized magnetic permeability as a method to assess ferrite content. As depicted in Figure 5, the Feritscope® was designed to be portable and provide the operator with a user-friendly interface which readily provides ferrite content on the ferrite number scale. Calibration of the Feritscope® has been performed using cast secondary standards. Cast secondary standards (Figure 6) were developed by NPO CNIIT-MASH (Russia) and produced by Mladis Co. (Russia) under organizational support of the Russian Welding Society. Each set of standards was produced from centrifugally chill cast rings and were distributed to TWI.³⁷ Cast secondary standards were used exclusively to calibrate Feritscopes®, but may also be used in the calibration of Magne Gages. The volume of

Magne Gage

Feritscope®

Figure 5. Magne-Gage and Fischer Feritscope®.

Primary Standards

Cast Secondary Standards

Figure 6. Primary and Cast Secondary Standards

ferrite in each standard was controlled through modifying the alloy content, such that a full range of ferrite numbers is attainable.

Additional round robin testing was initiated by D. J. Kotecki, in conjunction with IIW, to assess the reproducibility of Feritscopes® when calibrated using cast secondary standards. An interlaboratory variability of $\pm 14\%$ was established. This value was slightly higher than the variability established for Magne Gages ($\pm 10\%$) in previous round robin test series.³⁸

The advantages associated with the advent of the Feritscope® included increased operator efficiency and portability of the device. However, there has not been a significant research effort to characterize the service performance of this gage when applied to a multitude of conditions. Such conditions include analyzing the measurement probe's response to varying surface finishes, surface discontinuities and gage repeatability. As the manufacturer does not currently provide such a database, a study to clarify these operating variables has been introduced as a part of this research effort.

3.3 Literature Review - Conclusions

The IIW has remained involved in the implementation of additional round robin testing to further characterize factors which affect ferrite measurement. Such factors include, but are not limited to, the following:

- Substrate Surface Finish
- Measurement Probe Interaction Volumes
- Correlation between Ferrite Number and Ferrite Volume Percent

- Reliability and Repeatability of Available Techniques

Although it has been established that significant accomplishments have been made in the field of ferrite measurement, it remains the belief of researchers and engineers that additional testing, to explore the limitations of current techniques, is required to further develop accurate and repeatable methods of ferrite measurement.

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6.0 SPECIFICATIONS

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7.0

APPENDIX

Ferrite Measurement in Stainless Steel Castings

“A Round Robin Study”

Initiated by

**Dr. Carl D. Lundin
William J. Ruprecht**

**Materials Joining Research Group
Department of Materials Science and Engineering
The University of Tennessee – Knoxville**

in conjunction with

The Welding Research Council

and

The Steel Founders' Society of America

1.0 Introduction:

The UT Materials Joining Research Group is initiating a Ferrite Measurement Round Robin study to examine the following issues:

- The reproducibility of ferrite measurement data, between laboratories, using Magne Gage and Feritscope® techniques
- The applicability of manufacturing cast secondary standards from static and centrifugal castings
- A more defined correlation between ferrite measurement techniques will be established. These techniques include manual point counting and measurement by Magne Gage and Feritscope®.

2.0 Round Robin Timeline:

In an effort to minimize the work effort, the timeline described in Table 1 has been established. The primary goal is to send the round robin samples between the Welding Research Council (WRC) committee members prior to the WRC High Alloys Committee meeting in May. The sample set will then proceed to Steel Founders' Society of America (SFSA) participants before returning to UT.

Table 1: UT Ferrite Measurement Round Robin Schedule

Program Launch Date:	February 24, 1999
Samples Arrive / D. Kotecki:	March 1, 1999
D. Kotecki Evaluation Period:	March 1 - 10, 1999
Samples Shipped to Participant 2:	March 11, 1999
Samples Arrive / F. Lake:	March 15, 1999
F. Lake Evaluation Period:	March 15 - 24, 1999
Samples Shipped to Participant 3:	March 25, 1999
Samples Arrive / S. Jana:	March 29, 1999
S. Jana Evaluation Period:	March 29, 1999 through April 7, 1999
Samples Shipped to Participant 4:	April 8, 1999
Samples Arrive / T. Siewert:	April 12, 1999
T. Siewert Evaluation Period:	April 12 - 21, 1999
Samples Shipped to Participant 5:	April 22, 1999
Samples Arrive / J. Feldstein:	April 26, 1999
J. Feldstein Evaluation Period:	April 26, 1999 through May 5, 1999
Samples Shipped to Participant 6:	May 6, 1999
WRC High Alloys Meeting:	May 10 - 12, 1999
Samples Arrive / R. Bird:	May 10, 1999

Table 1 (Continued): UT Ferrite Measurement Round Robin Schedule

R. Bird Evaluation Period:	May 10 - 19, 1999
Samples Shipped to Participant 7:	May 20, 1999
Samples Arrive / C. Richards:	May 24, 1999
C. Richards Evaluation Period:	May 24, 1999 through June 2, 1999
Samples Shipped to UT:	June 3, 1999
Publication of Results:	June 30, 1999

Note: This timetable establishes 9 business days for experimental evaluation and 1 business day is provided to ship the samples to the next participant. Shipping will be provided. We anticipate that the WRC members will likely require less analysis time, as they are adequately equipped to measure ferrite on a routine basis. Should the Round Robin progress ahead of (or behind) schedule, each participant will be appropriately notified.

3.0 Requests of the Participants:

The Materials Joining Group is grateful for your participation in this study. We value your time and seek to minimize your work effort. However, the following requests are made to project your success.

3.1 Adherence to the Timetable:

Should a participant, for any reason, be unable to adhere to the timetable outlined in Table 1, please notify the Materials Joining Research Group. UT contacts are listed as follows:

Dr. Carl D. Lundin	William J. Ruprecht III
Director, Materials Joining Research	Graduate Research Assistant
Phone: (423) 974-5310	Phone: (423) 974-5299
FAX: (423) 974-0880	FAX: (423) 974-0880
E-Mail: lundin@utk.edu	E-Mail: ruprecht@utk.edu

In the event of such an occurrence, a quick scheduling response will facilitate the implementation of this round robin.

3.2 Questions regarding the Work Request:

If at any point in this investigation, there is a question with regard to experimental techniques, calibration procedures, reporting of data or scheduling, feel free to contact our office.

3.3 Suggestions from the Participants:

If you have any suggestions to improve the implementation of further studies, please submit them with your data package.

Immediate suggestions which would require a modification to your individual test procedure should be forwarded immediately.

Comments, are always appreciated.

4.0 Work Request:

5.1 Ferrite Measurement:

Participants are asked to measure ferrite (FN) on the sample set provided. Acceptable methods of ferrite measurement include, but are not limited to, the following:

Magne Gage

Feritscope® MP3 (MP3-C)

Using the attached checklist and the provided forms, participants will be asked to calibrate (or report their current calibration) according to AWS A4.2 prior to taking measurements.

5.1 Reporting of Data:

Using the attached forms, participants are asked to record their ferrite measurements and return them to the Materials Joining Group. A mailing envelope is included for the return of the entire package.

A Federal Express mailer has been included so that you may forward the cast standards to the next participant. Please use a Federal Express Box and utilize suitable packing material to prevent damage during shipping.

5.0 Cast Sample Set:

5.1 Contents:

The sample set provided contains 12 rectangular blocks which have been fabricated from austenitic and duplex stainless steels. They are labeled on the ends with a sample code. The following table correlates the sample code with the alloy type.

Sample Code	Alloy Type
A	CF8
B	CF3MN
C	CF8M
D	ASTM A890-4A
E	ASTM A890-4A
F	ASTM A890-4A*
G	ASTM A890-5A
H	ASTM A890-5A*
I	ASTM A890-5A
J	CD7MCuN*
K	CD7MCuN
L	CD7MCuN

* Indicates that the material was centrifugally cast, as opposed to a static casting.

5.2 Condition of Samples:

Each sample has been prepared, on the measurement face, with a surface finish equal to a metallographic polish. This was done so that a microstructural evaluation could be performed prior to initiating the round-robin. Note the presence of a scribed circle on the measurement face. No ferrite measurements are to be taken outside of this circle. This is done so that we may directly compare ferrite measurements with metallographic point counting techniques.

6.0 Ferrite Measurement Instruction Set:

6.1 Magne Gage:

Appendix 1 contains an operator checklist and instruction set for performing ferrite measurements with a Magne Gage.

6.2 Feritscope®:

Appendix 2 contains an operator checklist and instruction set for performing ferrite measurements with a Feritscope®

6.3 Other:

Should a participant wish to utilize other methods of ferrite measurement, please contact the Materials Joining Group as indicated in Item 3.1 of this manual.

7.0 Completion of your Work Effort:

7.1 Forwarding the Sample Set to the Next Participant:

A Federal Express invoice has been provided (pre-addressed / pre-paid). Please use a standard Federal Express Box to ship the sample set to the next participant.

7.2 Returning your Data to the University of Tennessee:

A return envelope (pre-addressed) has been provided. Please seal this manual, containing your data, charts, graphs and comments in the envelope and forward it to the University of Tennessee (c/o The Materials Joining Research Group).

8.0 Acknowledgements:

We would like to acknowledge the following individuals for their guidance and support in performing this round robin study.

Dr. Damian Kotecki – Lincoln Electric
Mr. Frank Lake – ESAB
Mr. Sushil Jana – Hobart Brothers Co.

Mr. Tom Siewert – N.I.S.T.
Mr. Ron Bird – Stainless Foundry
Mr. Joel Feldstein – Foster Wheeler
Mr. Christopher Richards – Fristam Pumps Inc.

Appendix 1: Ferrite Measurement Using a Magne Gage

Please follow the checklist (below) to assure proper measurement and documentation of ferrite content for each sample. You may check the boxes, located before each item number, as you proceed through this study.

