## SPB-3. Fatigue Properties of As-Welded and Postweld Heat Treated Type 410SS Repair Welds for Steam Turbine Components

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### Introduction

This project was sponsored by Siemens– Westinghouse. Siemens-Westinghouse manufactures land-based steam turbines to generate electrical power. A large amount of 410SS is used in the power generation industry, because of its corrosion resistance and mechanical properties. When repair welds need to be made on these gas turbines, post-weld heat treatment (PWHT) is often not practical because of complex geometries and the resulting thermal distortion. The purpose of this project was to determine whether or not PWHT is a necessary step in the weld repair of 410SS components for gas turbine applications. In order to help Siemens-Westinghouse decide if PWHT is required, we have performed fatigue testing on gas tungsten arc (GTA) repair welds of 0.093" thick 410SS sheet in the as-welded and PWHTed condition. This project compared the fatigue properties of GTA repair welds done on 410SS plate in both the as-welded and PWHT conditions.

### Procedure

The work scope consisted of five tasks. The first task was to perfect the welding process and determine welding parameters including voltage, current, and travel speed with the GTAW process. The second task was to perform the welds; 20 samples were made. Half of the samples were heat treated at 650°C (1200°F) for 4 hours. Next, the samples were machined to the fatigue test dimensions. The third task was to conduct the fatigue test. The fourth task was to perform metallurgical testing. These included taking pictures of the representative microstructures, and performing microhardness tests for base metal, HAZ, and weld metal in both the as-welded, and PWHTed conditions. The final task was to analyze the data.

### Results and Discussion

These welding conditions (Table 1) were developed with the use of the Lincoln Electric Process Handbook.

**Table 1 Welding parameters for 410 stainless steel**

| Parameter | .25" Thickness | .093" Thickness |
|---|---|---|
| Passes | 3-5 | 1 |
| current (A) | 180 | 95 |
| voltage (V) | 11.7 | 11.8 |
| wire feed speed (IPM) | 15 | 11 |
| travel speed (IPM) | 4 | 3 |
| shielding gas | 100% Ar | 100% Ar |
| gas flow rate (CFH) | 35 | 35 |
| backing gas flow rate (CFH) | 25 | 25 |

The following micrographs are of both the as-welded (Figure 1) and PWHTed (Figure 2) conditions. A similar microstructure is seen in both conditions. The weld

| As-Welded | | | PWHT | |
|---|---|---|---|---|
| Stress Range (ksi) | Cycles (10^5) | | Stress Range (ksi) | Cycles (10^5) |
| 147 | 1.288 | | 120 | 1.138 |
| 117 | 3.023 | | 100 | 5.677 |
| 113 | 0.992 | | 100 | 0.89 |
| 100 | 12.71 | | 100 | 1.134 |
| 80 | DNF | | 100 | DNF |
| 60 | DNF | | 90 | 9.449 |
| | | | 80 | DNF |
| | | | 70 | DNF |

**Conclusions**

The experiments can be summarized that:

1. PWHT reduced the HAZ hardness from 450 to 300$H_V$.
2. Fatigue behavior of as-welded and PWHT conditions were similar.
3. All fatigue samples failed at the fusion boundary due to the presence of weld reinforcement.
4. PWHT of 410SS repair welds is not necessary for fatigue resistance.

In conclusion, it is recommended that the PWHT step in the repair of gas turbine engine components can be eliminated, since it does not significantly impact the fatigue properties of repair welds.

**Reference**


1. Lippold, JC. Welding Engineering 612: Stainless Steel and Non-Ferrous Metallurgy. The Ohio State University. Columbus, OH. Winter 2005.
2. Lippold, JC. Alexandrov, BT. Welding Engineering 611: Structural Steel Metallurgy. The Ohio State University. Columbus, OH. Autumn 2004.

metal, HAZ and base metal microstructures do not appear to have changed. As there are no phase transformations associated with the martensite tempering heat treatment of 410SS, a change in microstructural appearance was not expected.

