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**FERRITE MEASUREMENT IN AUSTENITIC AND
DUPLEX STAINLESS STEEL CASTINGS**

FINAL REPORT

**C. D. Lundin
W. Ruprecht
G. Zhou**

August 1999

Work Performed Under Contract No. DE-FG07-99ID13734

**For
U.S. Department of Energy
Assistant Secretary for
Energy Research
Washington, DC**

**By
The University of Tennessee
Knoxville, TN**

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Submitted to:
SFSA/CMC/DOE

August 1999

Submitted by:
C. D. Lundin
W. Ruprecht
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Materials Joining Research Group
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ABSTRACT

Practical and accurate non-destructive means for the measurement of the ferrite content of duplex stainless steel castings is a necessity from the specification and service performance consideration standpoints. The ability to determine ferrite rapidly, accurately and directly on a finished casting, in the solution annealed condition, can enhance the acceptance, save on manufacturing costs and ultimately improve service performance of duplex stainless steel cast products. If the suitability of a non-destructive ferrite determination methodology can be demonstrated for standard industrial measurement instruments, the production of cast secondary standards for calibration of these instruments is a necessity. With these concepts in mind, a series of experiments were carried out to demonstrate, in a non-destructive manner, the proper methodology for determining ferrite content. The literature was reviewed, with regard to measurement techniques and vagaries, an industrial ferrite measurement round-robin was conducted, the effects of casting surface finish, preparation of the casting surface for accurate measurement and the evaluation of suitable means for the production of cast secondary standards for calibration were systematically investigated.

It was found that surface finish effects can induce significant differences in measured ferrite content. Several finishes were identified, which when applied (Feritscope® method), resulted in a significant decrease in measured ferrite content on a nominally 74 FN sample (>10 FN and well outside the 2σ variation of ± 0.5) defined for a polished surface.

An interlaboratory round-robin test series revealed that cast secondary calibration standards can be produced from castings. It was found that for both Magne Gage and Feritscope®, the repeatability ferrite measurement of centrifugal castings surpassed that of statically cast materials. Reproducibility was also unaffected by ferrite measurement technique.

Additional characterization of ferrite content, as a function of depth below a cast surface, revealed that the ferrite content immediately below a cast surface is not indicative of the bulk casting. At least 0.125" of material must be removed to ensure that the measured ferrite content is representative of the bulk casting. Analysis of operator and instrument error, for the Feritscope® showed that error induced by the operator exceeds that of the instrument alone.

Additional tests characterized the Feritscope® by establishing its probe interaction volume (0.050"). Considering instrument repeatability and reproducibility, the Feritscope® was clearly identified as the superior instrument for ferrite measurement. The data obtained from this research program provides recommendations to insure accurate, repeatable and reproducible ferrite measurement and qualifies the Feritscope® for field use on production castings.

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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.

3.0 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 PROCEDURES

The Magne Gage and Feritscope® were the exclusive instruments selected for non-destructive ferrite determination using the FN scale. ASTM E562 was utilized for manual point counting to determine the ferrite/austenite volume fraction. Operational procedures regarding use of the manual point counting, Magne Gage and Feritscope® are defined in the literature review. Metallographic preparation of the cast duplex stainless steels was conducted with standard procedures. Oxalic acid etching was employed to definitively reveal the ferrite/austenite phase morphology

3.1 Ferrite Measurement Round-Robin

A ferrite measurement round-robin study was initiated to examine the following issues:

- The repeatability and reproducibility in ferrite measurement, between laboratories, using the Magne Gage and Feritscope® techniques.
- The applicability of manufacturing cast secondary standards from static or centrifugal castings.
- A more defined correlation between different ferrite measurement techniques: manual point counting and measurement by Magne Gage and Feritscope®.

The round-robin process required that a comprehensive data packet be designed to instruct each participant to measure ferrite content using multiple techniques on a standard set of samples. Each participant was provided with detailed instructions, in the form of an operator checklist, to facilitate the data acquisition. Guidelines for proper calibration methods and measurement techniques were also provided to ensure repeatability between participants. A copy of the round-robin protocol is provided in the appendix. Refer to this appendix for further information regarding the round-robin timetable, instruction set and measurement guidelines.

Each participant was asked to measure ferrite on a specific set of samples and record their determinations using their available ferrite measurement techniques. Twelve round-robin samples, of varying ferrite content, were manufactured. The sample set consisted of a series of austenitic and duplex stainless steels whose chemical composition and ferrite content are documented. Ferrite content measurements are explored in the following sections of this analysis. The chemical composition of each block is presented in Table 1. Using the data recording forms provided, the participants forwarded their results to UTK for analysis and then sent the sample set to the next participant. The total duration of the round-robin was five months. Eight participants from academia and industry volunteered their resources for this study.

Prior to examining the participant responses, repeatability and reproducibility must be defined. For this round-robin, repeatability and reproducibility are defined according to the guidelines of ASTM E1301, "Standard Guide for Proficiency Testing by Interlaboratory Comparisons":

Table 1. Chemical Composition (wt %) of the Round-Robin Test Samples

Sample Code	Alloy	% C	% Mn	% Si	% P	% S	% Cr	% Ni	% Mo	% N
A	CF8	0.058	0.60	1.52	0.012	0.013	18.5	9.98	0.02	0.020
B	CF3M	0.027	1.04	1.02	0.009	0.009	18.8	10.79	2.12	0.030
C	CF8M	0.083	1.20	1.20	0.030	0.013	19.8	9.53	2.21	0.020
D	ASTM A890-4A	0.026	0.38	0.81	0.030	0.010	22.1	6.00	2.91	0.226
E	ASTM A890-4A	0.020	0.95	0.56	0.016	0.007	22.3	5.50	3.00	0.200
F	ASTM A890-4A -CC	0.020	0.95	0.56	0.016	0.007	22.3	5.50	3.00	0.200
G	ASTM A890-5A	0.020	0.78	0.64	0.011	0.008	24.0	7.60	4.50	0.180
H	ASTM A890-5A -CC	0.020	0.78	0.64	0.011	0.008	24.0	7.60	4.50	0.180
I	ASTM A890-5A	0.026	0.51	0.34	0.024	0.002	24.7	7.44	4.53	0.191
J	CD7MCuN -CC	0.030	0.94	0.68	0.023	0.005	24.8	5.50	2.90	0.200
K	CD7MCuN	0.030	0.94	0.68	0.023	0.005	24.8	5.50	2.90	0.200
L	CD7MCuN	0.038	1.00	0.98	0.018	0.008	25.0	5.54	2.92	0.128

“CC” indicates centrifugally cast material. All other alloys are statically cast.

Repeatability: “the closeness of agreement between test results obtained with the same test method, in the same laboratory, by the same operator with the same equipment in the shortest practical period of time using test units or test specimens taken at random from a single quantity of material that is as nearly homogenous as possible”

Reproducibility: “the closeness of agreement between test results obtained with the same test method on identical material in different laboratories”

In order to sufficiently qualify the repeatability of a round-robin sample, a gage repeatability and reproducibility study should be employed. This technique would mandate that multiple round-robin samples, of the same ferrite content, be examined by a single operator, utilizing a specified measurement technique. By isolating the technique and operator, the only remaining source of experimental error is limited to the repeatability of the test blocks. As multiple test blocks of identical ferrite content were not produced for this study, repeatability strictly cannot be characterized. However, “ 2σ values less than 10% of the mean ferrite content” has been established as criteria to indicate probable repeatability.¹ The 2σ values have been reported for each participant for information.

The reproducibility between laboratories has been expressed in previous round-robins as $2\sigma/\text{mean}$, where σ is the standard deviation for a set of measurements and the

mean is the arithmetic average of a set of measurements. The prevailing assumption indicating sufficient reproducibility between participants is $2\sigma \leq 14\%$ of the mean ferrite content of the round-robin sample.²

Having defined repeatability and reproducibility, attention is now focused on the individual characterization of the set of ferrite content samples by each of the participants. For each participants data, the mean and 2σ values were calculated. Repeatability of measurements can be assessed for each participant while reproducibility characterization is discussed for each ferrite measurement technique.

4.0 RESULTS AND DISCUSSION

4.1 Participant Responses

4.1.1 The University of Tennessee

Prior to initiating the round-robin, the University of Tennessee-Knoxville (UTK) was responsible for designing the round-robin protocol. Additionally, the sample set was manufactured and characterized by the UTK Materials Joining Research Group prior to the initiation of the study. Characterization included ferrite measurement by Magne Gage and Feritscope®. Additionally, metallographic point counting was employed to define volume percent ferrite and thus the relationship between ferrite volume percent and ferrite number.