- 1. Review AWS A4.2-91, Section 4, pp. 4-6, to familiarize yourself with the proper methods of calibrating a Magne Gage instrument. A copy of AWS A4.2-91 has been included for your convenience and is located at the end of this manual.
- 2. Calibrate your Magne Gage according to the specifications outlined in AWS A4.2-91 (Section 4).

Please include all graphs and tables used to calibrate your Magne Gage and report whether you are calibrating to Primary Thickness Standards or Secondary Weld Metal Standards. Calibration to Primary Thickness Standards is preferred. Examples of suitable calibration curves are located in the AWS specification on Page 6 and are illustrated by Figure 1.

- 3. The data recording sheet is presented on Page 3 of this appendix. Please provide the Instrument Type / Serial Number, Operator Name and Date, as indicated.
- 4. Utilize the samples submitted and reference the characteristics of each block, as described in Item 5 of this manual. Perform 5 “sets” of determinations as described below. Each “set” must contain 6 separate determinations. Only the highest FN measured will be reported for each “set” of determinations.

Lower the plastic “magnet guard” until it is in contact with the sample and is wholly contained within the scribed circle. Perform 6 successive determinations without moving the plastic “magnet guard”. This will constitute a single “set” of determinations. Ferrite determinations taken outside the scribed circle must be considered invalid.

Record only the highest FN, achieved from each of the 6 determinations, in the space provided. After each “set” of 6 determinations, raise the plastic “magnet guard” and lower it again, within the scribed circle, prior to performing the next “set” of determinations. The highest determined FN should be recorded for each individual “set” of determinations.

Review the data for each sample. For each sample, your data sheet should reflect five FN determinations, which are the highest FN's observed in each of the measurement "sets". (Each "set" should be composed of 6 individual measurements, obtained at one location within the scribed circle, with the plastic "magnet guard" in contact with the sample.)

- 5. Upon completion of the successive ferrite determinations, return the samples to their plastic cases and proceed to Appendix 2, *Ferrite Measurement using a Feritscope®*.

Data Sheet 1: Ferrite Measurement Using a Magne Gage

Part 1: Background Information:

Instrument Type / Serial Number: _____

Operator Name: _____

Date: _____

Part 2: Recording of Data:

Record your ferrite measurements in the following table.

Sample Code	Determination Set 1 (Highest FN)	Determination Set 2 (Highest FN)	Determination Set 3 (Highest FN)	Determination Set 4 (Highest FN)	Determination Set 5 (Highest FN)
A					
B					
C					
D					
E					
F					
G					
H					
I					
J					
K					
L					

Appendix 2: Ferrite Measurement Using a Feritscope®

Please follow the checklist (below) to assure proper measurement and documentation of ferrite content for each sample. You may check the boxes, located before each item number, as you proceed through this study.

- ☐ 1. Review AWS A4.2-91, Section 5, p.7, to familiarize yourself with the proper methods of calibrating a Feritscope® instrument. A copy of AWS A4.2-91 has been included for your convenience and is located at the end of this manual.
- ☐ 2. Calibrate your Feritscope® according to the specifications outlined in AWS A4.2-91 (Section 5). Calibration to secondary cast standards will be the accepted method for this study. Standardized forms have been provided to assist you in recording your calibration and are located on the following pages.

Table 1 is a sample Feritscope® calibration form, provided courtesy of IIS/IIW-1405-98. A blank calibration form is provided, in the form of Table 2 of this appendix. Highlight the measurements which exceed accepted tolerances, as demonstrated (Blue Underlined) in Table 1, on your calibration sheet (Table 2).

If you wish to provide data for multiple Feritscopes® and/or operators, additional copies of calibration forms may be made from this packet.

- ☐ 3. Locate the data recording sheet (Data Sheet 2) on Pages 4-5 of this appendix. Please provide the Instrument Type / Serial Number, Operator Name and Date, as indicated. If you wish to record data for multiple operators and/or Feritscopes®, additional copies of the data recording sheet should be made, as needed. Please differentiate between Feritscope® model numbers and operators in the “background information”.
- ☐ 4. Utilize the Sample Set and reference the characteristics of each block, as described in Item 5.0 of this manual.

By lowering the probe perpendicular to the sample, perform 10 successive measurements within the scribed circle. Ferrite measurements taken outside the scribed circle must be considered invalid.

Record each measurement on the attached data sheets and report the average FN value observed for each sample.

- _ 5. Upon completion of the ferrite measurements, return the samples to their plastic cases and review your paperwork to ensure that all data has been included. This concludes ferrite measurement by the Feritscope® technique.

Table 1: Sample Calibration Form (Reference IIS/IIW-1405-98)

Calibration Standard	Appl 4	Appl 3	Appl 1	Appl 2	Appl 1	Appl 2	Appl 3	Appl 4	Appl 2	Appl 4
Air	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1st Certified FN	4.6	31.0	6.5	4.6	4.6	26.8	52.0	67.0	16.7	58.5
2nd Certified FN	16.7	52.0	31.0	10.4	10.4	37.5	58.5	73.5	26.8	73.5
3rd Certified FN	31.0	85.0	85.0	16.7	14.6	47.0	67.0	85.0	37.5	85.0
Certified FN (and Range) per A4.2, Table 4	Average of 10 Check Readings on Standard Using Above Calibration									
1.7 (1.4 - 2.0)	1.4	1.7	1.5	1.4	1.4	1.8	1.8	1.8	1.6	1.8
4.6 (4.3 - 4.9)	4.4	5.5	4.6	4.3	4.3	5.6	5.7	5.6	5.3	5.9
6.5 (6.2 - 6.8)	6.7	7.6	6.4	6.1	6.2	8.0	8.1	8.0	7.5	8.4
10.4 (10.0 - 10.8)	12.1	12.7	12.3	10.6	10.6	13.4	13.6	13.6	12.2	14.3
14.6 (14.2 - 15.0)	14.5	15.2	14.5	13.5	14.5	16.1	16.2	16.3	14.7	17.0
16.7 (16.2 - 17.2)	16.6	17.3	16.8	16.4	16.7	18.4	18.5	18.8	16.7	19.6
20.3 (19.8 - 20.8)	20.3	20.5	20.5	19.6	19.8	21.8	22.1	22.4	20.7	23.5
26.8 (25.5 - 28.1)	25.8	25.3	25.7	24.2	24.3	27.0	27.7	27.7	26.8	29.7
31.0 (29.4 - 32.6)	31.3	29.8	30.6	28.0	28.4	32.0	32.2	32.7	31.3	34.5
37.5 (35.6 - 39.4)	37.9	37.5	37.8	33.2	33.9	37.8	39.4	39.9	37.7	42.5
47.0 (44.6 - 49.4)	46.8	49.1	45.7	41.0	41.2	47.2	49.1	49.4	47.5	54.0
52.0 (47.8 - 56.2)	48.5	51.6	49.0	43.0	43.6	49.1	53.1	53.0	50.1	58.0
58.5 (53.8 - 63.2)	48.6	52.2	47.8	42.2	43.7	49.1	55.1	52.3	48.8	56.8
67.0 (61.6 - 72.4)	61.6	63.9	60.1	53.6	54.2	64.1	67.9	68.6	63.7	68.7
73.5 (67.6 - 79.4)	67.3	69.2	66.5	58.0	58.0	70.2	74.1	73.2	70.1	72.7
85.0 (78.2 - 91.8)	86.9	85.3	85.7	71.9	71.8	89.4	98.8	86.7	90.7	87.7
Decision	dis-card	dis-card	dis-card	dis-card	use for 0-20 FN	dis-card	use for 30-70 FN	dis-card	use for 15-45 FN	use for 60-90 FN

Table 2: Participant Calibration Form

Calibration Standard	Appl	Appl	Appl	Appl	Appl	Appl	Appl	Appl	Appl	Appl
Air										
1st Certified FN										
2nd Certified FN										
3rd Certified FN										
Certified FN (and Range) per A4.2, Table 4	Average of 10 Check Readings on Standard Using Above Calibration									
Decision										

Data Sheet 2: Ferrite Measurement Using a Feritscope®

Part 1: Background Information:

Instrument Type / Serial Number: _____
Operator Name: _____
Date: _____

Part 2: Recording of Data:

Record your ferrite measurements in the following table.

Sample Code	FN 1	FN 2	FN 3	FN 4	FN 5	FN 6	FN 7	FN 8	FN 9	FN 10	Average FN
A											
B											
C											
D											
E											
F											
G											
H											

Data Sheet 2: Ferrite Measurement Using a Feritscope® - Continued

Sample Code	FN 1	FN 2	FN 3	FN 4	FN 5	FN 6	FN 7	FN 8	FN 9	FN 10	Average FN
I											
J											
K											
L											

Notes:

AWS A4.2-91

Keywords — instrument calibration, delta ferrite, stainless steel weld metal, austenitic stainless steel weld metal, duplex stainless steel weld metal

ANSI/AWS A4.2-91
An American National Standard

Approved by
American National Standards Institute
February 14, 1991

Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Austenitic-Ferritic Stainless Steel Weld Metal

Supersedes ANSI/AWS A4.2-86

Prepared by
AWS Committee on Filler Metal
and The Welding-Research Council Subcommittee
on Welding Stainless Steels

Under the Direction of
AWS Technical Activities Committee

Abstract

Calibration procedures are specified for a number of commercial instruments that can then provide reproducible measurements of the ferrite content of austenitic stainless steel weld metals. Certain of these instruments can be further calibrated for measurements of the ferrite content of duplex austenitic-ferritic stainless steel weld metals. Calibration with primary standards (non-magnetic coating thickness standards from the U. S. National Institute of Standards and Technology) is the preferred method for appropriate instruments. Alternatively, these and other instruments can be calibrated with weld metal secondary standards.