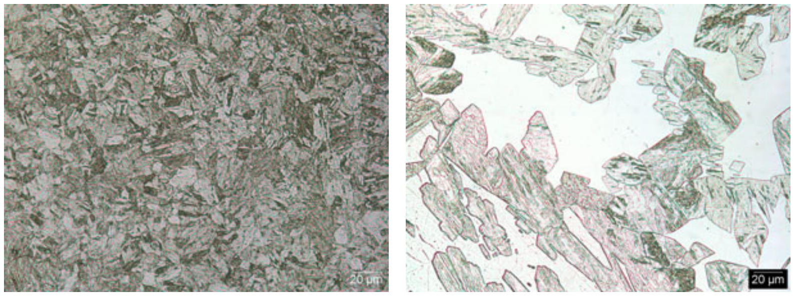

**Figure 1 HAZ, WM, 40X, as-welded condition**

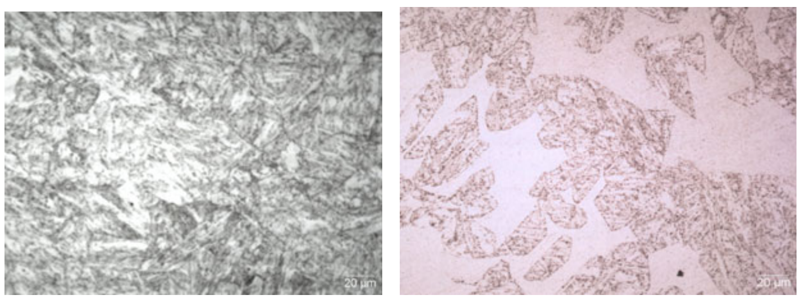

**Figure 2 HAZ, WM, 40X, PWHT condition**

Photo-micrographs of the weld metal in both the as-welded and the PWHTed conditions, show mixed microstructures of martensite and ferrite. The Balmforth diagram (Figure 3) indicates the composition lines for the nominal composition of our filler and nominal composition of the base metal. Assuming 50% dilution of base metal and filler metal, it is estimated that there is 20 to 40% of ferrite presented in the weld metal. This explains the presence of ferrite in the weld metal for both as-welded and PWHT conditions.

**Table 2 Nominal composition of AWS A5.9-93 ER410 filler metal**

| Composition | weight % | Composition | weight % |
|---|---|---|---|
| C | 0.08 | Si | 0.5 |
| Cr | 11.5-13.5 | P | 0.03 |
| Cu | 0.75 | S | 0.03 |
| Mo | 0.75 | Ni | 0.6 |
| Mn | 0.6 | | |

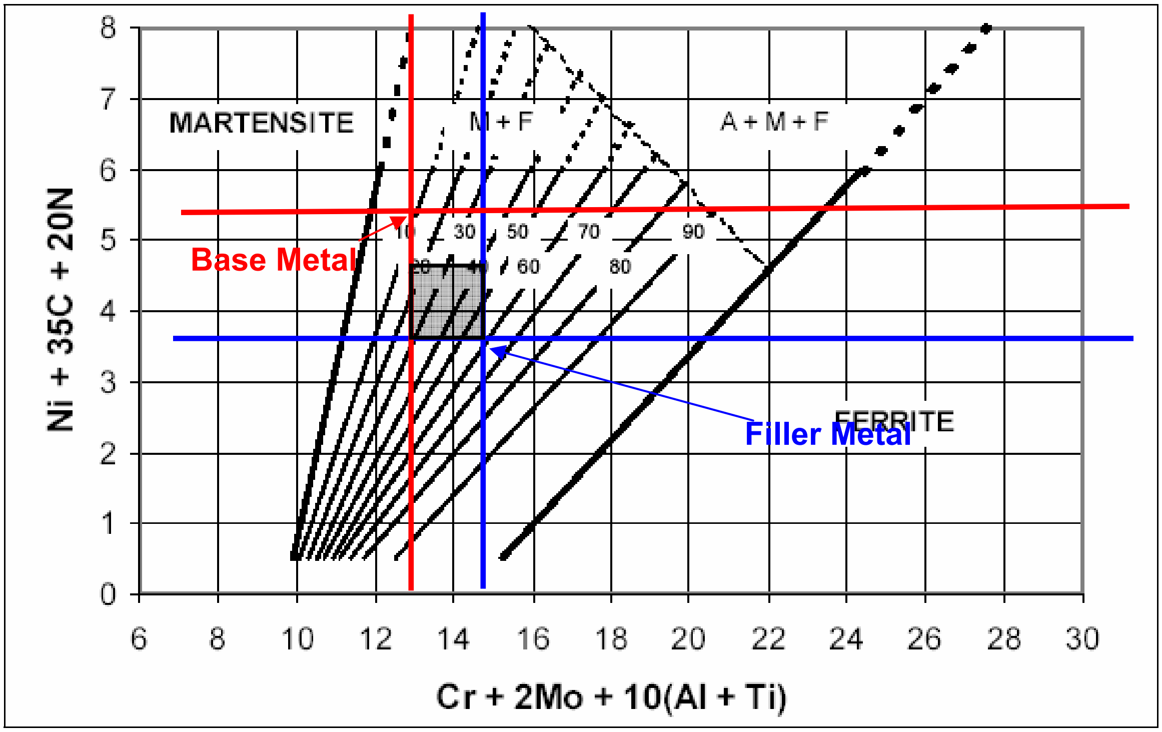


**Figure 3 Balmforth diagram with nominal filler metal and base metal compositions plotted. The gray box indicates the ranges of possible ferrite/martensite fractions in the weld metal based on dilution of the filler by the base metal.**

Although there was no change in the phases present after the heat treatment, there was a significant change in their hardness. Figure 4 shows micro-hardness test results. It shows a hardness drop in the weld metal compared to the base metal for both the AW and PWHTed condition. This change is due to the presence of ferrite in the weld metal microstructure as opposed to the fully martensitic base metal.