UTK characterization of the sample set included measurements by Magne Gage and Feritscope®. Calibration of each instrument was performed using AWS A4.2, per the round-robin protocol instructions. Tables 2 and 3 summarize the results of measurements by Magne Gage and Feritscope®. Each table illustrates the number of

Table 2. University of Tennessee Magne Gage Results

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)	Mean FN	Standard Deviation (2 σ)	Repeatability 2 σ ≤10%Mean (Yes or No)
A	3.1	3.4	3.1	3.4	2.8	3.2	0.5	No
B	9.8	11.2	9.5	10.3	14.0	11.0	3.6	No
C	11.2	12.6	11.7	11.2	15.1	12.4	3.3	No
D	63.2	68.6	62.6	63.5	62.6	68.6	5.1	Yes
E	62.5	62.2	65.5	62.2	62.2	65.5	2.9	Yes
F	63.2	62.2	62.6	66.6	64.6	64.8	3.6	Yes
G	70.6	71.2	75.5	69.2	74.9	72.3	5.5	Yes
H	62.9	61.8	61.8	62.3	63.2	62.4	1.3	Yes
I	77.5	70.6	75.5	69.2	74.9	73.5	7.0	Yes
J	76.9	76.6	76.0	75.8	75.5	76.2	1.2	Yes
K	80.6	82.6	84.0	83.5	78.6	81.9	4.5	Yes
L	95.5	96.9	93.2	95.2	95.5	95.3	2.7	Yes

Table 3. University of Tennessee Feritscope® Results

Sample Code	FN 1	FN 2	FN 3	FN 4	FN 5	FN 6	FN 7	FN 8	FN 9	FN 10	Mean FN	Standard Deviation (2σ)	Repeatability 2σ≤10%Mean (Yes or No)
A	3.0	2.7	3.1	3.0	3.0	3.1	3.0	2.9	3.0	3.1	3.0	0.2	Yes
B	6.0	9.3	8.8	11.4	6.3	11.7	7.6	5.6	10.2	9.4	8.6	4.4	No
C	11.5	11.1	12.4	12.7	11.7	13.0	11.2	12.7	12.3	13.2	12.2	1.5	No
D	45.4	58.3	51.1	57.1	51.4	55.7	50.5	53.4	57.4	57.0	53.7	8.2	No
E	63.4	45.7	49.1	49.2	45.8	45.6	45.2	45.5	45.7	61.2	49.6	13.7	No
F	56.5	59.5	56.4	64.4	59.8	56.5	62.5	58.3	65.2	56.6	59.6	6.8	No
G	65.2	67.5	68.7	63.9	67.0	66.8	67.5	73.3	65.8	71.7	67.7	5.7	Yes
H	64.8	65.3	62.6	64.1	60.1	61.3	62.6	62.1	63.3	61.8	62.8	3.2	Yes
I	71.2	71.0	71.9	72.0	71.2	65.3	74.2	71.1	74.9	69.8	71.3	5.2	Yes
J	74.0	73.1	71.7	72.0	75.0	74.2	75.2	74.5	67.5	74.6	73.2	4.7	Yes
K	74.0	72.5	77.4	74.5	75.1	76.2	77.1	75.8	78.0	74.4	75.5	3.4	Yes
L	93.3	98.0	90.0	91.8	94.6	94.2	97.9	92.4	92.4	89.4	93.4	5.8	Yes

ferrite determinations, followed by the mean ferrite number for each sample. The standard deviation (2σ) was also calculated and incorporated into the data.

Analysis of the data set reveals that the samples ranged in ferrite content from approximately 3 FN to 95 FN with minimal disparity ($<2\%$ of the mean FN) between the two techniques in measuring ferrite number. However, ferrite measurement using Magne Gage and Feritscope® techniques identified samples A, B, C, D, E and F with the 2σ values greater than 10% of the mean ferrite content. This statistic indicates insufficient repeatability for this group of samples utilizing either the Magne Gage or Feritscope® techniques. This indicates that this group of samples cannot be used as cast secondary standards. Samples G, H, I, J, K and L exhibited 2σ values less than 10% of the mean ferrite content, indicating acceptable repeatability for use as cast secondary standards.

4.1.2 The Lincoln Electric Company

The Lincoln Electric Company was the second participant in this round-robin. Lincoln Electric characterized the sample set using both the Magne Gage (Serial Number: P-6459) and Feritscope® (Model MP-3). Each gage was calibrated using AWS A4.2, as prescribed in the round-robin protocol. Tables 4 and 5 summarize the Lincoln Electric results of measurement by Magne Gage and Feritscope®.

Analysis of this data set reveals that the samples ranged in ferrite content from approximately 3 FN to 95 FN with minimal disparity between the two techniques in measuring ferrite number. Ferrite measurement using either the Magne Gage or

Table 4. The Lincoln Electric Company Magne Gage Results

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)	Mean FN	Standard Deviation (2 Sigma)	Repeatability $2\sigma \leq 10\% \text{Mean}$ (Yes or No)
A	3.4	3.3	3.2	3.4	3.4	3.3	0.2	Yes
B	11.8	12.6	12.4	12.5	11.3	12.1	1.1	Yes
C	14.1	14.6	15.3	15.0	14.6	14.7	0.9	Yes
D	59.3	63.5	61.4	61.9	61.2	61.5	3.0	Yes
E	62.6	67.8	68.3	66.6	60.2	65.1	7.1	No
F	59.7	59.3	64.7	65.7	65.0	62.9	6.2	Yes
G	71.1	74.7	73.5	70.9	71.1	72.3	3.5	Yes
H	61.4	62.8	62.1	62.1	62.1	62.1	1.0	Yes
I	74.0	70.9	74.5	77.8	73.1	74.1	5.0	Yes
J	76.9	73.5	73.3	77.1	76.4	75.4	3.8	Yes
K	79.7	84.5	80.2	75.2	82.8	80.5	7.1	Yes
L	92.7	91.0	92.7	91.7	94.3	92.5	2.5	Yes

Table 5. The Lincoln Electric Company Feritscope® Results

Sample Code	FN 1	FN 2	FN 3	FN 4	FN 5	FN 6	FN 7	FN 8	FN 9	FN 10	Mean FN	Standard Deviation (2 Sigma)	Repeatability $2\sigma \leq 10\% \text{Mean}$ (Yes or No)
A	2.8	2.8	2.9	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	0.1	Yes
B	10.0	8.2	7.8	9.3	8.9	8.6	10.0	11.0	9.3	8.9	9.2	1.9	No
C	12.0	11.0	12.0	11.0	12.0	12.0	13.0	12.0	14.0	12.0	12.1	1.8	No
D	60.0	59.0	59.0	59.0	48.0	53.0	60.0	57.0	57.0	48.0	56.0	9.4	No
E	49.0	51.0	63.0	47.0	59.0	46.0	46.0	52.0	47.0	59.0	51.9	12.5	No
F	50.0	60.0	60.0	59.0	65.0	48.0	48.0	61.0	64.0	49.0	56.4	13.7	No
G	66.0	66.0	64.0	63.0	68.0	65.0	66.0	72.0	66.0	70.0	66.6	5.4	Yes
H	61.0	65.0	64.0	64.0	63.0	63.0	65.0	63.0	64.0	63.0	63.5	2.4	Yes
I	71.0	69.0	72.0	76.0	72.0	73.0	75.0	74.0	65.0	74.0	72.1	6.4	Yes
J	74.0	74.0	74.0	74.0	73.0	73.0	73.0	75.0	75.0	73.0	73.8	1.6	Yes
K	75.0	74.0	76.0	76.0	76.0	76.0	77.0	76.0	77.0	75.0	75.8	1.8	Yes
L	87.0	86.0	86.0	87.0	85.0	85.0	84.0	82.0	86.0	87.0	85.5	3.2	Yes

Feritscope® revealed that samples B, C, D, E and F exhibited the 2σ values greater than 10% of the mean ferrite content, indicating insufficient repeatability for use as a cast secondary standard. Samples A, G, H, I, J, K and L exhibited acceptable repeatability for use as cast secondary standards.

4.1.3 The ESAB Company

The ESAB Company was the third participant in this round-robin. ESAB characterized the sample set using the Magne Gage (Serial Number: 18032-106). ESAB does not currently utilize the Feritscope®. Therefore, this data was unavailable. The Magne Gage was calibrated using AWS A4.2, as prescribed in the round-robin protocol. Table 6 summarizes the results of investigation by Magne Gage.

Preliminary analysis of this data set reveals that the samples ranged in ferrite content from approximately 3 FN to 87 FN. Ferrite characterization of the sample set at ESAB was consistent with the scope of the round-robin. Magne Gage ferrite measurement identified samples A and E with a 2σ value greater than 10% of the mean ferrite content, indicating insufficient repeatability for use as a cast secondary standard. Samples B, C, D, F, G, H, I, J, K and L exhibited 2σ value less than 10% of the mean ferrite content, indicating acceptable repeatability for use as a cast secondary standards.

Table 6. The ESAB Company Magne Gage Results

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)	Mean FN	Standard Deviation (2 Sigma)	Repeatability $2\sigma \leq 10\% \text{Mean}$ (Yes or No)
A	3.2	3.2	3.6	3.2	3.2	3.3	0.4	No
B	11.7	11.7	13.0	12.5	12.1	12.2	1.1	Yes
C	15.0	15.0	15.0	14.1	15.0	14.8	0.8	Yes
D	58.1	58.8	55.4	57.0	58.1	57.5	2.7	Yes
E	47.2	52.2	55.2	63.6	63.6	56.4	14.4	No
F	60.2	60.9	57.0	57.7	60.4	59.2	3.5	Yes
G	63.7	63.5	65.8	64.1	61.1	63.6	3.4	Yes
H	56.6	55.3	55.5	54.0	56.8	55.6	2.3	Yes
I	66.0	69.6	72.5	72.7	69.2	70.0	5.5	Yes
J	70.5	72.5	70.5	71.7	68.6	70.8	3.0	Yes
K	75.9	76.5	74.2	78.4	76.3	76.3	3.0	Yes
L	89.4	88.6	85.1	84.6	87.6	87.1	4.2	Yes

4.1.4 The Hobart Brothers Company

The Hobart Brothers Company was the fourth participant in this round-robin. The Hobart Brothers Company characterized the sample set using both the Magne Gage (Serial Number: P-6712) and Feritscope® (Model MP-30). Each gage was calibrated using AWS A4.2, as prescribed in the round-robin protocol. Tables 7 and 8 summarize the results of inspection by Magne Gage and Feritscope®. Sample L was not able to be characterized using a Magne Gage, as its ferrite content was beyond the limits of calibration. All other samples were fully characterized.

Analysis of this data set reveals that the samples ranged in ferrite content from approximately 3 FN to 95 FN with minimal disparity (<10% of the mean) between techniques in ferrite number. Ferrite measurement revealed that samples A, B, C and E had 2σ values greater than 10% of the mean ferrite content. This indicates insufficient repeatability for samples A, B, C, and E, when characterized using either a Magne Gage or Feritscope®, for use as a cast secondary standard. The remaining samples exhibited suitable repeatability for use as cast secondary standards.