Reproducibility of measurement after calibration is specified. Problems associated with accurate determination of ferrite are described.

American Welding Society

550 N.W. LeJeune Road, P.O. Box 351040, Miami, Florida 33135

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International Standard Book Number: 0-87171-361-6

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*Advisor

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Foreword

(This Foreword is not a part of ANSI/AWS A4.2-91, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Austenitic-Ferritic Stainless Steel Weld Metal*, but is included for information purposes only.)

This document is a revision of the *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal*, first published in 1974 and revised in 1986. This revision was by the Subcommittee on Welding Stainless Steel of the Welding Research Council and by the AWS Filler Metal Committee. The current revision expands the range of calibration and measurement to include, for the first time, duplex austenitic-ferritic stainless steel weld metals.

A certain minimum ferrite content in most austenitic stainless steel weld metals is useful in assuring freedom from microfissures and hot cracks. Upper limits on ferrite content in austenitic stainless steel weld metals can be imposed to limit corrosion in certain media or to limit embrittlement due to transformation of ferrite to sigma phase during heat treatment or elevated temperature service. Upper limits on ferrite content in duplex austenitic-ferritic stainless steel weld metals can be imposed to help assure ductility, toughness, and corrosion resistance in the as-welded condition.

Reproducible quantitative ferrite measurements in stainless steel weld metals are therefore of interest to filler metal producers, fabricators of weldments, weldment end users, regulatory authorities, and insurance companies.

Comments and suggestions for improvement are welcome. They should be sent in writing to Secretary, Filler Metal Committee, American Welding Society, 550 N.W. LeJeune Road, P.O. Box 351040, Miami, FL 33135.

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Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Austenitic-Ferritic Stainless Steel Weld Metal

1. Scope

1.1 This standard prescribes procedures for the calibration and maintenance of calibration of instruments for measuring, by magnetic attraction or permeability, the delta ferrite content of an austenitic or duplex austenitic-ferritic stainless steel weld metal in terms of its Ferrite Number (FN).

1.2 A thorough review of the Appendix is recommended before any instrument is calibrated or used. The Appendix presents background information which is essential to understanding the many problems and pitfalls in determining and specifying the ferrite content of weld metals.

1.3 Calibration can be accomplished with the use of the National Institute of Standards and Technology (NIST, formerly National Bureau of Standards) primary standards or weld metal secondary standards. At the present time, only three instruments [Magne-Gage (including a torsion balance using essentially a Magne-Gage Number 3 magnet, hereinafter referred to as a *Magne-Gage type instrument*), Feritscope (also sometimes identified as *Ferritescope*), and Inspector Gage] can be calibrated by the use of NIST primary standards, and the range of possible calibration depends upon the particular instrument (see Tables 1, 2, and 3). This is not an endorsement of any particular instrument. (See 3.1.)

2. Definitions¹

2.1 Delta Ferrite. The ferrite which remains at room temperature from that which was formed from the

1. For AWS terms and definitions, refer to the latest edition of ANSI/AWS A3.0, *Standard Terms and Definitions*. Please note that some of the terms and definitions used in this publication are not included in AWS A3.0. They are either new terms defined after the latest revision of A3.0 or they are used specific to this publication.

molten state upon freezing. Much of the original ferrite that formed upon freezing transforms to austenite during cooling.

2.2 Draw Filing. A weld pad surface preparation technique suitable for subsequent ferrite measurements only up to about 20 FN. (See 8.2.) A sharp clean 14-inch mill bastard file which has not been contaminated by ferromagnetic materials, held parallel to the base metal and perpendicular to the long axis of the weld metal sample, is stroked smoothly with a firm downward pressure, forward and backward along the weld length. No cross filing is done. The finished surface is flat with at least a 1/8-in. (3.2 mm) width where all weld ripples are removed.

2.3 Ferrite Number (FN). An arbitrary, standardized value designating the ferrite content of austenitic and duplex austenitic-ferritic stainless steel weld metal (see Appendix A2).

2.4 Primary Standards. Specimens with accurate thickness of non-magnetic material on carbon steel base plate containing 0.25 percent carbon maximum. Each primary standard is assigned an FN of an equivalent magnetic weld metal, this assigned value being specific to a particular make (and model, if applicable) of measuring instrument (i.e., Magne-Gage, Feritscope, or Inspector Gage). (See Appendix A3.1.)

The primary standards upon which the standard procedures are based are the NIST's sets of coating thickness standards, consisting of a very uniform layer of electroplated copper covered with a chromium flash over a carbon steel base. (See Appendix A4.1.)

2.5 Weld Metal Secondary Standards. Small weld metal pads certified for FN in a manner traceable to these standard procedures. (See Appendix A4.2.)

Table 1
Ferrite Numbers (FN) for Primary Standards
Calibration of Instruments Using a Magne-Gage No. 3 Magnet or Equivalent
(Magne-Gage-Type Instruments)

mils	mm	FN	mils	mm	FN	mils	mm	FN	mils	mm	FN
1.20	0.0305	89.5	3.5	0.0889	46.8	15.0	0.381	15.6	41.0	1.041	5.8
1.25	0.0318	87.5	3.6	0.0914	45.9	15.5	0.394	15.2	42.0	1.067	5.7
1.30	0.0330	85.7	3.7	0.0940	45.1	16.0	0.406	14.8	43.0	1.092	5.5
1.35	0.0343	83.9	3.8	0.0965	44.3	16.5	0.419	14.4	44.0	1.118	5.4
1.40	0.0356	82.3	3.9	0.0991	43.5	17.0	0.432	14.0	45.0	1.143	5.2
1.45	0.0368	80.6	4.0	0.1016	42.7	17.5	0.445	13.7	46.0	1.168	5.1
1.50	0.0381	79.1	4.1	0.1041	42.0	18.0	0.457	13.3	47.0	1.194	5.0
1.55	0.0394	77.6	4.2	0.1067	41.3	18.5	0.470	13.0	48.0	1.219	4.8
1.60	0.0406	76.2	4.3	0.1092	40.7	19.0	0.483	12.7	49.0	1.245	4.7
1.65	0.0419	74.9	4.4	0.1118	40.0	19.5	0.495	12.4	50.0	1.270	4.6
1.70	0.0432	73.6	4.5	0.1143	39.4	20.0	0.508	12.1	51.0	1.295	4.5
1.75	0.0445	72.4	4.6	0.1168	38.8	20.5	0.521	11.8	52.0	1.321	4.4
1.80	0.0457	71.2	4.7	0.1194	38.2	21.0	0.533	11.6	53.0	1.346	4.3
1.85	0.0470	70.0	4.8	0.1219	37.7	21.5	0.546	11.3	54.0	1.372	4.2
1.90	0.0483	68.9	4.9	0.1245	37.1	22.0	0.559	11.1	55.0	1.397	4.1
1.95	0.0495	67.8	5.0	0.127	36.6	22.5	0.572	10.8	56.0	1.422	4.0
2.00	0.0508	66.8	5.2	0.132	35.6	23.0	0.584	10.6	57.0	1.448	3.9
2.05	0.0521	65.8	5.4	0.137	34.7	23.5	0.597	10.4	58.0	1.473	3.8
2.10	0.0533	64.8	5.6	0.142	33.8	24.0	0.610	10.2	59.0	1.499	3.75
2.15	0.0546	63.9	5.8	0.147	32.9	24.5	0.622	10.0	60.0	1.524	3.67
2.20	0.0559	63.0	6.0	0.152	32.1	25.0	0.635	9.8	61.0	1.549	3.59
2.25	0.0572	62.2	6.2	0.157	31.4	25.5	0.648	9.6	62.0	1.575	3.52
2.30	0.0584	61.3	6.4	0.163	30.7	26.0	0.660	9.4	63.0	1.600	3.44
2.35	0.0597	60.5	6.6	0.168	30.0	26.5	0.673	9.2	64.0	1.626	3.37
2.40	0.0610	59.7	6.8	0.173	29.3	27.0	0.686	9.1	65.0	1.651	3.30
2.45	0.0622	58.9	7.0	0.178	28.7	27.5	0.699	8.9	66.0	1.676	3.24
2.50	0.0635	58.2	7.5	0.191	27.3	28.0	0.711	8.7	67.0	1.702	3.17
2.55	0.0648	57.5	8.0	0.203	26.0	28.5	0.724	8.6	68.0	1.727	3.11
2.60	0.0660	56.8	8.5	0.216	24.8	29.0	0.737	8.4	69.0	1.753	3.05
2.65	0.0673	56.1	9.0	0.229	23.7	29.5	0.749	8.3	70.0	1.778	2.99
2.70	0.0686	55.4	9.5	0.241	22.7	30.0	0.762	8.1	71.0	1.803	2.93
2.75	0.0699	54.8	10.0	0.254	21.8	31.0	0.787	7.9	72.0	1.829	2.88
2.80	0.0711	54.1	10.5	0.267	21.0	32.0	0.813	7.6	73.0	1.854	2.82
2.85	0.0724	53.5	11.0	0.279	20.2	33.0	0.838	7.4	74.0	1.880	2.77
2.90	0.0737	52.9	11.5	0.292	19.5	34.0	0.864	7.1	75.0	1.905	2.72
2.95	0.0749	52.3	12.0	0.305	18.8	35.0	0.889	6.9	76.0	1.930	2.67
3.00	0.0762	51.8	12.5	0.318	18.2	36.0	0.914	6.7	77.0	1.956	2.62
3.1	0.0787	50.7	13.0	0.330	17.6	37.0	0.940	6.5	78.0	1.981	2.57
3.2	0.0813	49.6	13.5	0.343	17.1	38.0	0.965	6.3	79.0	2.007	2.53
3.3	0.0838	48.6	14.0	0.356	16.6	39.0	0.991	6.2	80.0	2.032	2.48
3.4	0.0864	47.7	14.5	0.368	16.1	40.0	1.016	6.0			

