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Welding consumables — Predicted and measured FN in specifications — A position statement of the experts of IIW Commission IX

Produits consommables de soudage — Valeurs prévues et valeurs mesurées de l'Indice de Ferrite (FN) dans les spécifications — Position des experts de la Commission IX de l'IIW

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Foreword

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ISO/TR 22824 was prepared in collaboration with the International Institute of Welding, which has been approved by the ISO Council as an international standardizing body in the field of welding.

Introduction

This Technical Report was prepared by the International Institute of Welding, Commission IX, through its Subcommission IX-H, Welding of Stainless Steels and Nickel Base Alloys, on behalf of ISO/TC 44/SC 3. It constitutes the considered judgement of the experts on measurement and calculation of ferrite in nominally austenitic and duplex ferritic-austenitic stainless steel weld metals.

Welding consumables — Predicted and measured FN in specifications — A position statement of the experts of IIW Commission IX

1 Scope

This Technical Report provides guidance, based on the experience of experts, for setting appropriate requirements, in specifications and other standards and contract documents, on ferrite content of nominally austenitic or duplex ferritic-austenitic stainless steel weld metals.

2 Background

A small amount of ferrite in a nominally austenitic stainless steel weld metal is well established as a means for eliminating the tendency to hot cracking. An upper limit on ferrite may be necessary to avoid embrittlement in high temperature applications. Duplex stainless steel welds generally require both a minimum and a maximum ferrite content for optimum properties. Lefebvre[1] has detailed these and other reasons for specifying ferrite requirements in stainless steel welds, along with appropriate ferrite ranges for various needs. A measurement system, defined in the ISO 8249[2] and AWS A4.2[3], has been agreed internationally for determining Ferrite Numbers in weld metals. A number of constitution diagrams for stainless steel weld metals have been developed over the years, which propose the calculation of the ferrite content of a weld based upon its chemical composition. Probably the best known are the Schaeffler, DeLong, WRC-1988 and WRC-1992 diagrams. Most constitution diagrams are applicable to weld deposits made by arc welding under normal cooling conditions.

Problems arise when a purchaser specifies ferrite with both measured and calculated requirements. Firstly, there are disagreements between measured and calculated ferrite content; secondly, ferrite for a given welding filler metal is not a constant — it can vary with location in the weldment and with variations in welding procedure.

3 Reproducibility of FN measurement

IIW Commission II has conducted various round robin tests of ferrite measurement, where the participants have used instruments calibrated in accordance with ISO 8249. These round robin tests have established the interlaboratory reproducibility of measurement (95 % confidence interval) as ± 10 % of the interlaboratory mean value or less when calibration is done with primary standards and a Magne-Gage instrument[4], and as ± 14 %, or less, when calibration is done with secondary standards and a shop or field instrument[5]. This means that if the interlaboratory mean value for the ferrite content of a given weld is 4,0 FN, 95 % of laboratories making measurements will measure within the range of 3,6 FN to 4,4 FN with primary calibration, and within the range of 3,4 FN to 4,6 FN with secondary calibration. Likewise, if the interlaboratory mean value for a given weld is 10,0 FN, 95 % of laboratories making measurements will measure within the range of 9,0 FN to 11,0 FN with primary calibration, and within the range of 8,6 FN to 11,4 FN with secondary calibration. Further, if the given weld metal were a duplex stainless steel with an interlaboratory mean of 50 FN, then 95 % of laboratories making measurements with primary calibration would measure within the range of 45 FN to 55 FN, and within the range of 43 FN to 57 FN with secondary calibration. It should be noted that most laboratories and shops prefer to use instruments calibrated with secondary standards because the measurement is much quicker and simpler to make.

4 Reproducibility of FN calculation

Reproducibility of FN calculation depends primarily upon reproducibility of chemical analyses. Consider just three elements — chromium, nickel and nitrogen. The most popular method of chromium and nickel analysis in stainless steels is by optical emission spectrophotometry (OES), as given in ASTM E 1086-94[6]. The most popular method of nitrogen analysis is by the inert gas fusion thermal conductivity method as given in ASTM E 1019-00[7]. These standards include the measure of reproducibility as the 95 % confidence limit for differences between measurements made by two laboratories. The differences are, of course, level-dependent. At the level of a Type 316 (19 12 3) stainless steel, the differences were 0,46 % Cr (average 17,48 % Cr), 0,73 % Ni (average 12,54 % Ni), and 0,007 % N (average 0,096 % N). It is a simple matter to calculate the effect of such differences on the FN obtained from the WRC-1992 diagram. This can be done taking any single element to its extreme, or taking all elements to their extremes. For the purpose of illustration this is done in Table 1. The same analysis is then applied to Type 2209 (22 9 3L) weld metal, measured at 50 FN by laboratory A, also in Table 1.

Table 1 — Uncertainty in FN calculated by the WRC-1992 diagram from weld metal compositions obtained by two different laboratories on the same weld metal

Weld metal alloy type	Laboratory A FN by WRC-1992 diagram	Laboratory B FN by WRC-1992 diagram with the same chemical analysis as laboratory A, except for the differences given below							
								+0,46 % Cr –0,73 % Ni	–0,46 % Cr +0,73 % Ni
		+0,46 % Cr	–0,46 % Cr	+0,73 % Ni	–0,73 % Ni	+0,007 % N	–0,007 % N	–0,007 % N	+0,007 % N
316L (19 12 3)	4,1 FN	5,8 FN	3,0 FN	2,6 FN	6,4 FN	3,8 FN	4,5 FN	8,6 FN	1,5 FN
2209 (22 9 3 L)	50,0 FN	56,5 FN	44,5 FN	39,8 FN	62,5 FN	48,0 FN	52,6 FN	70,7 FN	32,1 FN

Clearly, small differences in chemical analysis can result in rather large differences in calculated ferrite — much larger differences than could be expected from calibrated instrument measurements.

