IV Conferencia Panamericana de END
Buenos Aires – Octubre 2007

AAENDE
Asociación Argentina de Ensayos No Destructivos y Estructurales

NDE for Type 304L Stainless Steel Material Characterization

Kenji Krzywosz
EPRI NDE Center
1300 West WT Harris Blvd.
Charlotte, NC 28262
USA

Abstract

This paper summarizes the results of applying the combined eddy current and magnetic NDE techniques to evaluate and assess the changing material conditions due to fatigue, including emergence of cracking, in Type 304 low carbon stainless steel plate samples. This on-going work is done to help identify and mitigate degraded materials with flaws in their incipient stages rather than later, when the flaws have grown to critical flaw dimensions.

Two separate AC eddy current and DC magnetic field measurement systems were utilized during the fatigue testing of "dog-bone" shaped stainless steel plate samples. The acquired NDE data consisted of both the DC magnetic field measurements by Feritscope MP30 and the normalized eddy current coil impedance measurements by a Swept-Frequency Eddy Current Tester. Individual measurements by AC eddy current and DC magnetic field measurements provided complementary information about the changing material conditions prior to and after the cracks were formed. AC eddy current measurements relied on the association of changing coil impedance to material conductivity values due to fatigue cycling and emergence of fatigue cracks. DC magnetic field measurements detected increased permeability due to austenitic stainless steel changing from nonmagnetic to magnetic martensitic conditions with increased fatigue cycles.

Background

The majority of mainstream NDE activities focus on flaw identification and flaw characterization. Most critical and essential components of a nuclear power plant are made of Alloy 600 and Type 304/316 materials, which are susceptible to stress corrosion cracking and fatigue cracking. There is a need to nondestructively detect, assess, and monitor incipient stages of material degradations to allow timely remedial measures. It makes more economic sense to detect and mitigate flaws in their incipient stages than later when the flaws have grown to some critical flaw dimensions.

This paper summarizes the EPRI results (1) of applying the conventional eddy current and magnetic NDE techniques to evaluate and assess the different fatigue degradation stages of Type 304 Low (L) carbon stainless steel (SS) material. The primary focus was to obtain successive NDE data from the Type 304L SS "dog bone" samples, which were subjected to life-cycle fatigue testing. The initial baseline NDE data consisted of both the DC magnetic field measurements by Feritscope MP30 and the normalized eddy current coil impedance measurements by Swept-Frequency Eddy Current Tester. The dog-bone configuration fatigue samples, 626 and 627, were approximately 590mm in length and 100mm in reduced width where it was subjected to cyclic fatigue testing.

Fatigue Testing of 304 L #626 Plate Specimen

The first sample, #626, was tested and data acquired at every 6000 cycles with the intention of failing the sample so that more detail testing can be done on the second sample at reduced cycle increments. Both the DC magnetic field and AC eddy current measurements were taken at 5,752 cycles and 10,000 cycles before the sample broke in half at 16,870 cycles. The sample was cycled at 30 cycles per minute with the total strain range held at 0.6%, which roughly equated to +/- 15.3mm deflection at the center of the specimen.

Initially, the eddy current coil impedance changes corresponding to changes in the material conductivity values were obtained prior to fatigue testing at an operating frequency of 50 kHz. During the calibration process, the eddy current system was normalized such that “0” normalized impedance value represented a conductivity value of 0.738 megasiemens per meter (MS/m), while a “1” normalized impedance value represented a conductivity value of 0.831 MS/m. In general, the conductivity value of Type 316 SS material is listed as 1.5 MS/m. So, if this value holds true for the tested sample, this would result in the normalized impedance value of around 2.0. The actual value obtained from the baseline test showed the averaged normalized impedance value of around 3.0. It should be noted that normalized baseline impedance values ranged from 2.7 to 3.4 for the top surface and 2.8-3.5 for the bottom surface. The subsequent plots show reduced changes in the normalized impedance values from the baseline values with increasing fatigue cycles.

At 10K fatigue cycles, the normalized impedance values decreased on both the top surface (2.3-3.0) and bottom surface (2.7-3.2). This decrease in the normalized impedance values was attributed to emergence of incipient cracks. At 16,870 cycles, the plate sample #626 broke in half as shown in Figure 1.