3. Calibration Methods

3.1 Primary Standards. Since each type of ferrite measuring instrument responds differently to the primary standards, it is not possible to specify a generic calibration procedure; rather, it is necessary to tailor a calibration procedure to a particular instrument. As of the previous revision of this standard, three types of instruments had been subjected to extensive testing, and

detailed procedures and appropriate tables and values were contained in that standard to provide for their calibration to primary standards. These instruments are the Magne-Gage-type instruments, Feritscope, and Inspector Gage. At the time of publication of ANSI/AWS A4.2-86, however, the probe of the Feritscope was changed so that the Feritscope calibration table does not apply to newer instruments. This situation continues. Since that time, the range of calibration by primary

Table 2
Ferrite Numbers (FN) for Primary Standards for Feritscope (Ferritescope)
Model FE8-KF Calibration (See 5.1.1)

Thickness			Thickness			Thickness		
mils	mm	FN	mils	mm	FN	mils	mm	FN
7.0	0.178	25.8	22.5	0.572	9.1	46.0	1.168	4.4
7.5	0.191	24.3	23.0	0.584	8.9	47.0	1.194	4.3
8.0	0.203	23.0	23.5	0.597	8.7	48.0	1.219	4.2
8.5	0.216	21.8	24.0	0.610	8.6	49.0	1.245	4.1
9.0	0.229	20.7	24.5	0.622	8.4	50.0	1.270	4.0
9.5	0.241	19.7	25.0	0.635	8.3	51.0	1.295	3.9
10.0	0.254	18.8	25.5	0.648	8.1	52.0	1.321	3.8
10.5	0.267	18.0	26.0	0.660	8.0	53.0	1.346	3.7
11.0	0.279	17.2	26.5	0.673	7.8	54.0	1.372	3.6
11.5	0.292	16.6	27.0	0.686	7.7	55.0	1.397	3.5
12.0	0.305	15.9	27.5	0.699	7.6	56.0	1.422	3.4
12.5	0.318	15.4	28.0	0.711	7.4	57.0	1.448	3.3
13.0	0.330	14.8	28.5	0.724	7.3	58.0	1.473	3.2
13.5	0.343	14.4	29.0	0.737	7.2	59.0	1.499	3.15
14.0	0.356	13.9	29.5	0.749	7.1	60.0	1.524	3.1
14.5	0.368	13.5	30.0	0.762	6.9	61.0	1.549	2.98
15.0	0.381	13.1	31.0	0.787	6.7	62.0	1.575	2.9
15.5	0.394	12.7	32.0	0.813	6.5	63.0	1.600	2.83
16.0	0.406	12.3	33.0	0.838	6.3	64.0	1.626	2.75
16.5	0.419	12.0	34.0	0.864	6.1	65.0	1.651	2.7
17.0	0.432	11.7	35.0	0.889	6.0	66.0	1.676	2.6
17.5	0.445	11.4	36.0	0.914	5.8	67.0	1.702	2.55
18.0	0.457	11.1	37.0	0.940	5.6	68.0	1.727	2.5
18.5	0.470	10.8	38.0	0.965	5.4	69.0	1.753	2.42
19.0	0.483	10.6	39.0	0.991	5.3	70.0	1.778	2.35
19.5	0.495	10.3	40.0	1.016	5.15	72.0	1.829	2.23
20.0	0.508	10.1	41.0	1.041	5.0	74.0	1.880	2.15
20.5	0.521	9.9	42.0	1.067	4.9	76.0	1.930	2.0
21.0	0.533	9.7	43.0	1.092	4.75	78.0	1.981	1.9
21.5	0.546	9.5	44.0	1.118	4.6	80.0	2.032	1.8
22.0	0.559	9.3	45.0	1.143	4.5			

standards of Magne-Gage-type instruments has been expanded to include FNs appropriate to duplex austenitic-ferritic stainless steel weld metals.

3.2 Secondary Standards

3.2.1 Calibration by means of primary standards is the preferred method of maintaining calibration of appropriate instruments. But the need for frequent in-process checks is recognized along with the fact that primary standards are not necessarily "durable" for frequent use outside of a laboratory environment. Therefore, it is recommended that a set of secondary standards be used for frequent in-process checks. (See Appendix A4.2.)

3.2.2 When secondary standards are used, the average reading on each standard shall be within the maxi-

mum allowable deviation from the calibration curve as specified in Table 4. If a maximum allowable deviation is exceeded, the instrument cannot be considered calibrated. Calibration with primary standards or instrument repair is then necessary.

3.2.3 Instruments for which there is not a detailed calibration procedure in this standard utilizing primary standards can only be calibrated using secondary standards. Refer to Section 7 for proper calibration instructions.

3.3 For all calibration methods and instruments, the range of calibration is defined by the interval of FNs between and including the lowest FN standard and the highest FN standard used in developing the calibration according to the corresponding procedure.

Table 3
Ferrite Numbers (FN) for Primary Standards for Inspector Gage Calibration*

Thickness			Thickness			Thickness		
mils	mm	FN	mils	mm	FN	mils	mm	FN
7.0	0.178		22.5	0.572	16.9	46.0	1.168	8.3
7.5	0.191		23.0	0.584	16.6	47.0	1.194	8.1
8.0	0.203		23.5	0.597	16.2	48.0	1.219	7.9
8.5	0.216		24.0	0.610	15.9	49.0	1.245	7.7
9.0	0.229		24.5	0.622	15.6	50.0	1.270	7.5
9.5	0.241		25.0	0.635	15.4	51.0	1.295	7.4
10.0	0.254		25.5	0.648	15.1	52.0	1.321	7.2
10.5	0.267	> 30	26.0	0.660	14.8	53.0	1.346	7.0
11.0	0.279	29.9	26.5	0.673	14.5	54.0	1.372	6.9
11.5	0.292	29.0	27.0	0.686	14.3	55.0	1.397	6.7
12.0	0.305	28.1	27.5	0.699	14.1	56.0	1.422	6.6
12.5	0.318	27.3	28.0	0.711	13.8	57.0	1.448	6.4
13.0	0.330	26.5	28.5	0.724	13.6	58.0	1.473	6.3
13.5	0.343	25.8	29.0	0.737	13.4	59.0	1.499	6.1
14.0	0.356	25.1	29.5	0.749	13.1	60.0	1.524	6.0
14.5	0.368	24.4	30.0	0.762	12.9	61.0	1.549	5.9
15.0	0.381	23.8	31.0	0.787	12.5	62.0	1.575	5.75
15.5	0.394	23.2	32.0	0.813	12.2	63.0	1.600	5.6
16.0	0.406	22.6	33.0	0.838	11.8	64.0	1.626	5.5
16.5	0.419	22.0	34.0	0.864	11.4	65.0	1.651	5.4
17.0	0.432	21.5	35.0	0.889	11.1	66.0	1.676	5.3
17.5	0.445	21.0	36.0	0.914	10.8	67.0	1.702	5.1
18.0	0.457	20.5	37.0	0.940	10.5	68.0	1.727	5.0
18.5	0.470	20.0	38.0	0.965	10.2	69.0	1.753	4.9
19.0	0.483	19.6	39.0	0.991	9.9	70.0	1.778	4.8
19.5	0.495	19.2	40.0	1.016	9.7	72.0	1.829	4.6
20.0	0.508	18.7	41.0	1.041	9.4	74.0	1.880	4.4
20.5	0.521	18.4	42.0	1.067	9.2	76.0	1.930	4.2
21.0	0.533	18.0	43.0	1.092	9.0	78.0	1.981	4.0
21.5	0.546	17.6	44.0	1.118	8.7	80.0	2.032	3.85
22.0	0.559	17.2	45.0	1.143	8.5			

*This table shall be used only for calibrating Inspector Gage Model Number 111 with 6F or 7F scale for measuring the delta ferrite content of as-welded austenitic stainless steel weld metals.

Table 4
Maximum Allowable Deviation,
Calibration Point to Calibration Curve,
for Instruments Being Calibrated with
Weld Metal Secondary Standards

Ferrite Number Range	Maximum Allowable Deviation
0 to 5 FN	± 0.30
over 5 to 10 FN	± 0.30
over 10 to 15 FN	± 0.40
over 15 to 25 FN	± 0.50
over 25 to 50 FN	± 5% of assigned FN
over 50 to 90 FN	± 8% of assigned FN

4. Calibration of Magne-Gage-Type² Instruments

4.1 Calibration by Means of Primary Standards. All Magne-Gage-type instruments can be calibrated by the following procedure. Torsion balances other than a Magne-Gage may not require use of counterweights, so that statements regarding ranges of calibration may not apply. However, the requirements for the number of standards for calibration over a specific FN range shall

2. Trademark of Magne-Gage Sales & Service. (See Appendix A6.1.)

apply to all Magne-Gage-type instruments. (See Appendix A6.1.)

4.1.1 The FNs shall be assigned from Table 1 to each of the available primary standards (coating thickness standards) as defined in 2.3. For thicknesses between those given in the table, the FNs shall be interpolated as closely as possible. Alternatively, FN may be calculated directly from one of the two following formulas:

For thickness (T) in mils:

$$\ln(\text{FN}) = 4.5891 - 0.50495 \ln(T) - 0.08918 [\ln(T)]^2 + 0.01917 [\ln(T)]^3 - 0.00371 [\ln(T)]^4$$

For thickness (T) in mm:

$$\ln(\text{FN}) = 1.8059 - 1.11886 \ln(T) - 0.17740 [\ln(T)]^2 - 0.03502 [\ln(T)]^3 - 0.00367 [\ln(T)]^4$$

See Section 9 for information on the precision of the measurements.