4.1.5 NIST

The National Institute of Standardization and Testing (NIST) was the fifth participant for this round-robin. NIST characterized the sample set using the Magne Gage (Serial Number: 3814). Currently, NIST does not utilize the Feritscope®; therefore, this data was unavailable. The Magne Gage was calibrated using AWS A4.2,

Table 7. The Hobart Brothers Company Magne Gage Results

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)	Mean FN	Standard Deviation (2 Sigma)	Repeatability $2\sigma \leq 10\% \text{Mean}$ (Yes or No)
A	3.3	3.5	3.3	3.1	3.1	3.3	0.3	Yes
B	11.3	12.6	11.9	10.6	11.5	11.6	1.5	No
C	14.4	15.0	14.4	14.4	14.1	14.5	0.7	Yes
D	54.4	54.3	57.7	52.4	56.5	55.1	4.1	Yes
E	54.0	53.5	53.0	61.0	57.0	55.7	6.7	No
F	61.3	61.5	61.3	61.5	61.3	61.4	0.2	Yes
G	65.0	63.7	63.5	63.5	63.5	63.8	1.3	Yes
H	59.0	59.0	57.3	56.5	58.6	58.1	2.3	Yes
I	67.0	66.5	66.7	67.0	67.5	66.9	0.8	Yes
J	68.8	68.6	71.5	68.6	71.3	69.8	3.0	Yes
K	71.3	75.5	74.3	75.0	76.8	74.6	4.1	Yes
L	NT	NT	NT	NT	NT	NT	NT	NT

NT = Not Tested

Table 8. The Hobart Brothers Company Feritscope® Results

Sample Code	FN 1	FN 2	FN 3	FN 4	FN 5	FN 6	FN 7	FN 8	FN 9	FN 10	Mean FN	Standard Deviation (2 Sigma)	Repeatability $2\sigma \leq 10\% \text{Mean}$ (Yes or No)
A	3.0	2.7	2.7	2.9	3.1	3.0	3.3	3.0	2.9	2.7	2.9	0.4	No
B	9.9	9.0	8.7	11.6	11.5	10.9	9.9	11.5	10.8	11.2	10.5	2.1	No
C	12.6	13.9	14.2	9.2	11.6	12.2	12.0	12.1	12.5	12.8	12.3	2.7	No
D	56.5	53.0	54.1	54.3	57.7	56.7	57.0	55.6	53.1	53.4	55.1	3.5	Yes
E	56.8	55.2	56.8	51.5	58.8	52.8	51.4	52.9	51.9	55.3	54.3	5.2	Yes
F	54.1	56.2	55.6	59.4	58.8	59.2	59.2	55.3	58.4	55.2	57.1	4.1	Yes
G	68.9	72.5	70.5	66.1	68.7	71.5	71.3	66.8	64.3	72.6	69.3	5.7	Yes
H	60.0	55.8	62.3	65.0	58.5	62.4	64.8	61.9	63.8	62.2	61.7	5.7	Yes
I	73.2	76.5	73.6	81.5	82.1	71.0	75.1	75.2	75.4	74.1	75.8	7.0	Yes
J	74.9	72.3	78.2	78.7	74.8	73.2	71.2	78.7	74.8	77.1	75.4	5.4	Yes
K	74.2	75.7	80.6	84.8	77.7	76.9	80.9	76.3	83.9	79.7	79.1	7.0	Yes
L	97.0	92.7	95.4	95.8	92.5	97.2	99.2	96.7	95.8	97.1	95.9	4.1	Yes

as prescribed in the round-robin protocol. Table 9 summarizes the Magne Gage results. Analysis of this data set reveals that the samples ranged in ferrite content from approximately 3 FN to 90. NIST's characterization of the sample set was consistent with the scope of the round-robin. Magne Gage measurements revealed that samples B and E exhibited a 2σ value greater than 10% of the mean round-robin sample ferrite content. This indicates insufficient repeatability for use as a Magne Gage cast secondary standard. The remaining samples exhibited 2σ values less than 10% of the mean round-robin sample ferrite content, indicating that the remaining samples are suitable for use as cast secondary standards.

4.1.6 Foster Wheeler Inc.

Foster Wheeler Inc. was the sixth participant for this round-robin. Foster Wheeler characterized the sample set using the Feritscope® (Model MP-3 / 122-13088A). Foster Wheeler does not currently utilize the Magne Gage; therefore, this data was unavailable. The Feritscope® was calibrated using AWS A4.2, as prescribed in the round-robin protocol. Table 10 summarizes the results utilizing the Feritscope®.

Analysis of this data set reveals that the samples ranged in ferrite content from approximately 3 FN to 92. Ferrite measurement at Foster Wheeler was consistent with the scope of the round-robin. Ferrite measurement, using the Feritscope®, revealed that samples A, B, C, D and E exhibited 2σ values greater than 10% of the mean round-robin sample ferrite content. This indicates insufficient repeatability for the above samples when characterized with a Feritscope®.

Table 9. The N.I.S.T. Magne Gage Results

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)	Mean FN	Standard Deviation (2 Sigma)	Repeatability $2\sigma \leq 10\% \text{Mean}$ (Yes or No)
A	3.3	3.5	3.3	3.5	3.5	3.4	0.2	Yes
B	10.6	10.7	12.6	12.1	12.2	11.6	1.8	No
C	14.3	14.8	14.4	14.8	14.9	14.6	0.5	Yes
D	60.7	60.3	60.1	58.6	58.3	59.6	2.2	Yes
E	58.1	66.4	63.5	58.8	61.4	61.6	6.8	No
F	60.9	62.0	60.4	60.3	63.3	61.4	2.5	Yes
G	69.0	67.7	66.9	65.6	66.7	67.2	2.5	Yes
H	58.8	58.8	57.5	58.3	59.6	58.6	1.5	Yes
I	73.5	74.0	71.6	71.4	72.1	72.5	2.3	Yes
J	73.2	75.0	70.7	71.6	72.1	72.5	3.3	Yes
K	76.3	72.7	81.5	79.2	79.2	77.8	6.8	Yes
L	91.2	90.4	88.1	89.4	87.0	89.2	3.4	Yes

Table 10. Foster Wheeler Inc., Feritscope® Results

Sample Code	FN 1	FN 2	FN 3	FN 4	FN 5	FN 6	FN 7	FN 8	FN 9	FN 10	Mean FN	Standard Deviation (2 Sigma)	Repeatability $2\sigma \leq 10\% \text{Mean}$ (Yes or No)
A	3.7	3.6	3.4	3.6	3.8	4.1	3.7	4.0	3.8	3.7	3.7	0.4	No
B	8.4	8.3	12.0	12.0	8.8	8.7	10.0	12.0	7.9	12.0	10.0	3.6	No
C	13.0	11.0	13.0	12.0	12.0	8.2	12.0	14.0	13.0	13.0	12.1	3.2	No
D	60.0	62.0	57.0	64.0	63.0	54.0	60.0	56.0	61.0	57.0	59.4	6.5	No
E	63.0	57.0	62.0	54.0	62.0	63.0	64.0	59.0	59.0	61.0	60.4	6.3	No
F	62.0	65.0	62.0	63.0	65.0	64.0	63.0	64.0	66.0	65.0	63.9	2.7	Yes
G	70.0	70.0	72.0	66.0	74.0	68.0	73.0	68.0	74.0	71.0	70.6	5.4	Yes
H	67.0	66.0	69.0	65.0	62.0	64.0	68.0	64.0	69.0	68.0	66.2	4.8	Yes
I	76.0	74.0	76.0	77.0	78.0	78.0	73.0	75.0	74.0	77.0	75.8	3.5	Yes
J	74.0	78.0	77.0	76.0	74.0	77.0	73.0	74.0	74.0	75.0	75.2	3.4	Yes
K	79.0	78.0	77.0	78.0	79.0	79.0	80.0	79.0	79.0	80.0	78.8	1.8	Yes
L	89.0	92.0	94.0	91.0	92.0	92.0	91.0	95.0	90.0	96.0	92.2	4.4	Yes

4.1.7 Stainless Foundry Inc.

Stainless Foundry Inc. was the seventh participant for this round-robin. Stainless Foundry characterized the sample set using the Feritscope® (Model MP-30 / 078-17838A). Stainless Foundry does not currently utilize the Magne Gage; therefore, this data was unavailable. The Feritscope® was not calibrated using AWS A4.2. Rather, this Feritscope® used the guidelines of AWS A4.2 as a reference but proceeded with a calibration according to the Feritscope® manufacturer's guidelines. This entailed the use of Fischer calibration standards, rather than the secondary standards, required by AWS A4.2. This data is invaluable as it provides insight into ferrite measurement interlaboratory variance among participants who use different calibration procedures. Table 11 summarizes the results of determinations by Feritscope®.

Analysis of this data set reveals that the samples ranged in ferrite content from approximately 3 FN to 104. Stainless Foundry's characterization was consistent with the scope of the round-robin. Ferrite measurement, utilizing the Feritscope®, revealed that samples B, E, F, I and J exhibited 2σ values greater than 10% of the mean round-robin samples ferrite content. This indicates insufficient repeatability for these samples utilizing the Feritscope® technique, calibrated under a manufacturer's procedure. These samples are not adequate for use as Feritscope® cast secondary standards. The remaining samples, A, C, D, G, H, K and L exhibited 2σ values less than 10% of the mean round-robin samples ferrite content, indicating suitable repeatability for use as cast secondary standards.

