

Study on Ferrite Measurement Methods for Duplex Stainless Steel Part 2: Focus on Measurement by Ferrite Scope

Nozomi Satake, Mikihiro Sakata
JGC Corporation
2-3-1 Minato-Mirai, Nishi-ku
Yokohama, 220-6001
Japan

ABSTRACT

When evaluating the ferrite content (%) to assess the quality of industrial products made of duplex stainless steels, two different measurement methods are generally used. One method is a destructive method with metallographic observation to directly determine the volume fraction of ferrite phase (%). The other method is a non-destructive method based on the magnetic properties of ferrite phase which is typically measured with a ferrite scope. Unlike the ferrite measurement by metallographic observation, the ferrite measurement with a ferrite scope cannot determine the volume fraction of ferrite phase (%) directly. Instead, it detects the degree of interaction between magnetic field and ferrite phase and convert it to the volume fractions of ferrite phase (%). Although the ferrite scope is a valuable inspection tool that offers a simple and quick measurement, it has been observed the ferrite content (%) obtained with a ferrite scope is not always equal to the true volume fraction. In the present study, in order to reveal the discrepancy, a round robin test for ferrite scope measurement was conducted by involving institute including industrial NDE companies from around the world who have been regularly assigned in plant construction and maintenance. The test used nine (9) 22% Cr duplex stainless steel samples for which the volume fractions of the ferrite phase had been previously determined by metallographic observation.

Key words: Duplex Stainless Steel, Welding, Ferrite Content, Ferrite Scope

INTRODUCTION

Duplex stainless steels consist of approximately 50% ferrite phase and 50% austenite phase and are widely used in the refining and oil and gas industries due to their superior corrosion resistance compared to austenitic stainless steels. It is known that the phase fraction in duplex stainless steels, generally described by the ferrite content (%), determines the corrosion resistance of these steels.¹

When the ferrite content (%) is evaluated to assess the quality of industrial products made of duplex stainless steels, two different measurement methods are commonly used, depending on the situation. One method is destructive metallographic observation, typically using optical microscopy. With this

method, the visible color contrast between the ferrite and austenite phases directly indicates the fraction of the ferrite phase in the samples. To statistically estimate the volume fraction in the micrographs obtained, manual point counts are used as specified in ASTM⁽¹⁾ E562 or automated image analysis is conducted as specified in ASTM E1245.^{2, 3} This direct assessment is generally used for material test certificates (MTC) or welding procedure qualification test records (PQR) during welding procedure qualification. The use of this type of measurement method for heat affected zone of duplex stainless steel welds has been discussed in Author's previous paper.⁴ The other method is non-destructive and uses the difference in magnetic tendency between the ferrite and austenite phases. When a magnetic field is applied to a sample, it interacts only with the magnetic portions of the sample (i.e., the ferrite phase). The degree of the interaction is used for estimating the volume fraction of the ferrite phase.⁵ The most commonly used instrument for this indirect assessment is a ferrite scope. It is widely used for checking the ferrite content (%) in production welds after welding fabrication. It is important to note that, while both of these methods are used to determine the ferrite content (%), they are measuring different physical properties. Moreover, although the ferrite content (%) in duplex stainless steels obtained by a ferrite scope is used as if the value obtained were equal to the exact volume fraction of ferrite, it seems no paper presenting a theoretical basis for using a ferrite scope to determine the exact volume fraction of ferrite in duplex stainless steels has been published.

In the last few years, a number of experimental investigations have been conducted focusing on the accuracy of using a ferrite scope to determine the volume fraction of ferrite in duplex stainless steels.⁶⁻¹⁰ For example, Putz et al., using samples of 22%Cr duplex stainless steels, investigated the difference between the ferrite content (%) obtained using a ferrite scope and the volume fraction of ferrite (%) determined by metallographic observation.⁶ They reported around a 10% difference in absolute value between the two measurement methods compared. Camerini et al., using samples of 25%Cr super duplex stainless steels, investigated the difference between the ferrite content (%) obtained using ferrite scope and the volume fraction of ferrite (%) determined by X-ray diffraction (XRD), and they reported an even larger difference.⁷