4.1.2 Magne-Gage-type instruments are sensitive to premature magnet detachment from a standard or from a sample due to very small vibrations. The Magne-Gage minimizes, but does not eliminate, this effect, as compared to other torsion balances. Repetitive measurements at a given point will yield a range of FN values due to this effect, and the range increases with increasing FN. With a Magne-Gage, above 20 FN, it is necessary to make several measurements at any given point of a standard or sample, and to accept only the highest FN as the correct value for that point. With other Magne-Gage-type instruments (torsion balances) this practice is necessary for all levels of FN.

4.1.3 A Magne-Gage can be used for measurements over a range of about 30 FN with a single calibration. The exact range to be used at any given time is determined by the choice of a counterweight (if any) added to the balance beam of the instrument at a hole provided for this purpose. The hole is located about 1.5 inches (38 mm) from the fulcrum opposite from the point of suspension of the magnet (see Figure A1). Care should be taken that the counterweight, if used, is free to swing without touching any other part of the instrument when the magnet is in contact with specimen or standards. Without a counterweight, a Magne-Gage will cover from 0 to about 30 FN. With a counterweight of about 7.5 grams, a Magne-Gage will cover from about 30 to 60 FN; with a counterweight of about 15 g, the measurement range will be about 60 to 90 FN. Exact ranges will depend upon the precise weight of the counterweight and upon the strength of the magnet in use. A separate calibration is required for each counterweight, and recalibration is required whenever the magnet is changed.

4.1.4 Without a counterweight, eight or more primary standards shall be used, with nominal thicknesses that provide corresponding Ferrite Numbers well dis-

tributed over the range of 0 to 28 FN. With the No. 3 magnet in place, the zero point (the white dial reading at which the magnet lifts free from a completely nonmagnetic material) shall be determined. If a counterweight is used, five or more primary standards, similarly well distributed, shall be used, but no zero point can be determined. In either case, the white dial reading for each of the available primary standards covering the FN range of interest shall then be determined. (See Appendix A4.1).

4.1.5 The white dial readings shall be plotted on Cartesian coordinate paper versus the FNs as illustrated in Figure 1. If no counterweight is used, the zero point reading (white dial reading when the magnet just barely lifts from a nonmagnetic material) on the dial of the gage can be included as 0 FN.

4.1.6 A "best fit" straight line shall be drawn through the points plotted in accordance with 4.1.5. Alternatively, a linear regression equation shall be fit to the data collected as described in 4.1.4. Magne-Gages tested to date have produced a straight line up to at least 10 FN. Most yield a straight line through all points, but some have shown a slight bend. An example of each is shown in Figure 1. For acceptable calibration, all points must fall within the maximum allowable deviations shown in Table 5. If any of the calibration points fall outside of the allowed variations, the data shall be restudied, or the manufacturer of the instrument shall be consulted, or both.

4.1.7 Two common sources of discrepant readings during calibration (as well as during measurement) are mechanical vibrations and dirt (usually magnetic particles) clinging to the magnet. Either factor tends to produce premature detachment of the magnet from the sample, with a correspondingly low FN determination (high white dial reading). A vibration-free environment is essential to accurate FN determination, especially above 15 FN. Wiping of the magnet end with a clean,

Table 5
Tolerance on the Position of
Calibration Points Using Primary Standards

Ferrite Number Range	Maximum Allowable Deviation
0 to 5	± 0.40
over 5 to 10	± 0.50
over 10 to 15	± 0.70
over 15 to 20	± 0.90
over 20 to 30	± 1.00
over 30 to 90	± 5% of assigned FN

Note: The maximum variations in the position of the calibration points from the curve (example is shown in Fig. 1) occur when the primary thickness standards are at the maximum five percent variation from the certified thicknesses.

NOTE: A different set of coating thickness standards was used for each instrument, although the sets included the same standard numbers

DATA FOR THE CURVES

NBS COATING THICKNESS STANDARD	GAGE #1 CALIBRATION				GAGE #2 CALIBRATION			
	mils	mm	FN	WHITE DIAL	mils	mm	FN	WHITE DIAL
1312					8.2	.208	25.5	13.2
1313	10.2	.259	21.5	28.0	9.8	.249	22.2	27.0
1314	14.7	.373	15.9	53.0	15.0	.381	15.6	57.0
1315	19.2	.488	12.6	68.0	19.7	.500	12.3	74.0
1316	24.5	.622	10.0	76.0	24.3	.617	10.1	84.1
1317	31.2	.792	7.8	84.0	30.5	.775	8.0	93.5
1318	43.0	1.092	5.5	92.0	45.5	1.156	5.2	107.3
1319	63.0	1.600	3.4	99.0	60.5	1.537	3.6	114.8
Zero Point			0.0	111.5			0.0	132.0

Figure 1 — Examples of Calibration Curves for Two Magne-Gage Instruments, Each with a No. 3 Magnet for Measuring the Delta Ferrite Content of Weld Metals

lint-free cloth is suggested when dirt is encountered. In case of doubt, examination of the magnet end under a microscope is appropriate.

4.1.8 The graph plotted as in 4.1.6, or a regression equation fit to it, may now be used to determine the FNs of stainless steel weld metals from the white dial readings of the instrument obtained on those weld metals with the same No. 3 magnet and counterweight (if used).

4.2 Calibration by Means of Weld Metal Secondary Standards

4.2.1 Calibration by primary standards is the recommended method, as previously mentioned, but calibration utilizing secondary standards is acceptable.³ Five or

3. Weld metal secondary standards have been commercially sold by The Welding Institute, Abington Hall, Abington, Cambridge, CBI 5AL, United Kingdom.

more such standards are required for calibration curves for 0 to 15 FN; eight or more are required for calibration curves for 0 to 30 FN; and five or more are required for any range of 30 FN above 15 FN. In all cases, the Ferrite Numbers of the standards shall be well distributed over the range of interest. (See also Appendix A4.2).

4.2.2 It should be recognized that weld metal secondary standards are unlikely to provide readings from point to point that are as uniform as those from primary standards. Care must therefore be exercised to take readings on secondary standards in precisely those locations used in assigning the original FNs to the standards. In case of doubt, the producer of the secondary standards should be consulted.

4.2.3 Other than the departures noted in 4.2.1 and 4.2.2, the remainder of the calibration procedure with secondary standards shall be the same as that used with primary standards as given in 4.1.2 through 4.1.8.

5. Calibration of Feritscopes ("Ferritescopes")

5.1 Calibration by Means of Primary Standards

5.1.1 This instrument is calibrated to the FN scale by the manufacturer, but calibration should be verified by the user. The only Feritscope⁴ (Ferritescope) which can be calibrated with primary standards according to Table 2 is the pre-1980 Model FE8-KF with analog readout and dual-contact ("normalized") probe. No tables for calibration with primary standards are available for post-1980 instruments (those with digital readouts or single-pole probes). Other Feritscopes may be calibrated by weld metal secondary standards as described in Section 7.

4. Trademark of Fischer Technology. (See Appendix A6.2.)

5.1.2 The manufacturer's instructions with regard to the use of the instrument and the adjustments of the scale shall be followed.

5.1.3 The FNs shall be assigned from Table 2 to each of the available primary thickness standards as defined in 2.3. For thicknesses between those given in the table, the FNs shall be interpolated as closely as possible. Eight or more thickness standards shall be used, with nominal thickness corresponding to Ferrite Numbers well distributed in the range 0 to 25 FN (see Appendix A4.1). The instrument reading for each of the available primary standards shall then be determined.

5.1.4 The instrument readings shall be plotted on Cartesian coordinate paper versus the FN assigned from Table 2 for each primary standard. A "best fit" line shall be drawn through the data. Alternatively, a regression equation shall be fit to the data collected as described in 5.1.3.

5.1.5 For approved calibration, all readings shall fall within the maximum allowable deviations from the "best fit" line shown in Table 6. If any of the calibration readings fall outside of these allowed variations, the data shall be restudied, or the manufacturer of the instrument shall be consulted, or both.

5.1.6 The graph plotted as in 5.1.4, or a regression equation fit to it, may now be used to determine the FNs of stainless steel weld metals from the instrument reading.

5.2 Calibration by Means of Weld Metal Secondary Standards

5.2.1 As previously mentioned, calibration to primary standards is the preferred method for suitable instruments, but calibration to weld metal secondary standards is acceptable. Calibration to weld metal secondary standards is necessary for other Feritscopes.

Table 6
Maximum Allowable Deviation of the
Periodic Ferrite Number (FN) Check for Feritscopes (Ferritescopes)

Ferrite Number Range	Maximum Allowable Deviation of the Periodic Ferrite Number Check		
	From the Ferrite Number Value Assigned to the Primary Standard in Table 2	From the Ferrite Number Value Assigned to the Secondary Standard by the Seller	From the Ferrite Number Value First Assigned to the Secondary Standard by the User
0 to 5	± 0.40	± 0.40	± 0.20
over 5 to 10	± 0.40	± 0.40	± 0.20
over 10 to 15	± 0.70	± 0.70	± 0.20
over 15	± 1.0	± 1.0	± 0.30

5.2.2 Refer to 7.2 for instructions to calibrate the Feritscope to weld metal secondary standards.

6. Calibration of Inspector Gages⁵

6.1 Calibration By Means of Primary Standards

6.1.1 This instrument is the Inspector Gage Model Number 111 with either a 6F ("% ferrite") or a 7F (FN) scale. The latter is preferable because it has smaller divisions. (see also Appendix A6.3).

6.1.2 The manufacturer's instructions with regard to the use of the instrument and adjustments of the scale shall be followed.