Table 11. Stainless Foundry Inc., Feritscope® Results

Sample Code	FN 1	FN 2	FN 3	FN 4	FN 5	FN 6	FN 7	FN 8	FN 9	FN 10	Mean FN	Standard Deviation (2 Sigma)	Repeatability $2\sigma \leq 10\% \text{Mean}$ (Yes or No)
A	2.9	3.0	3.0	2.9	3.0	2.9	2.9	2.9	2.9	2.9	2.9	0.1	Yes
B	11.3	11.9	9.4	7.4	10.0	8.7	10.1	7.8	8.6	11.4	9.7	3.1	No
C	12.7	12.7	12.9	12.7	12.0	13.0	13.4	12.9	12.2	13.0	12.8	0.8	Yes
D	56.0	52.6	59.8	54.8	55.7	52.2	53.2	56.1	57.9	51.2	55.0	5.4	Yes
E	58.6	56.5	55.1	50.8	63.4	54.2	51.5	58.4	52.6	64.1	56.5	9.3	No
F	66.1	61.3	60.1	65.5	58.0	58.9	57.6	58.0	62.7	67.9	61.6	7.5	No
G	64.9	65.2	68.6	66.9	69.7	67.3	67.4	67.1	62.7	67.0	66.7	4.0	Yes
H	66.4	62.0	61.2	58.8	59.7	59.8	59.6	62.3	63.7	59.1	61.3	4.8	Yes
I	65.0	78.0	64.7	72.5	79.2	74.0	65.2	70.9	74.0	74.0	71.8	10.5	No
J	69.2	70.7	76.8	75.7	76.7	69.6	65.6	74.7	68.0	77.4	72.4	8.6	No
K	77.3	73.4	77.0	74.2	81.4	79.1	78.9	81.1	81.9	77.0	78.1	5.8	Yes
L	98.1	104.0	110.0	105.0	104.0	103.0	104.0	104.0	103.0	102.0	103.7	5.8	Yes

4.1.8 Fristam Pumps Inc.

Fristam Pumps Inc. was the eighth and final participant for this round-robin. Fristam Pumps characterized the sample set using the Feritscope® (Model MP-30 / 058-17469A). Fristam Pumps does not currently utilize the Magne Gage; therefore, such data was unavailable. The Feritscope® was not calibrated using AWS A4.2. Rather, this Feritscope® used the guidelines of AWS A4.2 as a reference but proceeded with a calibration according to the Feritscope® manufacturer's guidelines. This entailed the use of Fischer calibration standards, rather than the secondary standards, required by AWS A4.2. This data is also invaluable, as it provides insight into ferrite measurement interlaboratory variance among participants who use different calibration procedures. Table 12 summarizes the results of inspection by Feritscope®.

Analysis of this data set reveals that the samples ranged in ferrite content from approximately 3 FN to 102. Ferrite characterization of the sample set, at Fristam Pumps, was consistent with the scope of the round-robin. Ferrite measurement revealed that samples B, C, D, E, F, G, H, I, K and L exhibited 2σ values greater than 10% of the mean round-robin ferrite content. This indicates insufficient repeatability for use as cast secondary standards, when calibrated under a manufacturer's procedure. Samples A and J exhibited 2σ values less than 10% of the mean round-robin ferrite content, indicating suitable repeatability for use as cast secondary standards.

Table 12. Fristam Pumps Inc., Feritscope® Results

Sample Code	FN 1	FN 2	FN 3	FN 4	FN 5	FN 6	FN 7	FN 8	FN 9	FN 10	Mean FN	Standard Deviation (2 Sigma)	Repeatability $2\sigma \leq 10\% \text{Mean}$ (Yes or No)
A	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.1	2.9	2.9	3.0	0.1	Yes
B	8.7	8.4	7.9	9.7	10.0	11.0	7.1	10.3	9.4	9.9	9.2	2.4	No
C	12.8	13.5	12.2	14.0	13.2	13.3	14.1	12.1	12.5	12.2	13.0	1.5	No
D	59.0	62	52.9	52.9	61.3	51.8	63.2	60.4	50.2	50.8	56.5	10.3	No
E	55.9	50.2	61.4	59.3	55.9	54.1	48.7	49.7	57.6	58.6	55.1	8.7	No
F	61.3	60.7	50.9	51.5	50.8	57.8	53.0	58.2	58.8	62.4	56.5	9.1	No
G	62.1	73.1	73.1	64.3	68.1	66.0	70.8	72.5	72.3	72.9	69.5	8.2	No
H	63.4	61.9	57.3	57.0	69.9	64.6	63.4	63.5	64.7	61.6	62.7	7.4	No
I	77.1	74.5	76.1	68.4	76.9	69.0	72.8	78.4	78.6	68.6	74.0	8.2	No
J	74.3	73.2	71.3	74.1	68.8	74.9	78.1	71.8	74.1	74.5	73.5	5.0	Yes
K	78.4	73.3	81.9	84.5	86.7	82.1	82.1	70.3	78.0	79.8	79.7	9.9	No
L	98.5	93.9	111.0	106.0	101.0	102.0	99.1	112.0	103.0	97.5	102.4	11.6	No

4.2 Observations on Participant Data

The following observations are based upon the data returned by each of the above participants in the round-robin study:

- All participants identified sample E as unsuitable for use as a cast secondary standard, regardless of calibration method.
- In general, participants using a manufacturer's calibration identified more noncompliant samples than participants utilizing an AWS A4.2 calibration.
- For those participants who calibrated to AWS A4.2, 5 of 6 participants identified sample B as unsuitable for use as a cast secondary standard. Four of six participants identified samples A and C as unsuitable and three of six identified sample D as unsuitable for use as a cast secondary standard. Samples A, B, C, and D are statically cast austenitic and duplex alloys.

Two of six participants identified sample F (centrifugally cast duplex) as non-compliant. However, this behavior is not considered conclusive. Note that the two participants who identified this sample utilized the same Feritscope secondary calibration standards. Participants utilizing other AWS A4.2 sanctioned secondary standards did not identify sample F as unsuitable. All other centrifugally cast duplex samples (H and J) demonstrated suitable repeatability for use as a cast secondary standard. Thus, it can be concluded that, in general, centrifugally cast materials exhibit improved repeatability over the statically cast materials.

4.3 Ferrite Measurement by Point Counting

As previously stated, the round-robin test samples were metallographically characterized prior to the initiation of the measurements. The first aspect of characterization was a systematic point count of ferrite content utilizing the techniques outlined in ASTM specification E562. This specification is the "Practice for Determining Volume Fraction by Systematic Manual Point Count." Prior to analysis, each of the twelve round-robin samples was metallographically polished to a uniform 0.05 μ surface finish. The samples were then electro-etched in oxalic acid (10V, 0.05A for 20-60 seconds) and viewed under an optical light microscope. Five locations, within a prescribed measurement region, were selected and photographed to obtain 200x micrographs. These micrographs were then utilized to perform the manual point count (grid method).

Ten point count determinations were employed for each micrograph location. In total, 600 individual determinations (50 determinations per sample) were employed to characterize the sample set. The average ferrite content and 2 σ standard deviation were calculated for each sample and are summarized in Table 13. Photomicrographs representative of the round-robin samples (A-L), are provided in Figures 1-12.

The results of the point counting analysis indicate that the ferrite content of the sample set ranges from 3.4 to 60.1 volume percent ferrite. The average 2 σ

Table 13. Ferrite Content (Volume %) of the Round-Robin Sample Set by Systematic Manual Point Count.

Sample Code	Sample Identification	Mean Ferrite Content (Vol %)	2 σ
A	CF-8	3.4	0.9
B	CF-3MHF	12.5	1.9
C	CF-8M	14.1	1.5
D	ASTM A890-4A	35.1	3.0
E	ASTM A890-4A	37.7	2.1
F	ASTM A890-4A (CC)	35.7	2.7
G	ASTM A890-5A	48.0	3.2
H	ASTM A890-5A (CC)	40.7	3.0
I	ASTM A890-5A	52.2	3.1
J	CD7MCuN (CC)	52.9	2.7
K	CD7MCuN	57.4	2.4
L	CD7MCuN	60.1	2.4

“CC” indicates centrifugally cast material. All other alloys are statically cast.

Figure 1. Round-Robin Sample A (CF8 – 3.4% Ferrite). (a) 50x and (b) 200x

Etchant: Oxalic Acid

(a)

(b)

Figure 2. Round-Robin Sample B (CF3M – 12.5% Ferrite). (a) 50x and (b) 200x

Etchant: Oxalic Acid

(a)

(b)

Figure 3. Round-Robin Sample C (CF8M – 14.1% Ferrite). (a) 50x and (b) 200x

Etchant: Oxalic Acid

(a)

(b)

Figure 4. Round-Robin Sample D (ASTM A890-4A – 35.1% Ferrite). (a) 50x and (b) 200x; Etchant: Oxalic Acid

(a)

(b)

Figure 5. Round-Robin Sample E (ASTM A890-4A – 37.7% Ferrite). (a) 50x and (b) 200x; Etchant: Oxalic Acid

(a)

(b)

Figure 6. Round-Robin Sample F (ASTM A890-4A-CC – 35.7% Ferrite). (a)

50x and (b) 200x; Etchant: Oxalic Acid

(a)

(b)

Figure 7. Round-Robin Sample G (ASTM A890-5A – 48.0% Ferrite). (a) 50x and (b) 200x; Etchant: Oxalic Acid

(a)

(b)

Figure 8. Round-Robin Sample H (ASTM A890-5A-CC – 40.7% Ferrite). (a)

50x and (b) 200x; Etchant: Oxalic Acid

(a)

(b)

Figure 9. Round-Robin Sample I (ASTM A890-5A – 52.2% Ferrite). (a) 50x and (b) 200x; Etchant: Oxalic Acid

(a)

(b)

Figure 10. Round-Robin Sample J (CD7MCuN-CC – 52.9% Ferrite). (a) 50x and (b) 200x; Etchant: Oxalic Acid

(a)

(b)

Figure 11. Round-Robin Sample K (CD7MCuN – 57.4% Ferrite). (a) 50x and (b) 200x; Etchant: Oxalic Acid

(a)

(b)

Figure 12. Round-Robin Sample L (CD7MCuN – 60.1% Ferrite). (a) 50x and (b) 200x; Etchant: Oxalic Acid

value, for the entire sample set, was 2.4, ranging from 0.9 to 3.2. The samples were selected from a series of austenitic and duplex stainless steel castings.