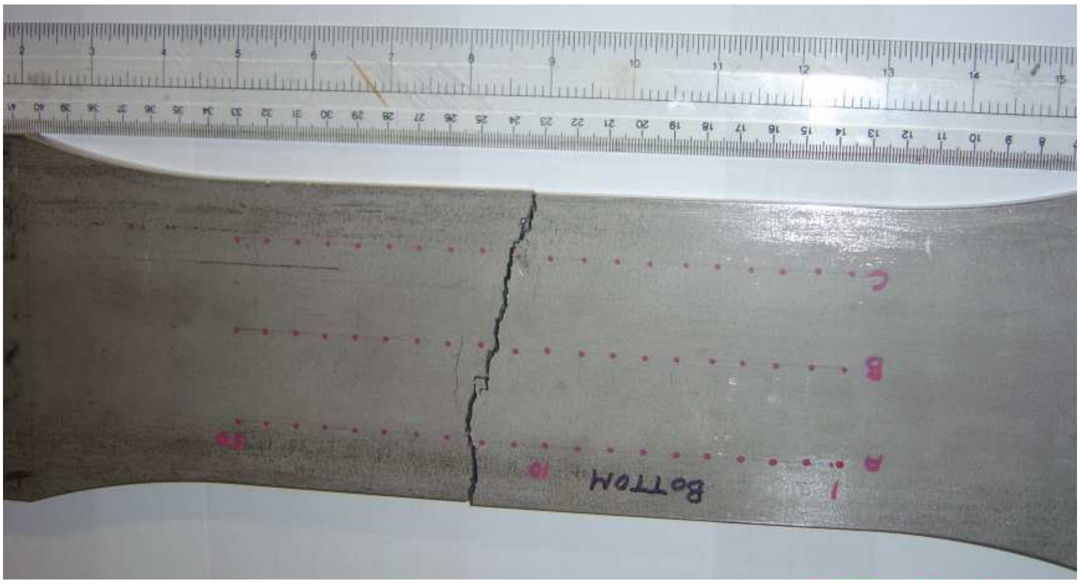
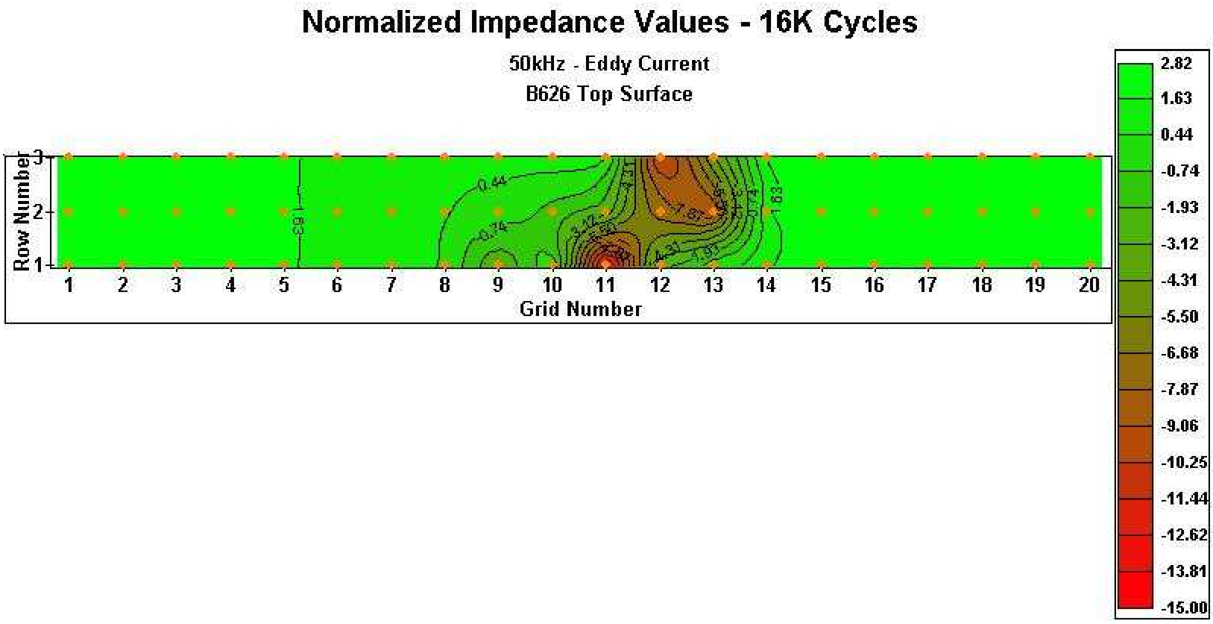