6.1.3 The FNs shall be assigned from Table 3 to each of the available primary thickness standards as defined in 2.3. For thicknesses between those given in the table, the FNs shall be interpolated as closely as possible. Eight or more thickness standards shall be used, with nominal thicknesses corresponding to Ferrite Numbers well distributed in the range 0 to 30 FN (see Appendix A4.1). The instrument reading for each of the available primary standards shall then be determined.

6.1.4 The instrument readings shall be plotted on Cartesian coordinate paper versus the FN assigned from Table 3 for each primary standard. A "best fit" line shall be drawn through the data. Alternatively, a regression equation shall be fit to the data collected as described in 6.1.3.

6.1.5 For approved calibration, all readings shall fall within the maximum allowable deviations from the "best fit" line shown in Table 7. If any of the calibration readings fall outside of these allowed variations, the data shall be restudied, or the manufacturer of the instrument shall be consulted, or both.

5. Trademark of Elcometer Instruments Ltd. (See Appendix A6.3.)

6.1.6 The graph plotted as in 6.1.4, or a regression equation fit to it, may now be used to determine the FNs of stainless steel weld metals from the instrument reading.

6.2 Calibration by Means of Weld Metal Secondary Standards

6.2.1 As previously mentioned, calibration to primary standards is the preferred method, but calibration to weld metal secondary standards is acceptable.

6.2.2 Refer to 7.2 for instructions to calibrate the Inspector Gage to weld metal secondary standards.

7. Calibration of Other Instruments

7.1 Calibration by Means of Primary Standards. As of this revision of this standard (see 3.1) only Magne-Gage type instruments, Feritscopes with normalized probes, and Inspector Gages can be calibrated to this standard by means of primary standards. All other instruments must be calibrated by means of weld metal secondary standards (see also Appendix A6.4).

7.2 Calibration by Means of Weld Metal Secondary Standards

7.2.1 Other instruments can be calibrated by weld metal secondary standards to produce a satisfactory correlation between the instrument readout and weld metal FN. While it may be desirable that the instrument readout be precisely the calibrated value of FN, this is not essential, so long as a unique correlation between readout and FN can be determined. Such instruments may be used if they have been calibrated using secondary weld metal standards to which FNs were assigned by an instrument with primary standard calibration.

7.2.2 Five or more such secondary standards are required for calibration curves covering 0 to 15 FN; eight or more such secondary standards are required for

Table 7
Maximum Allowable Deviation of the
Periodic Ferrite Number (FN) Check for Inspector Gages

Ferrite Number Range	Maximum Allowable Deviation of the Periodic Ferrite Number Check		
	From the Ferrite Number Value Assigned to the Primary Standard in Table 3	From the Ferrite Number Value Assigned to the Secondary Standard by the Seller	From the Ferrite Number Value First Assigned to the Secondary Standard by the User
0 to 5	± 0.40	± 0.40	± 0.20
over 5 to 10	± 0.40	± 0.40	± 0.20
over 10 to 15	± 0.70	± 0.70	± 0.20
over 15	± 1.0	± 1.0	± 0.30

calibration from 0 to 28 FN; and five or more such secondary standards are required for calibration of any 30 FN interval above 15 FN. In all cases, the Ferrite Numbers of the secondary standards shall be well distributed over the range of interest.

7.2.3 Instrument readings shall be determined for each of the available secondary standards and, if possible, for a zero point. When taking readings on secondary standards, the same precaution noted in 4.2.2 should be taken.

7.2.4 Instrument readings shall be plotted against assigned secondary standard FN values on Cartesian coordinate paper, and the zero point can be included if applicable.

7.2.5 A "best fit" smooth line shall be drawn through the points plotted in 7.2.4. For acceptable calibration, no data point may vary from the curve any more than the allowable deviations shown in Table 4. If any point falls outside of the appropriate allowed deviation, the data shall be restudied, or the manufacturer of the instrument shall be consulted, or both.

7.2.6 The graph plotted as in 7.2.4, or a regression equation fit to it, may now be used to determine the FNs of stainless steel weld metals over the calibration range.

7.2.7 It is the responsibility of the user to ensure that the instrument is properly calibrated — i.e., such that the results obtained with weld metal secondary standards in the FN range(s) of use are within the expected range of variations shown in Table 4.

8. Use of Calibrated Instruments

8.1 Maintaining Calibration. Instruments must be checked periodically on a regular basis against primary

or secondary standards to ensure and verify the maintenance of the original calibration. Records of such checks shall be maintained. It is the responsibility of the user to check at a frequency which is adequate to maintain calibration. For frequently used instruments, a weekly calibration check is recommended. For seldomly used instruments, a calibration check before each use is recommended. Two standards, one near each extreme of the calibration range being checked, shall be used for each of the ranges shown in Tables 4 and 6 through 8, as appropriate, for which the instrument is used. When the instrument no longer produces values within the maximum deviation specified in the relevant table, it shall be removed from service and the manufacturer shall be consulted. (see Appendix A3.2).

8.2 Variations in Measurements. Based upon round robin tests within the Welding Research Council Subcommittee on Welding Stainless Steels, the FNs determined by these instruments are expected to fall within the limits shown in Table 9, 10, or 11 as compared to the overall average FN values of stainless steel weld metals checked on other instruments of the same type calibrated to this standard. When measurements are made with a variety of calibrated instrument types, somewhat larger variation in measurements than those indicated in Table 9, 10, or 11 might be expected, but the magnitude of the variation has not been determined. Weld ripples and other surface perturbations must be removed because surface finish affects measurement accuracy. Up to about 20 FN, the practice known as "draw filing" produces acceptable accuracy (see 2.2). For accurate and reproducible ferrite measurements, above 20 FN, a Magne-Gage No. 3 magnet or equivalent requires a flat surface at least 1/8-in. (3.2 mm) in diameter finished no coarser than with a 600 grit abrasive [about 8 microinches (0.2 microns) RMS]. Rougher surfaces or convex sur-

Table 8
Maximum Allowable Deviation of the
Periodic Ferrite Number (FN) Check for Magne-Gage-Type Instruments

Ferrite Number Range	Maximum Allowable Deviation of the Periodic Ferrite Number Check		
	From the Ferrite Number Value Assigned to the Primary Standard in Table 1	From the Ferrite Number Value Assigned to the Secondary Standard by the Seller	From the Ferrite Number Value First Assigned to the Secondary Standard by the User
0 to 5	± 0.50	± 0.50	± 0.20
over 5 to 10	± 0.50	± 0.50	± 0.20
over 10 to 15	± 0.60	± 0.60	± 0.30
over 15 to 25	± 0.80	± 0.80	± 0.40
over 25 to 90	± 5% of assigned FN value	± 5% of assigned FN value	± 3% of assigned FN value

Table 9
Expected Range of Variation
in Measurements with Calibrated
Magne-Gage-Type Instruments*

Ferrite Number Range	67% of the Instruments	95% of the Instruments
0 to 10	± 0.30 FN	± 0.60 FN
over 10 to 18	± 0.35 FN	± 0.70 FN
over 18 to 25	± 0.45 FN	± 0.90 FN
over 25 to 90	$\pm 5\%$ of mean FN value	$\pm 10\%$ of mean FN value

*Based upon WRC round robin tests.

Table 10
Expected Range of Variation
in Measurements with Calibrated
Feritoscopes (Ferritescopes)*

Ferrite Number Range	67% of the Instruments	95% of the Instruments
0 to 10	± 0.20 FN	± 0.40 FN
over 10 to 18	± 0.40 FN	± 0.80 FN
over 18 to 25	± 0.50 FN	± 1.0 FN
over 25 to 80	$\pm 5\%$ of mean FN value	$\pm 10\%$ of mean FN value

*Based upon WRC round robin tests.

faces will result in artificially low FN values and shall be avoided. Other instruments may respond differently to rough, convex, or narrow surfaces and should be examined fully before use. At all ferrite levels, surface preparation must be accomplished without contamination by ferromagnetic materials.

Table 11
Expected Range of Variation
in Measurements with Calibrated
Inspector Gages*

Ferrite Number Range	67% of the Instruments	95% of the Instruments
0 to 10	± 0.20 FN	± 0.40 FN
over 10 to 18	± 0.40 FN	± 0.80 FN
over 18 to 30	± 0.50 FN	± 1.0 FN

*Based upon WRC round robin tests.

9. Significant Figures in Reporting Measurement Results

9.1 Calibration Data. For purposes of developing calibration data or demonstrating compliance of an instrument with calibration requirements, the number of significant figures shown in the relevant Table herein shall be used.

9.2 Measurement Data. For purposes of reporting measurement data on weld metal test samples or demonstrating compliance with the requirements of a specification other than this specification, the precision implied by the number of significant figures in the Tables herein is generally inappropriate. For ferrite measurements of 25 FN or higher, rounding off to the nearest whole number conveys appropriate precision. For ferrite measurement of 5 to 25 FN, rounding off to the nearest 0.5 FN conveys appropriate precision. For ferrite measurements less than 5 FN, rounding off to the nearest 0.1 FN conveys appropriate precision.

Appendix

(This Appendix is not a part of ANSI/AWS A4.2-91, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Austenitic-Ferritic Stainless Steel Weld Metal*, but is included for information purposes only.)

A1. Acknowledgment

These standard procedures are based upon the studies and recommendations made by the Subcommittee on Welding Stainless Steel of the High Alloys Committee of the Welding Research Council (WRC).⁶ The document on which most of this standard is based is the *Calibration Procedure for Instruments to Measure the Delta Ferrite Content of Austenitic Stainless Steel Weld Metal*, published by the WRC on July 1, 1972.

Expansion of the measurement system beyond 28 FN is based upon *Extension of the WRC Ferrite Number System*, D. J. Kotecki, *Welding Journal*, November, 1982 and International Institute of Welding Documents II-C-730-84, II-C-821-88, II-C-835-88 and II-C-836-88.