4.4 Ferrite Measurement by Magne Gage

Ferrite measurement, using the Magne Gage, was reported for the five round-robin participants who utilized this technique. Table 14 is a summary of round-robin ferrite content utilizing the Magne Gage, as determined by the five participants.

Analyzing the entire data set, encompassing all five participants, the round-robin samples are characterized by a mean FN value and interlaboratory reproducibility. Summarizing the Magne Gage trials, Table 14 reveals that the average ferrite content of the round-robin samples ranges from 3.3 to 91 FN.

Ferrite measurement using the Magne Gage technique, properly calibrated to AWS A4.2, identified samples C, D and E with 2σ values greater than 14% of the mean. The significance of this correlation is as follows:

- Utilizing previous round-robin studies as a reference, a 2σ variance greater than 14% of the mean indicates that the corresponding round-robin sample does not exhibit sufficient interlaboratory reproducibility, for use as a Magne Gage cast secondary calibration standard.

All other 2σ values were less than 13% for this data set, indicating sufficient interlaboratory reproducibility for samples A, B, F, G, H, I, J, K and L.

Table 14. Summary of Round-Robin Ferrite Content utilizing the Magne Gage, as Determined by Participants.

Sample Code	University of Tennessee (FN)	Lincoln Electric (FN)	ESAB (FN)	Hobart Brothers Co. (FN)	NIST (FN)	Round-Robin Mean FN	Standard Deviation (2σ)	Reproducibility
A	3.2	3.3	3.3	3.3	3.4	3.3	0.2	6%
B	11.0	12.1	12.2	11.6	11.6	11.7	1.0	9%
C	12.4	14.7	14.8	14.5	14.6	14.2	2.1	15%
D	68.6	61.5	57.5	55.1	59.6	60.4	10.3	17%
E	65.5	65.1	56.4	55.7	61.6	60.9	9.3	15%
F	64.8	62.9	59.2	61.4	61.4	61.9	4.1	7%
G	72.3	72.3	63.6	63.8	67.2	67.8	8.6	13%
H	62.4	62.1	55.6	58.1	58.6	59.4	5.7	10%
I	73.5	74.1	70.0	66.9	72.5	71.4	5.9	8%
J	76.2	75.4	70.8	69.8	72.5	72.9	5.6	8%
K	81.9	80.5	76.3	74.6	77.8	78.2	6.0	8%
L	95.3	92.5	87.1	N/A	89.2	91.0	7.2	8%

Reproducibility (%) = $2\sigma/\text{Mean FN} * 100$ Reproducibility less than 14% is typical of previous WRC round-robins.

4.5 Ferrite Measurement by Feritscope®

Ferrite measurement, using the Feritscope®, was reported by six round-robin participants. However, prior to summarizing these results, it is necessary to recount that of the six participants who returned Feritscope® data, four calibrated according to AWS A4.2 while the remaining two participants calibrated their Feritscopes® using the manufacturer's calibration. Table 15 documents round-robin ferrite content (FN) utilizing the Feritscope®, as determined by participants who calibrated according to AWS A4.2

Summarizing these AWS A4.2 calibrated Feritscope® trials, Table 15 reveals that the mean ferrite content of the round-robin samples ranges from 3.1 to 91.8 FN. Ferrite measurement using an AWS A4.2 calibrated Feritscope® reveals that sample B exhibited a 2σ value greater than 14% of the mean. As previously stated, this value indicates that sample B does not exhibit suitable interlaboratory reproducibility for use as a cast secondary standard. All 2σ values, for the remaining samples, were less than 11%, indicating sufficient interlaboratory reproducibility.

Summarizing Feritscope® trials utilizing a modified AWS A4.2 calibration, Table 16 reveals that the average ferrite content of the round-robin samples ranges from 3.0 to 103.1 FN. Ferrite measurement, using this modified calibration procedure, demonstrated that sample A exhibited a 2σ values greater than 14% of the mean. The remaining samples exhibited 2σ values less than 14% for this data set, indicating sufficient interlaboratory reproducibility.

Table 15. Summary of Round-Robin Ferrite Content utilizing the Feritscope®, as Determined by Participants
who Calibrated According to AWS A4.2.

Sample Code	University of Tennessee	Lincoln Electric	Hobart Brothers Co.	Foster Wheeler	Mean FN	Standard Deviation (2σ)	Reproducibility
A	3.0	2.8	2.9	3.7	3.1	0.2	6%
B	8.6	9.2	10.5	10.0	9.6	1.9	20%
C	12.2	12.1	12.3	12.1	12.2	0.2	2%
D	53.7	56.0	55.1	59.4	56.1	2.3	4%
E	49.6	51.9	54.3	60.4	54.1	4.7	9%
F	59.6	56.4	57.1	63.9	59.3	3.3	6%
G	67.7	66.6	69.3	70.6	68.6	2.7	4%
H	62.8	63.5	61.7	66.2	63.5	1.8	3%
I	71.3	72.1	75.8	75.8	73.7	4.8	7%
J	73.2	73.8	75.4	75.2	74.4	2.3	3%
K	75.5	75.8	79.1	78.8	77.3	4.0	5%
L	93.4	85.5	95.9	92.2	91.8	10.9	11%

Reproducibility (%) = $2\sigma/\text{Mean FN} \times 100$ Reproducibility less than 14% is typical of previous WRC round-robins.

Table 16. Summary of Round-Robin Ferrite Content utilizing the Feritscope®, as Determined by Participants
who Calibrated According to a Modified AWS A4.2 procedure.

Sample Code	Stainless Foundry	Fristam Pumps	Mean FN	Standard Deviation (2σ)	Reproducibility
A	2.9	3.0	3.0	0.9	29%
B	9.7	9.2	9.5	0.8	8%
C	12.8	13.0	12.9	0.9	7%
D	55.0	56.5	55.7	4.5	8%
E	56.5	55.1	55.8	5.5	10%
F	61.6	56.5	59.1	7.5	13%
G	66.7	69.5	68.1	4.0	6%
H	61.3	62.7	62.0	5.1	8%
I	71.8	74.0	72.9	4.1	6%
J	72.4	73.5	73.0	2.8	4%
K	78.1	79.7	78.9	1.6	2%
L	103.7	102.4	103.1	12.6	14%

Reproducibility (%) = $2\sigma/\text{Mean FN} * 100$ A variance less than 14% is typical of previous WRC round-robins.

Examining Feritscope® data and discriminating between calibration procedures, the following observations are evident:

- In general, the reproducibility associated with calibration to AWS A4.2 was approximately equal to the reproducibility associated with the modified calibration. This indicates that both calibrations provide sufficient reproducibility for the assessment of ferrite content using a Feritscope® and Magne Gage.
- Utilization of a modified AWS A4.2 calibration procedure will not promote sufficient repeatability when characterizing round-robin samples. Examining the results of participants who calibrated to AWS A4.2 and comparing this with participants who used a manufacturer's calibration, it was found that participants using a manufacturer's calibration reported a significantly larger number of non-compliant samples ($2\sigma > 10\%$ of the mean ferrite content).

An example of this is clearly illustrated by the response of Fristam Pumps, where nearly the entire round – robin sample set was outside of the 2σ window, for use as cast secondary standards based upon repeatability measurements. This was not the case for those participants using an instrument calibrated to the industry accepted standard, AWS A4.2. Additionally, ferrite measurement on sample L indicated that participants utilizing a modified calibration were not able to establish accurate ferrite measurement for all $FN > 90$. This is due to the fact that a manufacturer's calibration or modified AWS A4.2 calibration procedure, can not calibrate the Feritscope® for use over the entire FN range. (calibration

is only valid over the FN range of the standards provided)

4.6 FN vs. Percent Ferrite

The literature review indicated that engineers in academia and industry have struggled to correlate ferrite number (FN) to a volumetric estimation of ferrite content (percent ferrite). The completion of the round-robin allows a correlation to be drawn between the FN evaluations, obtained from Magne Gage and Feritscope® surveys, and the volumetric determinations obtained from manual point counting. Utilizing the data sets provided in Tables 15 and 16, a correlation can be drawn to relate ferrite number to percent ferrite when the appropriate instrumentation is calibrated to AWS A4.2.

Figure 13 illustrates the correlation between FN and volume percent, as determined by the round-robin test data. Only data which was obtained from a proper AWS A4.2 calibration was utilized to compose this chart. Note that the chart contains data obtained from both the Magne Gage and Feritscope®. The results show that the correlation, between FN and volume percent ferrite for round robin samples A, B and C, is 0.9:1. The correlation between FN and volume percent ferrite, for round-robin samples D-L, is 1.5:1. This result clearly shows a disparity between the correlation factors over the full FN scale. It is important to note that the correlation between ferrite number and volume percent ferrite is not uniform over the full FN range and the proper correlation factor should be chosen when transposing ferrite number and volume percent ferrite.

Figure 13. Ferrite Number vs. Ferrite Content, as determined by AWS A4.2 Calibration of Magne Gage and Feritscope® Instruments. (a) Slope = 0.9; (b) Slope = 1.5

4.7 Round-Robin – Conclusions

The primary goals of the round-robin study were defined as follows:--

- Assess the repeatability and reproducibility of ferrite measurement data, between laboratories, using Magne Gage and Feritscope® techniques.
- Determine the applicability of manufacturing cast secondary standards from static and centrifugal castings.
- Determine a more defined correlation between measurement techniques, including ferrite measurement by manual point counting, Magne Gage and Feritscope®.