Figure 1

Cracked Type 304 L specimen at 16,870 fatigue cycles

The normalized impedance plots of the cracked specimens are shown as Figure 2. As expected, the overall reduction in the normalized impedance values was noted due mainly to the presence of multiple fatigue cracks. Negative impedance values were the results of the eddy current sensor placed in the immediate proximity to the opened crack. The overall reductions in the normalized coil impedance values were more in line or along the developed crack line shown in Figure 1.



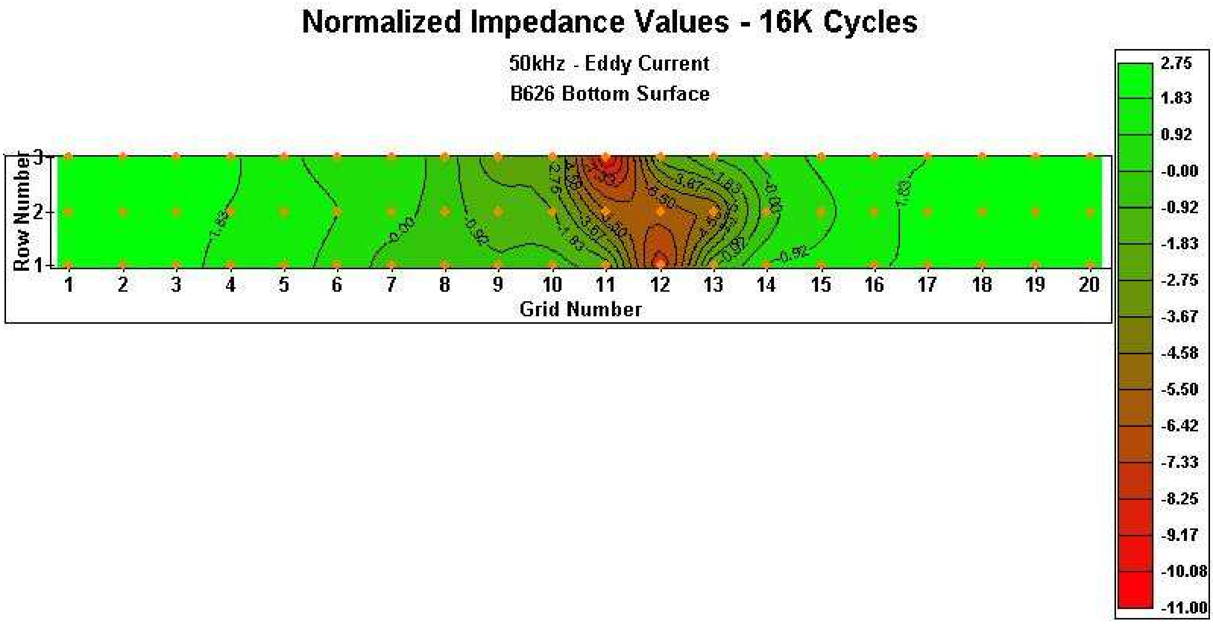


Figure 2

Normalized impedance values at 16,870 fatigue cycles

It was interesting to note that at one point before the emergence of cracks, the normalized coil impedance values increased slightly. However, with emergence of cracks, the impedance values were reduced more by the presence of cracks thus overshadowing any impedance increase from the increased material permeability.

Similarly, the percent ferrite content ranged from 1.3-1.6 on top surface and from 1.2-1.7 on bottom surface at the beginning. By the time the specimen broke at 16,870 fatigue cycles, more pronounced ferrite content increase was noted, especially on one side of the cracked interface as shown in Figure 3. It should be noted that Row1 Grid 11 of the top surface is same as Row 3 Grid 11 of the bottom surface.