A2. Ways of Expressing Ferrite Content

A2.1 The methods of determining ferrite content in stainless steel weld metals have evolved over an extended time period. The interested reader is referred to WRC Bulletin 318 (September, 1986). Only a few of the pertinent conclusions of that Bulletin are summarized briefly in the following paragraphs.

A2.2 Measured Percent Ferrite. The percent ferrite in austenitic stainless steel weld metals in the past has too often been regarded as a firm fixed value. Extensive round robins have been run on sets of weld metal specimens, containing up to a nominal 25 percent ferrite, in the U.S. under the sponsorship of the WRC and on similar sets in Europe by the International Institute of Welding (IIW). These round robins showed that most laboratories used somewhat different calibration curves as well as a variety of instruments. At nominal levels of up to 10 percent ferrite, which is often the most useful

and pertinent range, the values obtained by participating laboratories ranged from 0.6 to 1.6 times the nominal value. The instrument calibration procedure defined in this standard is designed to overcome this problem.

A similar problem existed with metallographic determinations due to the extreme fineness of the ferrite in weld metals, variations in the etching media and the degree of etch, and to the Quantitative Television Microscope (QTM) settings, if a QTM was used. Similar problems, though perhaps to a lesser degree, have been encountered with magnetic saturation, x-ray diffraction, Mossbauer studies, and with other methods of determining the ferrite content of weld metals. Thus a "percent ferrite" figure in past literature is very dependent upon the source, and should be defined in relation to the instrument, the laboratory using it, and the calibration source, or to the diagram if derived from a constitution diagram. In the opinion of the WRC Subcommittee, it has been impossible, to date, to determine accurately the true absolute ferrite content of stainless steel weld metals.

A2.3 Ferrite Number. Because on a given specimen, laboratory A might rate the percent ferrite at as low as 3 percent, laboratory B at 5 percent, and laboratory C at as high as 8 percent, the WRC Subcommittee decided to use the new term *Ferrite Number* (FN) to define the ferrite quantity as measured by instruments calibrated with its recommended procedure. Thus, FN is an arbitrary, standardized value related to the ferrite content of an equivalently magnetic weld metal. It is not necessarily the true absolute ferrite percentage of the weld. FNs below 10 do represent an excellent average of the "percent ferrite" as determined by U.S. and world methods of measuring delta ferrite, based upon the previously discussed round robins conducted by the WRC Subcommittee and the IIW Subcommission II-C. FNs above 10 clearly exceed the true volume percent. Magnetic saturation measurements on castings of known percent ferrite have shown that the magnetic response of a given percent ferrite depends upon its composition. So

6. Welding Research Council, 345 East 47th St., New York, NY 10017.

any relation between percent ferrite and FN will be influenced somewhat by composition of the ferrite. For common duplex austenitic-ferritic weld metals, it is not unreasonable to estimate that the percent ferrite is on the order of 0.7 times the FN as measured herein, but this should not be considered as exact.

A2.4 Ferrite Content Calculated From Constitution Diagrams. The several committees that have investigated and reviewed this subject recommend for most applications the use of measured ferrite as opposed to the use of ferrite calculated from the weld metal analysis. The basic reason for this is that the variables involved in determining the chemical composition, and other variables involved in the diagrams themselves, are very likely to have substantially greater effects than those associated with the direct determination of ferrite content using instruments calibrated in accordance with this standard. Nevertheless, constitution diagrams are very useful tools, even though they are less exact, because they permit anticipation or prediction of ferrite content for a variety of situations. By taking into account dilution effects, such diagrams can also be useful for anticipating or predicting the ferrite content of weld overlays and dissimilar metal joints.

The Schaeffler diagram, developed in the late 1940s, presents its values as percent ferrite, but these are said to be directly equivalent to FNs. The DeLong diagram, January 1973 version, was the first diagram presented in terms of FN. Espy, in 1982, proposed a modification of the Schaeffler Diagram to take into account high nitrogen, high manganese stainless steel weld metals. The more recent diagram of Siewert, McCowan, and Olson, prepared under WRC sponsorship in 1988, is, at the time of this writing, the best estimation tool available for most austenitic and duplex austenitic-ferritic stainless steel weld metals. See *Welding Journal*, December, 1988, pp. 289s-298s, or WRC Bulletin 342, April, 1989. To assist in Ferrite Number estimation, a Personal Computer software package, FERRITEPREDICTOR, is available from the American Welding Society, although, at the time of this writing, only the Schaeffler and DeLong Diagrams are included.

A3. Cautions on the Use of Ferrite Number

A3.1 Instrument Calibration

A3.1.1 Various thicknesses of nonmagnetic material over carbon steel represent a very convenient method of calibrating instruments for the measurement of ferrite in stainless steel weld metals. Useful general information on the subject can be obtained from the latest edition of The American Society for Testing and Materials (ASTM) B499, *Standard Method for Measurement of*

*Coating Thicknesses by Magnetic Method: Nonmagnetic Coatings on Magnetic Base Metals.*⁷ The response of the instrument when a nonmagnetic "skin" is between the measuring probe and the plate, versus its response to ferrite in stainless steel weld metal at several levels, can be plotted and the relationship between them established. A change in the magnet size or strength, or in the probe characteristics, changes the relationship. Thus, a calibration curve or table for FN versus nonmagnetic coating thickness for a Magne-Gage-type instrument (Figure A1) will be different for each of the magnets (Nos. 1, 2, 3 and 4) because the strengths of the magnets are different.

A3.1.2 With Magne-Gage-type instruments, only calibration using a No. 3 magnet is considered in this standard. A weaker magnet (No. 1 or No. 2), if used with the calibration points of Table 1, will on weld metal yield falsely high FN values. Conversely, a stronger magnet (No. 4), if used with the calibration points of Table 1, will on weld metal yield falsely low FN values. If the No. 3 magnet of a Magne-Gage is damaged, such as by rough handling or exposure to an ac field which weakens it, it will also yield false readings. Work within the WRC Subcommittee on Welding Stainless Steel, on behalf of the International Institute of Welding, Subcommittee II-C, has demonstrated that accurate readings on weld metal are obtained via calibration from Table 1 when the magnet strength is such that it provides a tearing-off force as a function of FN of 5 FN/gram ± 0.5 FN/gram. With a torsion balance other than a Magne-Gage, compliance with this requirement is determined directly from the slope of the calibration line. With a Magne-Gage, this can be evaluated simply by suspending a 5 gram iron weight from the No. 3 magnet. When the white dial of the Magne-Gage is turned to just barely lift the weight past the balance point of the instrument, the reading should correspond to 25 FN ± 2.5 FN using the calibration line of white dial readings versus FN.

A3.1.3 It is strongly recommended that reference weld metal secondary standards be used along with the calibration curves obtained from primary standards when using a Feritscope to check for compliance with Table 6, when using an Inspector Gage to check for compliance with Table 7, or when using a Magne-Gage type instrument to check for compliance with Table 8. If compliance cannot be obtained as required by the appropriate table, the instrument is in need of recalibration or servicing by the manufacturer, or it is not suitable for calibration with primary standards.

7. ASTM standards can be obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

A3.2 Instrument Malfunction. Recalibration or rechecking of each instrument at periodic and sometimes frequent intervals is necessary to ensure that the instrument is operating properly (see 8.1). Permanent magnets may be partially demagnetized by exposure to any significant ac field such as that generated by a strong alternating current in a wire or by a weaker alternating current in a coil. The tips of such permanent magnets, or of the probes which are used to establish a magnetic field in the specimen, may become worn and the response of the system may change for this reason. Bearings may become fouled with dirt and thus fail to operate freely.

A4. Standards for Instrument Calibration

A4.1 Primary Standards. NIST⁸ coating thickness standards were developed many years ago to calibrate instruments for the determination of coating thickness. The standards useful for the determination of delta ferrite consist of varying thicknesses of copper electroplated on a carbon steel base and protected with a chromium flash. NIST certifies the thickness of the total coating to within $\pm 5\%$ of the stated thickness, but the majority will be within $\pm 2\%$ or even $\pm 1\%$. The use of the two sets listed below is recommended for calibration up to 28 FN.

SRM 1363A Nominal Thicknesses—9.6, 16, 20, and 26 mils

SRM 1364A Nominal Thicknesses—32, 39, 59, and 79 mils

These 8 thicknesses correspond nominally to 0.26, 0.39, 0.50, 0.64, 0.80, 1.00, 1.53, and 1.94 mm, respectively.

Sets SRM 1368 (8 to 20 mils), SRM 1369 (25 to 60 mils) and individual standards are no longer available. The 8 mil thickness is now available in set SRM 1362A.

For Ferrite Numbers from about 30 to about 85, the use of the three sets listed below is recommended for calibration:

SRM 1323, Nominal Thicknesses—3.7, 4.4, 5.3, and 6.6 mils (.094, .112, .135, and .167 mm, respectively).

SRM 1322, Nominal Thicknesses—2.1, 2.4, 2.7, and 3.2 mils (.053, .060, .069, and .080 mm, respectively).

SRM 1321, Nominal Thicknesses—1.34, 1.46, 1.65, and 1.85 mils (.034, .037, .042, and .047 mm, respectively).

The sets can be ordered from NIST. Other thickness sets are also available, but do not, of themselves, offer close enough spacing of corresponding Ferrite Numbers for adequate calibration.

A4.2 Secondary Standards

A4.2.1 Weld Metal Secondary Standards. Magnetic instruments may also be calibrated by using weld metal secondary standards prepared from weld metals rated by 2 or more instruments carefully calibrated through the use of these standard procedures. Each such standard should be provided with FN values at specific points on its test surface. These secondary standards can be used for the calibration of a suitable instrument or for maintaining calibration. They can also be used to establish the relationship between other instruments and Magne-Gage-type instruments.