The following conclusions can be drawn:

1. Round Robin participant measurements of samples A, B, C, D, and E repeatedly exhibited a 2σ value which indicate probable insufficient repeatability when used with a Magne Gage and/or a Feritscope®. Samples A, B, C, D, and E are statically cast austenitic and duplex alloys whose 2σ repeatability is greater than 10% of the mean FN of the respective round-robin sample. Data obtained from all five participants, who calibrated to AWS A4.2 and used a suitable application method, confirmed this conclusion.
2. Samples H and J exhibited a 2σ repeatability less than 10% of their mean FN values, as determined by all participants using proper calibration and application

techniques. Sample F was identified as unsuitable for utilization as a cast secondary standard. However, this behavior could not be conclusively confirmed. In general, the improved repeatability of the centrifugal castings was independent of ferrite measurement technique. Improved repeatability is attributed to the centrifugal casting process, which generally results in a more uniform ferrite/austenite phase morphology. This microstructure is a key in producing a cast secondary standard with little ferrite content variation. Thus, it is to be concluded that cast secondary standards should be manufactured using the centrifugal casting process.

3. Instrument calibration, utilizing AWS A4.2, demonstrated improved repeatability. It is recommended that AWS A4.2 be utilized for the calibration and operation of Magne Gage and Feritscope® instruments to maintain optimum repeatability. Interlaboratory reproducibility was unaffected by calibration procedure.
4. A comparison of point count, Magne Gage and Feritscope® techniques revealed that a suitable correlation could be drawn between ferrite number (FN) and volume percent. For FN values ranging from 0-15, this correlation factor is 0.9:1 (FN:Volume Percent). For FN values ranging from 55-90 FN, this correlation factor is 1.5:1 (FN:Volume Percent).

4.8 Depth Profile Characterization

Producers and users of cast stainless steels require the ability to accurately assess the ferrite content of a casting. Ideally, a non-destructive test, designed to assess ferrite content, is desired to characterize a solution annealed and finished casting. Differences in cooling rates between the surface and center of a casting can affect its ferrite content as well as the potential for mold-liquid metal interaction. The goal of the depth profile study was to determine at what depth below a cast surface, a uniform level of ferrite representative ferrite content representative of the casting occurs.

Three depth profile blocks were manufactured. One each from two different heats of ASTM A890-4A and one from a single heat of ASTM A890-6A. The 1" cubic blocks were removed perpendicular to the cast surface. Initial ferrite measurement included a profile of each block, which entailed utilizing the Feritscope® to characterize the ferrite content of the cube on each of four mutually orthogonal sides. Each side evaluated was perpendicular to the cast surface. After establishing the ferrite content as a function of depth from the cast surface, material was removed, using a ceramic grinding disk, from the cast surface of the block, proceeding perpendicularly into the casting, until a uniform ferrite content was established. The ferrite content was determined, using a Feritscope®, at five separate locations on the measurement face (parallel to the cast surface), as material was removed from the cast surface. A uniform ferrite level was considered attained when successive ferrite measurements remained relatively unchanged (± 5 FN) with increasing depth below the cast surface.

4.8.1 ASTM A890-4A – Heat 1

ASTM A890-4A is a common duplex grade alloy which has been employed by the United States Navy for marine service. Its widespread acceptance in the European community and increasing use in the United States makes it an ideal candidate for extensive characterization.

As previously described, a cube of ASTM A890 (Heat 1) was extracted perpendicular to the cast surface. As material was successively removed from the cast surface and the ferrite content recorded, a relationship was defined between ferrite content and the depth below the cast surface. Figure 14 illustrates this relationship for ASTM A890-4A (Heat 1).

A ferrite survey on the cast surface revealed that the surface ferrite content equals 40 FN. However, after 0.025” of material removal, the depth profile sample reaches a uniform ferrite content of 62 FN. Figure 14 illustrates that removal of more than 1/8” of material is more than adequate to establish a uniform ferrite content for the bulk of the casting.

4.8.2 ASTM A890-4A – Heat 2

In order to assess any variation between heats, a second heat of ASTM A890-4A was selected for similar analysis. Using the same technique, ASTM A890-4A (Heat 2) was characterized to establish the relationship between ferrite content and depth below a

Ferrite Number vs. Depth From Cast Surface ASTM A890-4A - Heat 1

Figure 14. Ferrite Number vs. Depth from Cast Surface for ASTM A890-4A – Heat 1.

cast surface. Figure 15 illustrates this relationship for ASTM A890-4A (Heat 2). A ferrite survey on the cast surface revealed a surface ferrite content of 22 FN. However, after 0.050" of material removal, the depth profile sample reaches a uniform ferrite content of 48 FN. Thus, removal of more than 1/8" of material is sufficient to establish a uniform ferrite content for the bulk of the casting with a reasonable degree of certainty.

4.8.3 ASTM A890-6A

To compare depth profile data between alloys, a heat of ASTM A890-6A was selected for analysis. Using the same technique, ASTM A890-6A was characterized to further establish the relationship between ferrite content and depth below a cast surface.

Figure 16 illustrates this same relationship for ASTM A890-6A. A ferrite survey on the cast surface revealed a surface ferrite content of 42 FN. However, with only 0.025" of material removed, the ferrite content reaches a uniform ferrite level of 45 FN. Figure 16 further illustrates that removal of 1/8" of material is more than sufficient to establish a uniform ferrite content for the bulk of the casting with a reasonable degree of certainty.

4.8.4 Probe Interaction Volume

An inherent factor which affects the accuracy of ferrite measurement, using a Feritscope®, is the measurement probe interaction volume. Recall from the literature

Ferrite Number vs. Depth From Cast Surface ASTM A890-4A (Heat 2)

Figure 15. Ferrite Number vs. Depth from Cast Surface for ASTM A890-4A – Heat 2.

Ferrite Number vs. Depth From Cast Surface ASTM A890-6A

Figure 16. Ferrite Number vs. Depth from Cast Surface for ASTM A890-6A.

review that the measurement probe induces a magnetic field in the substrate and compares the magnetic response to the calibration set stored in memory. It is logical to assume that an interruption in the induced magnetic field would adversely affect the accuracy of ferrite measurement. Initial work on the depth profile study required that edge profiles be conducted to estimate the ferrite content of the block. The initial characterization served as a guideline for material removal, establishing changes in ferrite content with increasing depth below a cast surface.

An increase in ferrite content, as a function of depth below the cast surface, was noted for each depth profile block, as demonstrated in Figures 14-16. However, since ferrite measurement proceeded from the edge, adjacent to the cast surface, towards the interior of the casting, it was proposed by the UTK Materials Joining Research Group that the magnetic field induced by the Feritscope® was influenced by the proximity of the measurement probe to the edge of the block. This suggestion was based upon preliminary work with the Feritscope® prior to the institution of this program.

To fully characterize this phenomenon, a standard sample, consisting of a 1" cube of statically cast ASTM A890-6A, was prepared for analysis. Ferrite surveys showed that the ferrite content remained virtually unchanged as function of position within the block. The block was then placed on a calibrated measurement stage and the Feritscope® probe was centered on the edge of the block. Precisely one half of the probe was positioned within the sample. Ferrite measurement then proceeded in 0.005" increments until a uniform ferrite content was achieved. Uniform ferrite content is defined as three or more successive ferrite determinations whose FN values are relatively unchanged (± 5 FN). The results are illustrated in Figure 17.

Ferrite Content vs. Distance from Edge ASTM A890-6A

Figure 17. Ferrite Content vs. Distance from Edge for ASTM A890-6A.

As depicted in Figure 17, the ferrite content at the edge of the sample is approximately 24 FN, however, after incrementing to 0.025", the ferrite content reaches a uniform value of 40 FN. This suggests that measurements taken at least 0.025" below a surface discontinuity or edge will reveal an accurate ferrite content. Note that 0.025" is also the radius of the Feritscope® probe. This indicates that the radius of the full interaction volume can be approximated by the probe diameter.

4.8.5 Depth Profile Characterization – Conclusions

Based upon the data obtained for the depth profile characterization study, the following conclusions can be derived:

1. Removal of 1/8" of material from the cast surface will result in a ferrite content most characteristic of the bulk of the finished casting. Trials using two alloy systems and two heats of one alloy system confirmed this behavior.
2. Ferrite measurements, utilizing a Feritscope®, taken directly on a cast surface are not indicative of the true ferrite content of the casting. Producers and users of cast products are encouraged to measure ferrite content at a subsurface location, preferably at a depth greater than 1/8" below the cast surface. Removal of 1/8" of material eliminates changes in ferrite content due to cooling rate/microstructure/mold interaction immediately on or below the cast surface.
3. The interaction volume of the Feritscope® probe is defined as 0.050", which is the diameter of the probe. Ferrite measurement performed, with an uninterrupted interaction volume, will promote accurate ferrite measurement. Thus, care should

be taken to ensure a full interaction volume, free of edge effects and surface finish discontinuities, as previously discussed.

4.9.6 Effect of Surface Roughness on Ferrite Measurement

It has been indicated that surface finish can affect the accurate ferrite measurement. Recognizing that producers and users of stainless steel castings wish to characterize the ferrite content of the cast product in the solution annealed and machined forms, a study was implemented to assess ferrite content as a function of surface finish.

Five standard surface finish test blocks, of uniform ferrite content, were prepared from a “CD7MCuN” duplex stainless steel centrifugal casting. CD7MCuN was chosen due to its uniform ferrite content as a function of depth. Each 1”x 3/4”x 3/4” block was designed such that the measurement face was radially oriented in the centrifugal casting.. The measurement face was initially prepared to a uniform surface finish of 0.05μ utilizing metallographic polishing techniques.

Five specific locations were examined on each block using optical light microscopy. Each location was then documented photographically. Next, each specific region was located on a Feritscope® measurement stage and ferrite measurement was performed using a Feritscope®. After metallographic and Feritscope® characterization, a specific surface finish was imparted. The blocks were then placed on the measurement stage and ferrite measurement was performed at the identical locations to directly correlate any change in ferrite content. The results of this work effort are presented in the following sections.