It should be noted that it is not possible to nondestructively determine the percent ferrite content directly. Therefore, a set of known reference standards was used to conduct this testing. The Feritscope instrument was calibrated first using a sample containing 100% ferrite, followed by three samples containing 0.54%, 2.64%, and 14.6% ferrite content.

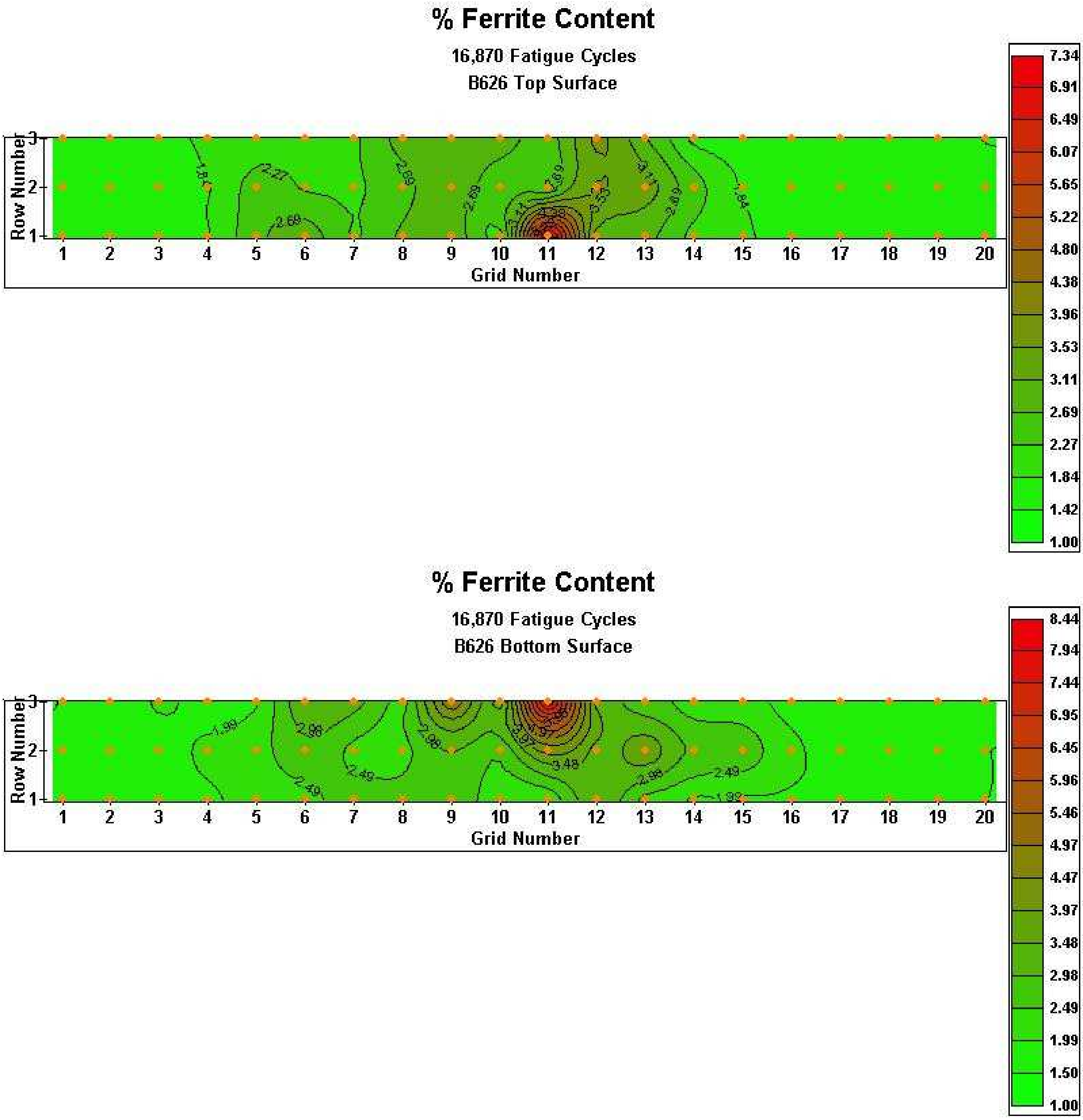


Figure 3

Percent ferrite content by DC field measurements after 16,870 fatigue cycles

Fatigue Testing of Type 304 L #627 Plate Specimen

After the initial cracking of the specimen #626, more frequent measurements were made on the second plate specimen. The NDE measurements were taken from the same 6mm by 20mm rectangular area within the necked-down region of the dog bone plate specimen. As before, the measurements were taken from both the top and bottom sides of the sample. This second sample was fatigue cycled and data taken at 5,000, 7,000, 10,000, 12,000, 13,000, and 14,000 cycles before the sample cracked partially at 14,899 cycles. It was also necessary to cool the sample to room temperature before the data can be gathered after removing the sample from the tester.

