Guidelines for specification and measurement of ferrite in austenitic stainless steel weld metal

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The experience of the 1940s demonstrated beyond doubt the connection between the presence at room temperature of a small amount of ferrite in an otherwise austenitic weld deposit and the absence of cracking or even microfissuring in that weld deposit. With the publication of the Schaeffler Diagram in 1948, one might have expected all cracking and microfissuring difficulties with these weld metals to vanish. However, it should be noted that Schaeffler claimed no better than ±4% ferrite accuracy.

Clearly, the widespread use of Schaeffler Diagram alleviated the problem. But a new one arose. How can the several parties to a major weldment (the elctrode producer, the weldment fabricator, the weldment user, and possibly the insurance company and the appropriate regulatory agency) satisfy themselves that the required minimum ferrite content was indeed obtained? The Schaeffler Diagram provides an approximate relation between chemical composition of the weld metal and a ferrite content estimated by metallographic examination of that weld metal. The accuracy of this relation is affected by accuracy of the chemical analysis of the weld metal, the repeatability of the etching and metallographic interpretation of the weld metal microstructure, and the accuracy of the approximations made in developing the diagram.

The Welding Research Council in the USA and IIW Sub-Commission IIC demonstrated centrally that the repeatability of the etching and metallographic interpretation of the weld metal microstructure is a major source of variability in estimating weld metal ferrite. To quote from AWS A4.2-74,"..... on a given specimen, laboratory A might rate the percent ferrite at as low as 3%, laboratory B at 5%, and laboratory C as high as 8%."

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Subsequent to the publication of the Schaeffler Diagram, it was discovered by W.T. DeLong and others that nitrogen has a potent austenitizing effect on these weld metals. Nitrogen is, to a certain extent, outside of the control of the electrode producer. A homogeneous lot of covered electrodes providing adequate ferrite under controlled conditions can produce weld metal that is ferrite-free or nearly ferrite-free in the hands of a careless welder who draws a long arc and thereby allows air to enter the arc. Similarly, a gas tungsten arc or gas metal arc deposit with a filler metal normally of adequate ferrite can be rendered ferrite-free by a draught or loss of shielding gas that permits air to enter the arc. A submerged arc deposit can be similarly affected by a too-shallow flux cover that permits "flashing" to occur and air to enter the arc.

All of the above can easily lead to microfissures or cracks in weld metal that should be of good quality.

So the question of ferrite specification and measurement has two important aspects to it. First, the parties involved in weldment need to be able to agree on a measurement system that produces reproducible results when the measurement is made by any party involved with the weldment. Secondly, a measurement system is needed that allows direct measurement on completed or partially completed weldments and thus permits quality assurance verification that the expected ferrite level is in fact being obtained under fabrication conditions. Obviously, metallographic measurement is totally unsuitable for this second concern, even if one could devise a method giving reproducible results.

Fortunately, ferrite has a property which austenite lacks that permits easy detection of its presence and therefore measurement of its concentration : ferrite is ferromagnetic. Any number of devices can be conceived giving a response that is approximately proportional to the quantity of ferrite that is within the volume being sampled by the device. Such devices can be rendered portable so that measurements on individual weld passes during the course of fabrication of a large weldment become possible.

With the availability of magnetic devices, the last major concern in specification of weld metal ferrite and reproducibility of measurement becomes calibration of the devices to a standardized scale. Magnetic devices for weld metal ferrite measurement have existed for 30 years or more. However, their calibration has been an uncontrolled variable. To quote again from the Appendix of AWS A 4.2-74 "The percent ferrite in austenitic stainless steel weld metal 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% ferrite, in the US 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 use somewhat different calibration curves as well as a variety of instruments. At nominal levels of up to 10% ferrite, which is the most useful and pertinent range, the values obtained by participating laboratories range from 0.6 to 1.6 times the nominal value".

The problem with calibration of instruments based upon a percent ferrite scale led IIW Sub-Commission IIC to conclude that, "At the present time, experimental methods are not available that qive an absolute measurement of the amount of ferrite in a weld metal, either destructively or non-destructively." This should not be taken as a cry of despair, however. By the act of concluding that an absolute measurement scale is, at the present time, impossible, the way is clear for an arbitrary measurement scale. Such a scale, based upon the force required to pull a standard magnet from the sample, has been agreed upon, first by the American Welding Society as AWS A4.2-74 and subsequently with minor modifications by the International Institute of Welding (document II-964-81) which is in the process of being adopted as an International Standard (ISO/DIS 8249). The arbitrary unit of the AWS and IIW method is a ferrite number rather than a "ferrite percent".

Once the calibration scale has been defined using primary standards and a standard magnet, then ferrite numbers can be assigned to secondary weld metal standards. These weld metal standards are in turn suitable for calibrating a variety of instruments operating on magnetic or eddy current principles. Suitable IIW secondary weld metal standards are available from The Welding Institute in the United Kingdom.

Using the ferrite number system, laboratory-to-laboratory reproducibility of ferrite determinations has been established as ± FN or less over the range 0-28 FN. Constitution diagrams such as the Schaeffler and the DeLong diagrams provide useful guidance in anticipating ferrite content, particularly in dissimilar metal joints, but should not be referenced in specifying ferrite in weld metal. Likewise, instruments nominally reading "percent ferrite" are unsuitable as references unless their calibration is traceable to an agreed standard. Specification of ferrite, measurement of ferrite, and reporting of ferrite in terms of ferrite numbers is, at the present time, the best way to be sure that an order for ferrite will be understood at all levels involved in filling that order.