4.9.1 250 Microinch Surface Finish

A 250 microinch milled surface finish was imparted on Surface Finish Sample 1. Total material removed by milling was 0.025". Prior ferrite measurement on the 0.05 μ as-polished surface, using a Feritscope®, revealed a mean ferrite content of 70.1 FN with a 2σ standard deviation of 0.5 FN. After the 250 microinch milled surface finish was imparted, the average ferrite content recorded was 68.0 FN with a 2σ standard deviation of 0.2 FN. The disparity between measured ferrite content is not significant in this case. It is apparent that imparting a 250 microinch finish did not significantly influence the measurement of ferrite content in this sample, although, the mean milled surface finish FN falls outside of the 2σ variance established for the metallographically polished surface. A photograph of Sample 1 is shown in Figure 18.

4.9.2 64 Microinch Surface Finish

A 64 microinch milled surface finish was imparted on Surface Finish Sample 2. Total material removal by milling was 0.025". Ferrite measurement on the 0.05 μ as-polished surface, using a Feritscope®, revealed an average ferrite content of 76.0 FN with a 2σ standard deviation of 0.0 FN. After the 64 microinch milled surface finish was imparted, the mean ferrite content recorded was 68.0 FN with an average 2σ standard deviation of 0.2 FN. It is apparent that imparting a 64 microinch finish significantly

Figure 18. Surface Finish Sample 1 – 250 Microinch Finish

Magnification = 4.5x

influenced the measurement of ferrite content in this sample. A 10 FN reduction in ferrite content was noted after the 64 microinch surface finish was imparted. This reduction is well below the 2σ variance established for the metallographically polished surface finish, indicating significant surface finish effects due to milling. Additionally, regardless of the surface finish, the 2σ value is small when compared to the mean ferrite content. This indicates suitable grouping of the experimental data about the mean ferrite content. A photograph of Sample 2 is shown in Figure 19.

4.9.3 16 Microinch Surface Finish

A 16 microinch milled/ground surface finish was imparted on Surface Finish Sample 3. This was accomplished by milling the sample surface to obtain 0.025" of material removal, including 320 grit sanding to impart the final surface finish. Ferrite measurement on the as-polished 0.05 μ surface, using a Feritscope®, revealed an average ferrite content of 72.2 FN with a 2σ standard deviation of 0.1 FN. After the 16 microinch milled surface finish was imparted, the mean ferrite content recorded was 74.6 FN with an average 2σ standard deviation of 0.1 FN. The disparity between ferrite content is not significant in this case. It is apparent that imparting a 16 microinch finish did not significantly influence the measurement of ferrite content in this sample.

Further analysis of the 2σ values for both surface finish conditions indicates excellent grouping of the experimental data about the mean ferrite contents. Also, note that the mean ferrite content of the 16 microinch surface finish is above the 2σ variance associated with a metallographically polished surface. This type of deviation is typical of

Figure 19. Surface Finish Sample 2 – 64 Microinch Finish

Magnification = 4.5x

this alloy system, therefore, it is warranted that the ferrite content could be elevated after milling. This further illustrates that the impartment of a 16 microinch surface finish did not significantly affect ferrite measurement. A photograph of Sample 3 is shown in Figure 20.

4.9.4 Ground Finish

Using a 4 _" general purpose 24-grit, angle grinding wheel, a surface finish was imparted on Surface Finish Sample 4. 0.025" of material was removed. Ferrite measurement on the as-polished 0.05 μ surface, using a Feritscope®, revealed an average ferrite content of 73.5 FN with an average 2 σ standard deviation of 0.1 FN. After the ground surface finish was imparted, the mean ferrite content recorded was 62.7 FN with a 2 σ standard deviation of 0.4 FN. The disparity between ferrite content is significant in this case. It is apparent that imparting an angle ground finish significantly influenced the measurement of ferrite content. It is apparent that the utilization of an angle grinder, to impart a surface finish, resulted in an approximate 10 FN reduction in ferrite number. A photograph of Sample 4 is shown in Figure 21. Again, 2 σ variations are small, as compared to mean ferrite content of either the metallographically polished or ground surface finish. This further illustrates that the ferrite determinations are well grouped about the mean ferrite contents for each surface finish.

Additionally, the 10 FN reduction is below the 2 σ variance established for the polished surface finish, indicating significant surface finish effects due to angle grinding. Metallographic specimens were prepared in a direction transverse to the imparted surface

Figure 20. Surface Finish Sample 3 – 16 Microinch Finish

Magnification = 4.5x

Figure 21. Surface Finish Sample 4 – 24 Grit Ground Finish

Magnification = 4.5x

finish. The results showed that no microstructural changes occurred due to angle grinding.

Additional characterization revealed that removal of the ground surface finish with 120 grit sandpaper (or equivalent) will restore the original ferrite content, as measured on the metallographically polished surface. Grinding with 120 grit sandpaper requires a minimum 0.005" of material removal to eliminate the angle ground surface finish.

4.9.5 #14 Bastard Mill File Finish

Using #14 Bastard Mill File, an as-filed surface finish was imparted on Surface Finish Sample 5. This was accomplished by filing the sample surface to obtain 0.025" of material removal. Ferrite measurement on the as-polished 0.05 μ surface, using a Feritscope®, revealed a mean ferrite content of 73.1 FN with a 2 σ standard deviation of 0.1 FN. After the #14 Bastard Mill file surface finish was imparted, the average ferrite content recorded was 71.4 FN with an average 2 σ standard deviation of 0.2 FN. The disparity between ferrite content is not significant in this case, although the mean ferrite content of the imparted surface finish is below the variance associated with the 2 σ value of the metallographically polished surface. The tight grouping of the ferrite determinations is characterized by 2 σ values, which are small when compared to the mean ferrite content of the block. Thus, it is apparent that imparting an as-filed surface finish did not significantly influence the measurement of ferrite content in this sample. A photograph of Sample 5 is shown in Figure 22.

Figure 22. Surface Finish Sample 5 – #14 Bastard Mill File Finish

Magnification = 4.5x

4.9.6 Effect of Surface Finish on Ferrite Measurement – Conclusions

The goal of the surface finish study was to correlate ferrite measurement performed on a machined surface finish to the actual ferrite content of the component. The component ferrite content was simulated using a metallographically polished surface finish sample. Based upon the experimental data obtained, the following conclusions are reached:

1. Impartment of a 250 microinch, 16microinch or #14 Bastard Mill file surface finish did not adversely affect ferrite measurement, as compared to a metallographic polish. The difference in ferrite measurement between the metallographically polished surface and the imparted surface finish was < 2 FN. The standard deviation associated with ferrite measurement is sufficiently small to assume that the data supporting these surface finishes, surrounds the mean (74 FN). The largest standard deviation encountered was 0.50. A ± 3.0 FN variation in ferrite content is considered acceptable at this ferrite content, based upon guidelines established in AWS A4.2. Because impartment of the above surface finishes did not initiate a change greater than 3 FN, the effect of the above surface finishes, on ferrite determination, is not considered significant.
2. The imparting of a 64 microinch surface finish, on a sample with nominally 76 FN, adversely affected ferrite measurement. The 64 microinch surface finish resulted in a 10 FN reduction in measured ferrite content. This change in measured ferrite content is greater than the ± 3 FN variation, which is expected.

A reduction in ferrite content can be attributed to either a decrease in ferrite content, or an interruption of the probe interaction volume. The 64 microinch finish, like all milled/ground finishes, provides a series of ridges on/in the surface of the sample. In the case of the 250 microinch or 16 microinch, the spacing and depth of the machined marks did not adversely affect the probe interaction volume, promoting adequate contact between the probe and sample surface. The spacing between 250 microinch machine marks is approximately 0.070". This value is larger than the 0.050" interaction volume established by previously discussed measurements. Conversely, the 16 microinch surface finish exhibits depth and width of machined marks that promote uniform measurement by optimizing the probe interaction volume.

The 64 microinch surface finish exhibits a distance between machined grooves approximately equal to 0.020". As this distance is smaller than the probe interaction volume, it is likely that the magnetic field induced by the Feritscope® probe is interrupted by the 64 microinch surface finish. This resulted in a marked reduction in measured ferrite content because the probe is not making sufficient contact with the sample to promote accurate measurement. The associated interruption in the interaction volume denotes the reduction in measured ferrite content.

3. Impairment of an angle grinder ground surface finish (24 grit) adversely affects ferrite measurement. The angle ground surface finish resulted in a 10 FN

reduction in measured ferrite content. This change in measured ferrite content is greater than the 3 FN variation expected.

Metallographic characterization of a section transverse to the angle ground surface revealed no microstructural. Surface finish topography remains the only interruption in the probe interaction volume affecting ferrite measurement. Additional characterization illustrated that modification of the angle ground surface finish, by removal of 0.005" of material, using a 120 grit abrasive, results in a ferrite determination equivalent to that of the polished surface. It is recommended that in the measurement of cast duplex stainless steel, a two step procedure, employing 120 grit grinding to remove the angle ground surface effects, prior to performing ferrite measurements, be utilized.

4. Producers and users of duplex stainless steel castings should be sensitive to the effects of surface finish on ferrite determinations using a Feritscope®. It is suggested that a #14 Bastard Mill File or angle ground, followed by a 120 grit surface finish, be utilized to provide the optimum surface finish for accurate ferrite measurement. This work also suggests that 250 and 16 microinch surface finishes may also be employed.
5. A limited amount of inspection, using the Magne Gage, on the surface finish samples revealed that the determination of ferrite content is generally unaffected.

4.10 Operator Error vs. Instrument Error

Prior to concluding this program, an endeavor was made to characterize the error associated with operation of the Feritscope® and of the instrument itself. Using a fixture and calibrated stage, ferrite content was measured on round-robin sample J using a semi-automated technique. 100 ferrite determinations were conducted and the mean ferrite content and 2σ standard deviation were recorded. Another series of 100 ferrite determinations were then performed manually, on the same sample, at the same location, to assess any change in the mean ferrite content and 2σ standard deviation due to operator error.