Figure 4 shows the area of interest containing multiple surface cracks from the top side of the sample. The fatigue process was stopped before the specimen cracked completely in half as was the case for specimen #626. The sample was cracked partially through wall at top mid-point of the inspected area. The sample cracked partially closer to Row 1 Grid 7 of the top surface – this crack location on the bottom side was associated to Row 3 and fell between Grids 6 and 7. The above locations applied to detail scan regions of the normalized impedance plots. For the percent ferrite content plots, the crack location was identified as Row 1 Grid 10 of the top surface. The similar crack location on the bottom side was at Row 3 and fell between Grids 9 and 10.

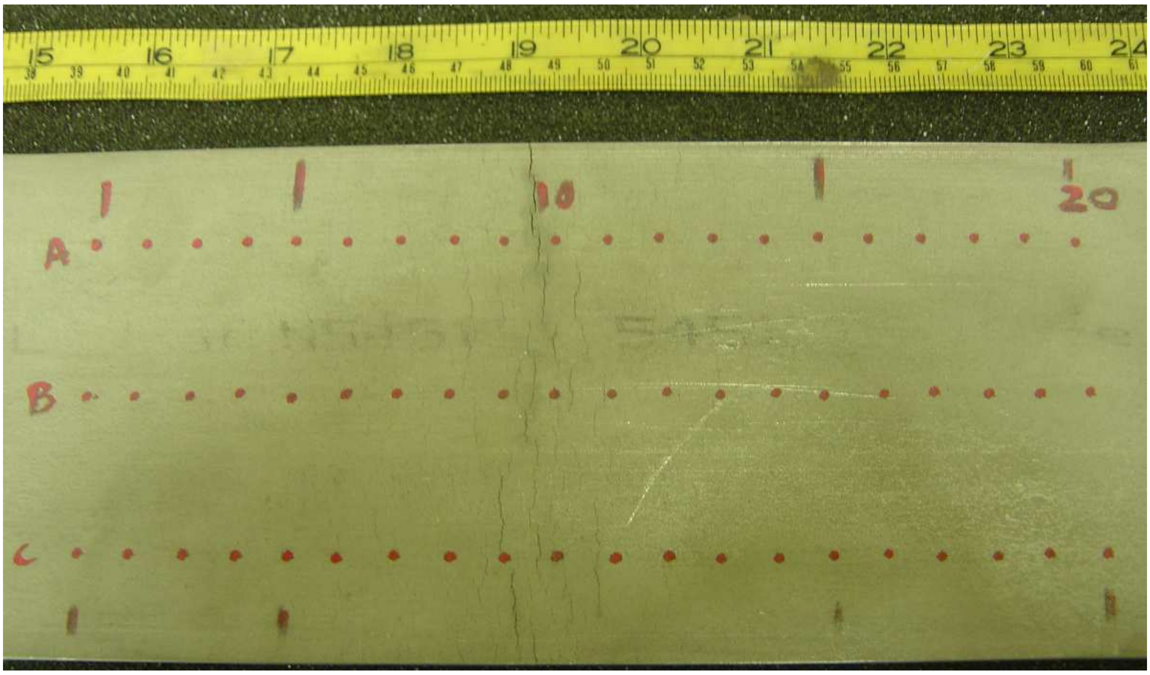


Figure 4

Partially cracked specimen #627 as viewed from the top side

Table 1 summarizes the range of normalized impedance values obtained after each fatigue cycles. Unlike the first specimen #626, no increase in the normalized impedance value was noted. Any increase in the normalized impedance due to increased permeability was more than offset by decrease in material conductivity caused by emergence of multiple fatigue cracks.