More significant changes in hardness were seen in the HAZ of the AW and PWHTed conditions. This change in hardness is a result of carbon migration (ref. 1). The PWHT introduces enough thermal driving force to allow the decomposition of martensite into ferrite and carbides.

Ultimate hardness is based on the amount of carbon in the martensite. It is important to remember that martensite is actually a specific morphology of ferrite and carbides that results from a massive diffusionless shear transformation (ref. 2). The presence of both ferrite and carbides is key to the understanding of the mechanisms that occur. As the carbon locally diffuses out of the matrix and serves as a nucleation site, the carbides ($Fe_3C$) grow and/or increase in number. And as the amount of dissolved carbon decreases, the ultimate hardness of the martensite decreases.

The peak in the hardness of the as-welded HAZ is a result of a specific temperature regime experienced in that area. In this regime, the base metal martensite will be completely austenitized and any carbides will be dissolved. The dissolution of carbides results in an increase in the amount of free carbon in the microstructure. Carbon is extremely soluble in austenite, so the free carbon is absorbed and dissolved in the newly formed austenite. At lower temperatures, the solubility of carbon in austenite decreases. However, the cooling rates associated with welding are sufficiently high to overcome the rate of carbon precipitation out of the matrix. Thus the carbon is effectively trapped in the austenite. Upon final cooling a supersaturated carbon martensite remains. The high carbon level is what gives this region of the HAZ such a high hardness.

During the PWHT, there is enough thermal driving force to allow for carbon precipitation out of the prior austenite grains. Upon precipitation, the carbon will combine with iron, and other elements to form carbides ($Fe_3C$ and $M_{23}C_6$). The second type of carbide, the $M_{23}C_6$ is most commonly formed in the presence Cr, where it becomes $Cr_{23}C_6$ (ref. 1).

It should be noted that there is a difference of nearly 100Hv between the left and right HAZ in figure 4. The reason for this is multi-pass partial tempering. The specimen that was tested for hardness was of the 0.25" thickness. 3-5 weld passes were required to fill this joint. As weldments are laid on top of each other, the bottom bead will experience a second or possibly third thermal cycle. This additional heat input is sufficient to allow for some carbon precipitation out of the high carbon martensite. As carbon precipitates out, $Fe_3C$ is formed and the amount of carbon in the matrix is decreased. Thus the hardness of this microstructure will also decrease. The anti-symmetry of the hardness profile is due to this phenomenon. The left side of the weld has the hardness that is associated with a single weld thermal cycle, so it must have been the final filler bead.

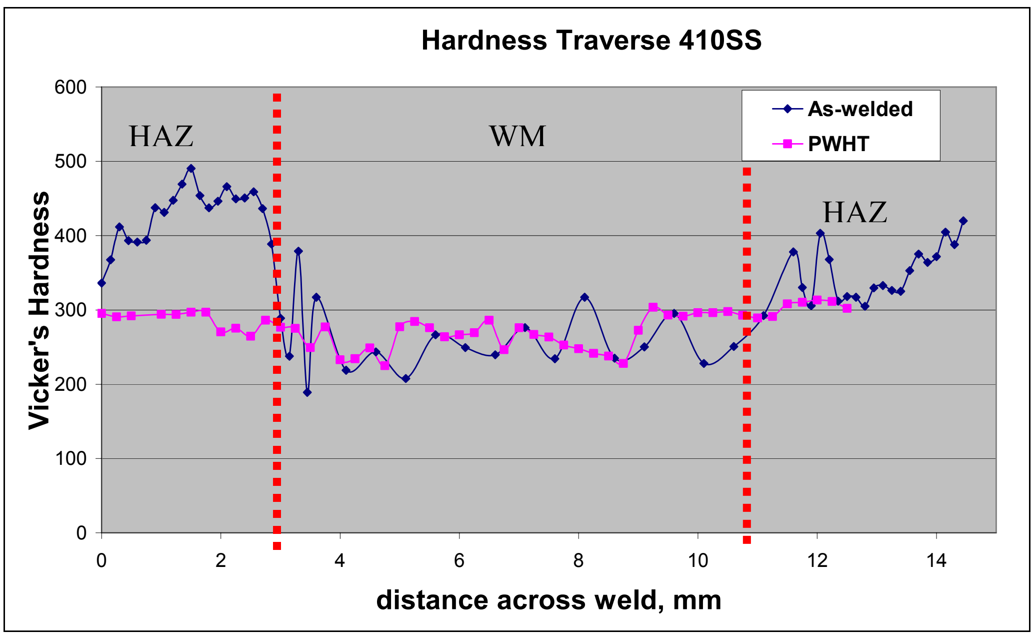


**Figure 4 Micro-Hardness results for As-Welded and PWHT conditions**

The fatigue data is shown in Table 3. From Table 3, it can be seen that the endurance limit for the as-welded condition is between 100 and 80 ksi, while the endurance limit for the PWHTed samples is between 90 and 80 ksi. Since these values are very similar, and even overlapping, the effect of PWHT are not marked enough to merit this extra step in a repair procedure.

**Table 3 Fatigue test results (DNF: do not fail)**