Utilizing the fixture and stage, the mean ferrite content was 76.9 FN with a 2σ standard deviation of 0.80 FN. In comparison, the mean ferrite content associated with manual Feritscope® use was 74.7 FN with a 2σ standard deviation of 2.56 FN. Based upon the 2σ standard deviations associated with each methodology, it is apparent that removing variances associated with an individual operator's ferrite measurement technique significantly reduced the magnitude of 2σ . The reduction in 2σ , resulting from a semi-automated technique, implies that there is a larger variance in ferrite measurement associated with an operator technique.

5.0 CONCLUSIONS

Utilizing a series of round-robin tests, this program was able to characterize the capabilities of metallographic, magnetic and magnetic permeability methods of ferrite measurement. Depth profile studies further documented the change in ferrite content as a function of depth below a cast surface, providing casting producers and users with guidelines for machining and finishing. Finally, an analysis of surface finish and its effect on ferrite measurement served to further document the proper methods of characterizing the ferrite content of finished castings. Highlighting the important issues from this program, the following program conclusions are presented:

1. Round-robin testing demonstrated that cast secondary standards can be produced from duplex stainless steel castings. It is recommended that centrifugal castings be utilized for this purpose, as their repeatability, when subjected to three ferrite measurement techniques, was more favorable than statically cast materials. The reproducibility of measurements between participants was uniform, regardless of ferrite measurement technique.

A standard procedure for manufacturing cast secondary standards can be described as follows:

- (a) Select an alloy (austenitic/duplex) whose ferrite content matches a desired ferrite range.
- (b) Produce a centrifugal cast ring. Static castings should not be used.
- (c) Remove a 1" x " x " cube from the ring such that the primary ferrite measurement surface is oriented perpendicular to the radial direction of the ring and at least 1/8" below the cast surface, as shown in Figure 23.
- (d) Metallographically polish the measurement face to a 0.05 μ surface finish. Etch appropriately using an oxalic acid electro-etch technique (10V, 0.05A for 20-60 seconds). Photographically document a region of interest and perform a manual point count (ASTM E562) to assess the ferrite content. This region of interest will later be utilized as the measurement location during calibration.
- (e) Permanently scribe the border of the region of interest on the polished surface.
- (f) Measure ferrite in the region of interest using a Magne Gage or Feritscope®, which has been calibrated to AWS A4.2. Perform 10 determinations within the region of interest and calculate the mean ferrite content and standard deviation.
- (g) Mark the mean ferrite content and standard deviation permanently on the block.

Figure 23. Cast Secondary Standard Extraction

(Ensure that the measurement face is 1/8" below the cast surface)

- (h) Perform several additional determinations within the scribed region and compare the data to the mean ferrite content of the block. If 10 successive individual determinations are within 5% of the mean ferrite content, the block is suitable for calibration. Larger values shall be cause for rejection of the block as a calibration standard.

Note: This procedure has not been sanctioned by any standardization organization and is subject to review.

2. The round-robin further demonstrated that instrument calibration, utilizing AWS A4.2, produced improved repeatability, as compared to other calibration methods. It is recommended that AWS A4.2 be utilized for the calibration and operation of Magne Gage and Feritscope® instruments to maintain repeatability. Interlaboratory reproducibility was unaffected by differing calibration methods.
3. Additionally, it was found that a suitable correlation could be drawn between ferrite content and ferrite number. This correlation was established as 0.9:1 (FN:Volume Percent Ferrite) for the low ferrite range (0-15 FN). A second correlation factor was established as 1.5:1 (FN:Volume Percent Ferrite) for the upper ferrite range (55-90 FN). These correlations were comprised of ferrite measurements using metallographic, Magne Gage and Feritscope® techniques.

4. Depth profile studies revealed that removal of 1/8" of material from the cast surface will establish a uniform ferrite content for the finished casting. Trials using two alloy systems and three heats of material confirm this behavior.
5. Ferrite measurements, utilizing a Feritscope®, taken directly on a cast surface are not indicative of the ferrite content of the entire casting. Producers and users of cast products are encouraged to measure ferrite content at a subsurface location, at a depth greater than 1/8" below the cast surface.
6. The interaction volume of the Feritscope® probe is defined as 0.050", which is the diameter of the probe. Ferrite measurement performed, such that the measurement probe is not contained within a discontinuity or edge, will promote accurate ferrite measurement.
7. Surface finish analysis revealed that the impartment of a 250 microinch, 16 microinch or #14 Bastard Mill file surface finish did not adversely affect ferrite measurement. The difference in ferrite measurement between the metallographically polished surface and the imparted surface finish was acceptable.
8. Further surface finish analysis concluded that impartment of a 64 microinch or angle ground surface finish did adversely affect ferrite measurement. Impartment of a 64 microinch or angle ground surface finish (24 grit) resulted in a 10 FN

reduction in measured ferrite content. Ferrite measurement should not be employed directly on either surface finish. However, the effects of angle grinding can be removed by grinding the casting with a 120 grit wheel (or equivalent). A minimum of 0.005" of removal is recommended to free the measurement surface of any pre-existing angle grinding marks.

9. A standard practice for measuring ferrite using either a Magne Gage or Feritscope® is as follows:
 - (a) Calibrate the Magne Gage or Feritscope® according to AWS A4.2.
 - (b) Examine the surface finish of the sample to ensure that it is free of curvature. Samples exhibiting significant curvature require the use of a conversion factor which accounts for surface curvature effects on ferrite measurement accuracy.
 - (c) Examine the surface finish of the sample. This study has shown that a suitable surface finish is required for accurate ferrite determinations. Beyond the recommendations previously discussed, surface finish effects will be left to the discretion of the operator.
 - (d) Following the measurement procedure outlined by the manufacturer, perform ferrite measurement determinations using either the Magne Gage or Feritscope®. Ensure that the instrument probe is not contained within a surface discontinuity or sufficiently near an edge to promote inaccurate measurement. Edge/distance effects have been summarized in conclusion (6).

10. It was found that the greatest source of error, when comparing Feritscope® operator technique and instrument variations, was associated with the operator. 2 σ analysis revealed that the largest variation in ferrite content, for a given sample, is associated with the operator's technique and not the instrument.

For additional information relating to this program, feel free to contact the University of Tennessee – Knoxville, Materials Joining Research Group.

Materials Joining Research Group
The University of Tennessee – Knoxville
434 Dougherty Engineering
Knoxville, TN 37996-2200

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8.0 SPECIFICATIONS

1. 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, ISBN: 0-87171-36-6 American Welding Society, Miami, Florida, 1991
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9.0

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	<u>5.5</u>	4.6	4.3	4.3	<u>5.6</u>	<u>5.7</u>	<u>5.6</u>	<u>5.3</u>	<u>5.9</u>
6.5 (6.2 - 6.8)	6.7	<u>7.6</u>	6.4	<u>6.1</u>	6.2	8.0	8.1	8.0	<u>7.5</u>	8.4
10.4 (10.0 - 10.8)	<u>12.1</u>	<u>12.7</u>	<u>12.3</u>	10.6	10.6	<u>13.4</u>	<u>13.6</u>	<u>13.6</u>	<u>12.2</u>	<u>14.3</u>
14.6 (14.2 - 15.0)	14.5	<u>15.2</u>	14.5	<u>13.5</u>	14.5	<u>16.1</u>	<u>16.2</u>	<u>16.3</u>	14.7	<u>17.0</u>
16.7 (16.2 - 17.2)	16.6	<u>17.3</u>	16.8	16.4	16.7	<u>18.4</u>	<u>18.5</u>	<u>18.8</u>	16.7	<u>19.6</u>
20.3 (19.8 - 20.8)	20.3	20.5	20.5	<u>19.6</u>	19.8	<u>21.8</u>	<u>22.1</u>	<u>22.4</u>	20.7	<u>23.5</u>
26.8 (25.5 - 28.1)	25.8	<u>25.3</u>	25.7	<u>24.2</u>	<u>24.3</u>	27.0	27.7	27.7	26.8	<u>29.7</u>
31.0 (29.4 - 32.6)	31.3	29.8	30.6	<u>28.0</u>	<u>28.4</u>	32.0	32.2	<u>32.7</u>	31.3	<u>34.5</u>
37.5 (35.6 - 39.4)	37.9	37.5	37.8	<u>33.2</u>	<u>33.9</u>	37.8	39.4	<u>39.9</u>	37.7	<u>42.5</u>
47.0 (44.6 - 49.4)	46.8	49.1	45.7	<u>41.0</u>	<u>41.2</u>	47.2	49.1	49.4	47.5	<u>54.0</u>
52.0 (47.8 - 56.2)	48.5	51.6	49.0	<u>43.0</u>	<u>43.6</u>	49.1	53.1	53.0	50.1	<u>58.0</u>
58.5 (53.8 - 63.2)	<u>48.6</u>	<u>52.2</u>	47.8	<u>42.2</u>	<u>43.7</u>	49.1	55.1	<u>52.3</u>	<u>48.8</u>	56.8
67.0 (61.6 - 72.4)	61.6	63.9	<u>60.1</u>	<u>53.6</u>	<u>54.2</u>	64.1	67.9	68.6	63.7	68.7
73.5 (67.6 - 79.4)	<u>67.3</u>	69.2	<u>66.5</u>	<u>58.0</u>	<u>58.0</u>	70.2	74.1	73.2	70.1	72.7
85.0 (78.2 - 91.8)	86.9	85.3	85.7	<u>71.9</u>	<u>71.8</u>	89.4	<u>98.8</u>	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 Ferritscope®

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.

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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, CB1 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
Feritscopes (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 Subcommittee 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).

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.

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

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.