Table 1
Normalized impedance values of fatigued specimen #627

	Normalized Impedance	Normalized Impedance
Fatigue Cycles	Bottom side of #627	Top Side of #627
0	2.70 – 3.63	2.90 – 3.66
5K	2.70 – 3.57	2.70 – 3.39
7K	2.48 – 3.21	2.70 – 3.27
10K	2.30 – 3.18	2.40 – 3.14
12K	1.40 – 2.93	2.20 – 3.09
13K	0.30 – 2.99	0.5 – 2.94
14K	-1.0 – 2.94	0.5 – 2.94
15K	-4.0 – 2.96	-3.15 – 2.89

Figure 5 shows normalized impedance plots of the bottom line from top and bottom sides of specimen #627. They all indicate gradual progression of normalized impedance reduction with increasing fatigue cycles, especially after 10,000 cycles.

The major crack location is indicated by the lowest normalized impedance value. For this specimen, the crack was located at the axial location of 6 as shown in the figure. This point is equivalent to axial location 9 of Figure 4 starting from the left-hand side of the plate. The corresponding top and bottom surface profiles were very close even though they were separated by 10mm thick plate width.

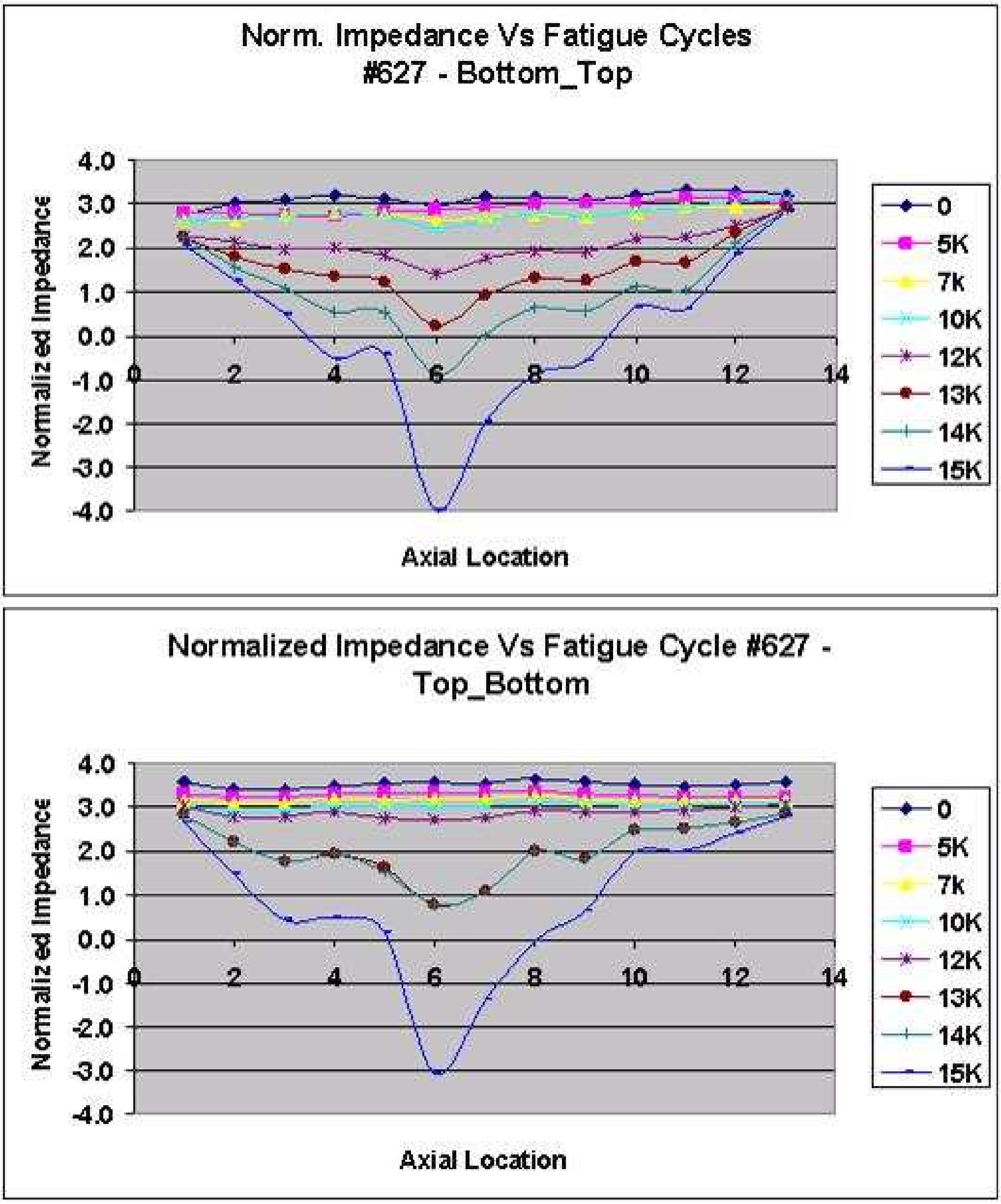


Figure 5

Corresponding top line scans of normalized impedance plots with fatigue cycles

Similarly as shown in Table 2, a gradual increase in the percent ferrite content was noted with increasing fatigue cycles. This increase in the ferrite content was attributed to austenitic SS changing into ferromagnetic martensitic condition with increasing fatigue cycles.

Table 2
Percent ferrite content of fatigued specimen #627

	Percent Ferrite Content	Percent Ferrite Content
Fatigue Cycles	Bottom side of #627	Top Side of #627
5K	1.08 – 1.30	1.08 – 1.39
7K	1.20 – 1.51	1.20 – 1.49
10K	1.10 – 1.90	1.30 – 1.69
12K	1.38 – 2.38	1.30 – 1.89
13K	1.30 – 3.02	1.30 – 2.09
14K	1.30 – 2.89	1.40 – 3.03
15K	1.30 – 3.48	1.38 – 2.95

Unlike specimen #626, where the highest percent ferrite content was located at the crack initiation site, the higher percent ferrite contents for specimen #627 were found just outside of the crack initiation site. Figure 6 shows complex nature of the observed percent ferrite contents with increasing fatigue cycles. Higher fatigue cycles did result in higher percent ferrite contents but for this specimen, those higher values did not correspond with the major crack site. As shown in the figures, higher percent ferrite contents were noted adjacent to the observed crack locations.