A4.2.2 Other Types of Secondary Standards. The use of cast specimens or powder compacts is risky because the size, shape, and orientation of the magnetic particles may influence the response of the magnetic or other type probes to varying degrees. However, cast specimens or powder compacts calibrated with one instrument traceable to this procedure can be used for calibrating instruments of the same type and manufacture or for day-to-day verification of such instruments.

A5. Effect of Ferrite Size, Shape, and Orientation

It has been established that the ferrite size, shape, and orientation can influence the relative response of the low field strength magnets and probes used with the measuring instruments. For this reason, a measuring instrument may respond differently to a given volume percent ferrite in a stainless steel weld metal as compared to the same volume percent ferrite in a cast stainless steel, or even in a solution heat treated stainless steel weld metal. The ferrite in as-welded weld metal up to about 15 FN is very fine and in the form of lacy, dendritic stringers generally perpendicular to the fusion line, and often extensively interconnected at ferrite contents over 3 or 4 FN. Above about 15 FN in as-welded weld metal, the ferrite and austenite generally form laths which are also very fine. The ferrite in castings is usually much larger and tends to be more spheroidal and much less interconnected except perhaps at very high ferrite contents. The ferrite in wrought steels and in solution heat-treated weld metals tends to be lesser in volume and more spheroidized than in an as-welded weld metal of the same composition because heat treatment tends to

8. Office of Standard Reference Materials, Room B311, Chemistry Building, National Institute of Standards and Technology (formerly National Bureau of Standards), Gaithersburg, MD 20899, Phone 301-975-6776.

transform some ferrite to austenite and spheroidize the balance. Since the volume percent of ferrite in castings is in close agreement when measured by either magnetic response or by metallographic point count, the ferrite content of castings is expressed as a percentage and not by the arbitrary FN, as noted in ASTM Practice A800.

A6. Instruments

A6.1 Magne-Gage and Magne-Gage-Type Instruments

A6.1.1 The Magne-Gage⁹ (Figure A1) is usable only in the flat position on relatively small specimens. The probe is a long, thin magnet hung on a spiral spring. The spring is wound by means of turning a knob with a corresponding reading on a dial. When the magnet is pulled free of a specimen, the white dial reading used in conjunction with the calibration curve establishes the FN of the specimen.

A6.1.2 Returning the Magne-Gage periodically to the factory for maintenance is desirable. With heavy use, 1 year is a reasonable time; with light use, 2 years.

A6.1.3 A Magne-Gage Number 3 Magnet or equivalent can be used with a variety of torsion balances to obtain the same results as are obtained with a Magne-Gage. A complete example of such a Magne-Gage-type instrument is given in "Extension of the WRC Ferrite Number System" referenced in Section A1. Numerous other configurations could also be conceived. This is outside the scope of this Standard.

A6.2 Feritscope¹⁰ (Ferritescope). This instrument, consisting of a probe connected by a cable to an electronics package (Figure A2), is usable in any position. Several models and a variety of probes are available. Only one model and probe has been shown to be able to be calibrated with primary standards as given in Table 2 (see 5.1.1). All others must be calibrated with weld metal secondary standards. Models are available in either battery powered or ac current versions. At least one model can be calibrated with secondary standards up to 80 FN.

A6.3 Inspector Gage.¹¹ This instrument (Figure A3), is usable in any position. It is a hand held magnetic instrument with thumb actuated springs tension. The instrument gives direct readings in FN if it is a new model designed to do so. Older models can be rebuilt by the manufacturer to give acceptable readings on weld

metal in terms of FN. As of 1989, the ability of Inspector Gages to determine ferrite above 30 FN is unknown.

A6.4 Other Instruments

A6.4.1 The following instruments at the time of the writing of this revision are not capable of being calibrated to primary standards. They can, however, be calibrated to weld metal secondary standards and produce acceptable consistent results. Again, it is the responsibility of the user to ensure that instrument calibration is maintained and to have the instrument repaired by the manufacturer if consistent readings on the weld metal secondary standards cannot be obtained. As of 1989, the ability of these instruments to determine ferrite above 30 FN is unknown.

A6.4.1.1 Ferrite Indicator (more commonly called a Severn Gage).¹² This instrument (Figure A4) is usable in any position. It is a go-, no-go-type gage which determines whether the ferrite content is above or below each of a number of inserts of various magnetic strengths which come with the instrument. At least one unthreaded test insert must be available for use in conjunction with one of the threaded inserts with specified FN values. The purpose of the unthreaded inserts is to assure that the magnet has not lost strength. Details may be obtained from the manufacturer for conversion of percent ferrite values on earlier model Severn gages to FN. Severn gages calibrated directly in terms of FN are now available. Older model gages can be converted to the FN scale by the manufacturer.

A6.4.1.2 Foerster Ferrite Content Meter.¹³ This is a light, portable, battery-operated instrument (Figure A5) usable in any position. It closely resembles the Feritscope in its operation except that it has a single contact point probe which allows ferrite determination in very localized regions. On older models, the meter output indicates ferrite content as a percentage, which can be effectively converted to FN values by the use of suitable weld metal secondary standards to produce a satisfactory calibration curve. Newer models are now available on which the meter reads directly in FN values.

A6.4.2 A number of other magnetic measuring instruments are available for various purposes. Many are regarded as not suitable in their present form because of limitations such as range, problems in calibration, or varying response due to the position of use or to their relation to the north-to-south magnetic field lines of the

9. Manufactured by Magne-Gage Sales & Service, 14376 Dorsey Mill Road, Glenwood, MD 21738.

10. Manufactured by Fischer Technology, 750 Marshall Phelps Road, Windsor, CT 06095.

11. Manufactured by Elcometer Instruments Ltd., 1180 East Big Beaver, Troy, MI 48083.

12. Manufactured by Severn Engineering Co., Inc., 98 Edgewood Street, Annapolis, MD 21401.

13. Marketed by Foerster Instrument Inc., 202 Rosemont Dr., Coraopolis, PA 15108.

(A) STANDARD MAGNE-GAGE

(B) MAGNE-GAGE FROM REAR, COUNTERWEIGHT
ADDED TO LEFT SIDE OF BALANCE BEAM

Figure A1 — Magne-Gage-Type Instruments

(C) TORSION BALANCE WITH MAGNE-GAGE NO. 3 MAGNET

Figure A1 (Continued) — Magne-Gage-Type Instruments

Figure A2 — Ferritescope

Figure A3 — Inspector Gage

Figure A4 — Ferrite Indicator (Severn Gage)

Figure A5 — Foerster Ferrite Content Meter

earth. One that seems promising is the Ferritector Gage.¹⁴ Instruments which are suitable in other respects must still be calibrated to the FN scale in a manner traceable to this standard. This can be accomplished by the use of a set of 5 or more weld metal secondary standards if the calibration is extended up to 15 FN, or 8 or more if it is up to 25 FN. The establishment of an adequate correlation is the responsibility of the user.

A7. Use of Calibrated Instruments

A7.1 Distance for Ferromagnetic Material. The FN values of stainless steel weld deposits on ferromagnetic base metal may be increased by varying degrees on each instrument depending on the distance of the magnet or probe from the base metal, on the ferrite content, and on the permeability of the base metal. Hence, to limit the increase in FN values to 0.2 FN maximum due to the effect of a ferromagnetic carbon steel base metal, the carbon steel base plate should be approximately 0.3 in. (8 mm) or more away from a Magne-Gage magnet or Inspector Gage magnet, 1.0 in. (25 mm) from a Ferrite

Indicator (Severn Gage), and 0.2 in. (5 mm) from a Feritscope or Foerster Ferrite Content Meter probe. For other instruments, a safe distance can be obtained by experimentation or by contacting the instrument manufacturer. If it is not possible to obtain the above minimum distances from ferromagnetic material in a production situation, FN measurements can still be meaningful if the effect of the proximity of the ferromagnetic can be taken into account. One way to do this is by comparing FN measured with ferromagnetic material in place to FN measured with ferromagnetic material removed using laboratory samples.

A7.2 Wrought Stainless Steels. It is not intended that the determination of FN be extended to wrought stainless steels. Wrought steels are beyond the scope of this standard.

A7.3 Cast Stainless Steels. The FNs are not used for cast stainless steels. The same measurement scales used for weld metals cannot be used for cast steels (see A5 for an explanation). To calibrate instruments for measuring the ferrite content of cast stainless steels, obtain ASTM A799, *Standard Practice for Calibration Instruments for Estimating Ferrite Content of Cast Stainless Steels*. Equally useful will be ASTM A800, *Standard Practice for Estimating Ferrite Content in Austenitic Alloy Castings*.

14. Manufactured by Elcometer Instruments Ltd., 1180 East Big Beaver, Troy, MI 48083.

ACKNOWLEDGEMENTS

The author wishes to thank the following individuals, whose contributions significantly assisted in the completion of this study and my academic degree. Gratitude is expressed to the members of the Materials Joining Research Group, Wei Liu, Peng Liu, Songqing Wen and Mark L. Morrison, whose invaluable assistance was greatly appreciated.

Sincere gratitude is expressed to Mr. Malcolm Blair, Vice President of the Steel Founders' Society and Dr. Damian Kotecki (Lincoln Electric Company) for their continued commitment to academia and research. Appreciation is expressed to Mr. Frank Lake (ESAB), Mr. Sushil Jana (Hobart Brothers Co.), Dr. Tom Siewert (NIST), Mr. Joel Feldstein (Foster Wheeler, Inc.), Mr. Ron Bird (Stainless Foundry Inc.) and Mr. Chris Richards (Fristam Pumps) for their participation in the round-robin test series.

Lastly, I would like to thank the Department of Energy, the South Carolina Research Authority and the University of Tennessee for their guidance and support.