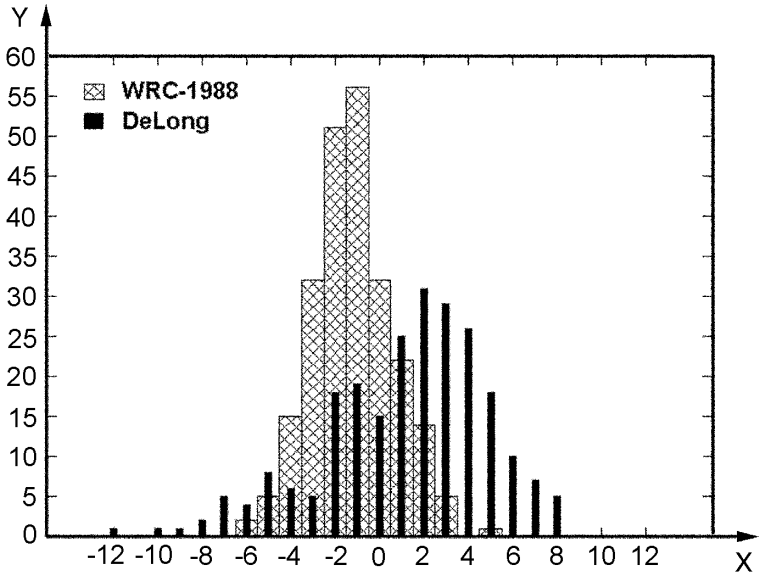
5 Comparison between FN calculation and FN measurement

If labatory B, in the examples above, does not exactly agree with labatory A as to the chemical composition of a given weld metal, then it is also likely that neither laboratory would agree exactly with the laboratory(ies) which prepared a given constitution diagram. The Schaeffler and DeLong diagrams were presumably prepared using the chemical analysis data from a single laboratory. The WRC-1988 diagram (identical to the WRC-1992 diagram except that the latter includes a factor for copper in the nickel equivalent) was prepared using about 900 chemical analyses and corresponding measured Ferrite Numbers generated by several laboratories. This should have eliminated biases in analysis from any single laboratory. After this diagram was prepared, an additional 200 data points in the 0 FN to 18 FN (measured) range were obtained from one laboratory. These new data points were used to compare the predicting accuracy of the WRC-1988 diagram with that of the DeLong diagram[8].

Figure 1 shows the error histograms observed. Ideally, the error histogram should be centered about zero, and should have as small a spread as possible. It can be seen from Figure 1 that the DeLong diagram has a bias of about + 2 FN (i.e., it tends to over-estimate the measured FN) for the data of this particular laboratory. On the other hand, the WRC-1988 diagram has a bias of about – 1 FN for the data of this particular laboratory. Now, the biases could be due to a bias in chemical analysis of the laboratory supplying the data, or the biases could be due to real errors in the respective diagrams. That cannot be determined when the experimental data are from one laboratory only. Data from a number of laboratories would be needed to eliminate biases in chemical analysis.

However, Figure 1 also shows that the spread in errors with the DeLong diagram is about ± 8 FN (in the zero to 18 FN range of measured values) but the spread in errors of the WRC-1988 diagram is about ± 4 FN in the same range of measured FN values. This spread in errors provides a clear basis for considering the

WRC-1988 diagram to be more accurate than the DeLong diagram. Based upon this observation, the ASME Code replaced the DeLong diagram with the WRC-1992 diagram as its recommendation for the best way to predict ferrite.



Key

X difference = calculated FN – measured FN

Y number of cases within 0,5 FN

Figure 1 — Histogram of differences between calculated FN and measured FN

6 Location of ferrite measurement

It should be recognized that ferrite is not homogeneously distributed within a weld. ISO 8249 and AWS A4.2 specify unambiguously that FN measurements be made along the top centreline of a given weld pass. In particular, it is clear that ferrite content is generally lower at the interface between two weld passes because the reheating of one pass associated with deposition of the subsequent adjacent pass causes some ferrite to transform to austenite and possibly other phases. Ferrite measurements on a cross-section of a weld will encounter these reheated areas. As a result, in general, measurements made along the top centreline of a weld will exhibit a higher average FN, and will have a smaller standard deviation than will measurements made on a weld cross-section. Correlations of weld properties and freedom from hot cracking with ferrite content, are generally based upon FNs measured along the top centreline of a weld pass. Therefore, it is appropriate to base acceptance or rejection decisions upon FN measurements made along the weld pass top centreline and not on measurements scattered over a weld cross-section or randomly scattered around a multi-pass weld surface.

7 Effect of postweld heat treatment (PWHT)

In general, PWHT produces a reduction in the ferrite content of weld metal as compared to its as-deposited condition[1]. This reduction can be due to transformation of ferrite to austenite, to intermetallic compounds or to a non-magnetic chromium-rich ferrite (alpha-prime). It should, therefore, be obvious that the same Ferrite Number range cannot, in general, be specified for both as-deposited weld metal and the same weld metal after PWHT. If freedom from hot cracking is the concern, only as-deposited ferrite should be of interest. After PWHT a greater concern is the effect of ferrite decomposition products on the weld metal[1], [9], [10], in which case ferrite measurement is of little direct concern.