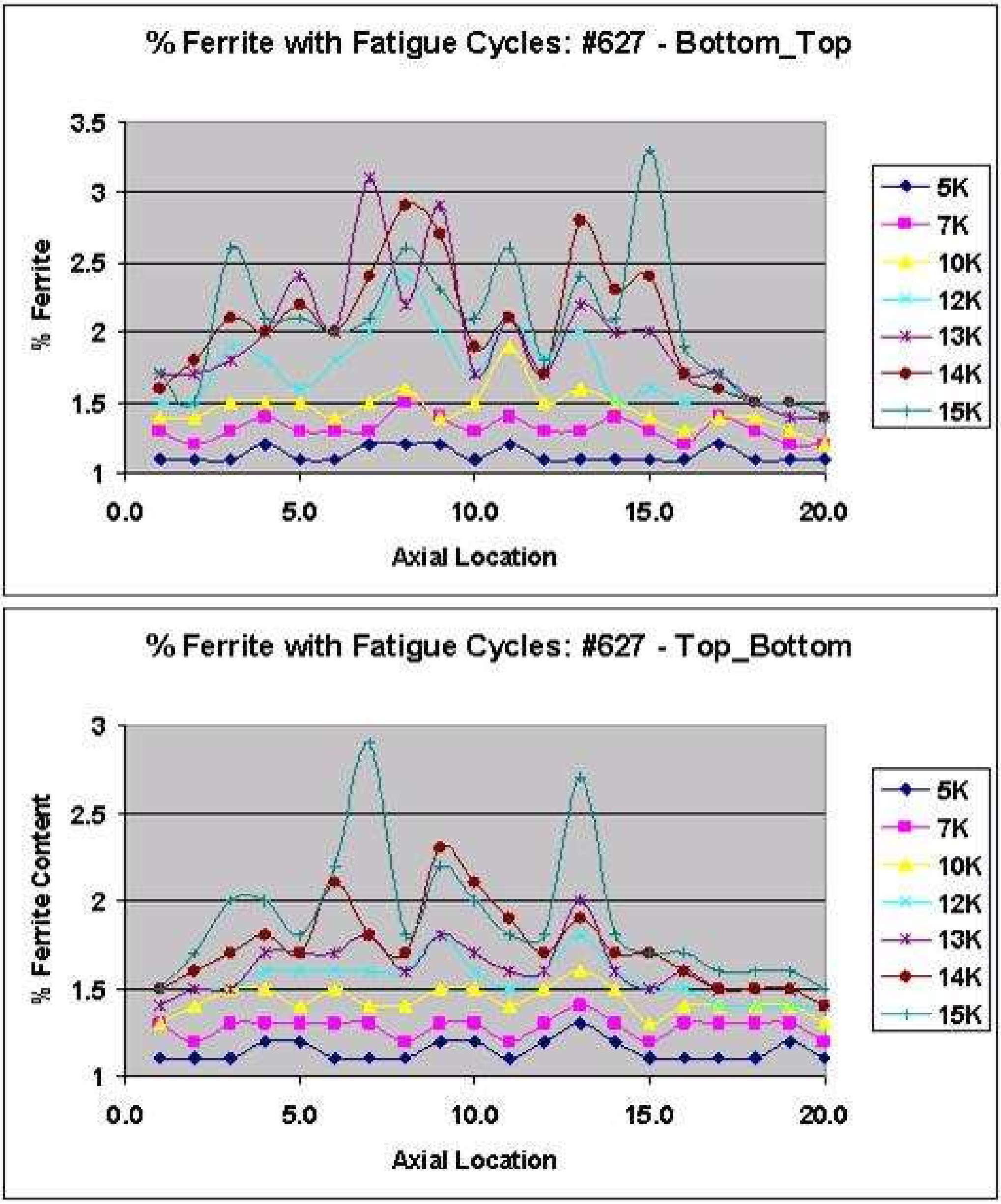


Figure 6

Corresponding top line scans of percent ferrite plots with fatigue cycles

Summary

Individual measurements by AC eddy current and DC magnetic field measurements provided complementary information about the changing material conditions prior to and after the cracks were formed.

The following observations were made from the analysis of separate AC eddy current and DC magnetic field measurements.

- AC normalized impedance values showed momentary increase in normalized impedance values during the initial fatigue cycling to 5K. This increase was due more likely to austenitic material changing into ferromagnetic martensitic condition. This increase was noted on both the top and bottom sides of specimen #626. Unfortunately, this increasing impedance condition was not noted from the normalized impedance measurements of specimen #627.
- AC normalized impedance values decreased successively with increased fatigue cycles due mainly to appearance of fatigue cracking
- The lowest impedance values were obtained along the crack line
- Any increase in the normalized impedance due to martensitic condition was more than offset by emergence of surface cracking
- Normalized impedance profiles of top and bottom sides were very similar despite the 10mm plate thickness
- DC magnetic field measurements confirmed the emergence of ferromagnetic martensitic condition from nonmagnetic austenitic condition
- The percent ferrite content increased with increasing fatigue cycling but the overall increase was about one-half the change noted in the normalized impedance values
- No appreciable change in the percent ferrite content was noted in specimen #627 in the 5-7K fatigue cycles
- Multiple sites of increased percent ferrite content were noted from both the top and bottom sides, indicating non-uniform application of fatigue cycling
- Higher percent ferrite contents were noted at adjacent to crack sites and not at the crack initiation site for specimen #627

Reference

1 K. Krzywosz, Nondestructive Evaluation: NDE for Type 304/316 Stainless Steel Material Characterization, EPRI Report 1013528, November 2006