A ferrite scope is a valuable inspection tool that offers a simple and quick non-destructive measurement with a handheld instrument. It is used as one of the final product quality inspections of duplex stainless steel welds. However, as mentioned in previous paragraph, it has been observed that ferrite content (%) obtained by ferrite scope is not always equal to the exact volume fraction of ferrite phase (%). Hence, without understanding the discrepancy which likely occurs during the quality assessment process, the results may be different from those truly needed. In the present study, in order to reveal the discrepancy, a round robin test for ferrite scope measurement was conducted by involving institutes including industrial NDE companies from around the world who have been regularly assigned in plant construction and maintenance. The test used nine (9) 22% Cr duplex stainless steel samples for which the volume fractions of the ferrite phase (%) had been previously determined by metallographic observation. The causes of the discrepancy found between the ferrite scope measurements and the metallographic observations are explained.

SAMPLE PREPARATION FOR ROUND ROBIN TEST

Samples for Ferrite Measurement

Nine samples with the size of approximately 20 mm x 20 mm were prepared from either 22% Cr duplex stainless steel base metal or weld metal pieces as shown in Figure 1. The description of each sample and the typical microstructure of the surface subject to measurement of the samples are shown in Figure 2. As shown in Figure 2, one of the samples was taken from a commercially available calibration standard having specified ferrite content of 42.1%. The chemical compositions of these samples are shown in Table 1.

⁽¹⁾ ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.

Ferrite Measurement by Metallographic Observation in accordance with ASTM E1245

Prior to a round robin test, the volume fraction of ferrite phase (%) for each sample was determined by metallographic method using image analysis according ASTM E1245. For this measurement, the samples were polished and etched by using Beraha's reagent listed in ASTM E407 No.99.¹¹ The measurements were performed by using 500X magnification for the samples. The results of image analysis are shown in Table 2. The measured surfaces were then used for ferrite measurement with ferrite scope performed during the round robin test.

PROCEDURE OF ROUND ROBIN TEST

A round robin test for ferrite measurement using ferrite scope on the nine 22% Cr duplex stainless steel samples was carried out by involving six institutes including NDE companies from around the world who have been regularly assigned in plant construction and maintenance. For Sample A to Sample G, ferrite measurements were performed at all the six laboratories but the ferrite measurements for Sample H and Sample I were performed at three of them. Ferrite measurements at each laboratory were performed by using a ferrite scope owned by the laboratory. All of the ferrite scopes were Fischer Feritscope[†]. Before the measurement, it was calibrated by using a set of calibration standards listed in Table 3. Those calibration standards were also from Fischer. After the calibration, ten measurements were performed for each sample.

RESULTS OF ROUND ROBIN TEST

Figure 3 shows the average ferrite content (%) with relative accuracy for each sample obtained by using the ferrite scope at each laboratory along with the volume fraction of ferrite phase (%) of each sample determined by metallographic observation. As it can be seen in Figure 3, the difference between the ferrite content (%) obtained by using the ferrite scope and the volume fractions of ferrite phase (%) is up to 12% in absolute value.

DISCREPANCY BETWEEN FERRITE CONTENT OBTAINED BY FERRITE SCOPE AND VOLUME FRACTION OF FERRITE PHASE

The differences in ferrite content (%) obtained by ferrite scope from the volume fractions of ferrite phase are plotted in Figure 4. In addition to the results obtained by this study, the results obtained by Putz et al., Jonsson et al. and Japanese Welding Institute are shown in the same graph.^{6, 8, 9} As it can be seen in Figure 4, the magnitude of observed discrepancy in this study is similar to those obtained by others as the discrepancy is up to around 15% in absolute value. This discrepancy is explained by the following two aspects in the measurement method which is supported by an additional experiment.

(1) Arbitrary nature in detecting the magnetic properties by using ferrite scope

By referring to AWS⁽²⁾ A3.0, Standard Welding Terms and Definitions, the magnetic properties detected by ferrite scope are defined as "an arbitrary, standardized value designating the ferrite content of austenitic or duplex ferritic-austenitic stainless steel weld metal based on its magnetic

[†] Trade name

⁽²⁾ American Welding Society, 550 NW LeJeune Road, Miami, FL 33126.