Microstructural Analysis of Thick Section Austenitic Steel Weldments

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Abstract

Investigational metallography and fractography is performed on welded tie plate specimens for the ITER Central Solenoid system. Metallography shows anomalous microstructural appearance at some weld pass interfaces that could be related to the reduced fatigue performance of the samples. Chemical analyses of the unusual weld pass interface regions revealed higher manganese, lower iron, and lower nickel content than expected in the samples. Correlation of the unusual microstructural regions with the fracture surface is evidence that there is an issue with the quality of the weld which affects the fatigue life of the specimens. Weld microstructure, fatigue and fracture specimen fractography, and localized chemical analyses are shown that help the understanding of the welded tie plate's mechanical performance.

Introduction

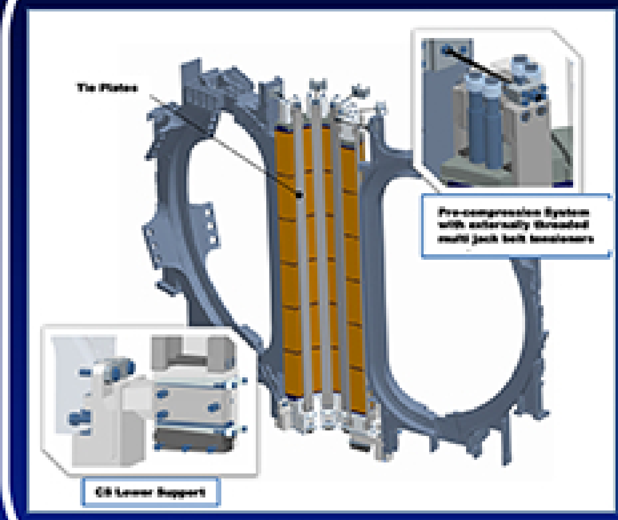


Figure 1. Section view of the CS with tie plate.

ITER (International Thermonuclear Experimental Reactor) is a multinational energy project currently under construction in France which will hopefully be the future of energy. The main goal of the plasma fusion reactor is **Q ≥ 10**, or to deliver ten times the power it consumes. The Central Solenoid (CS) coil occupies the bore of the ITER tokomak and provides a dynamic magnetic field which inductively drives the plasma current. The ITER Central Solenoid (CS) is comprised of six independent coils, stacked vertically and held together by a large pre-compression support structure designed to restrain huge electro-magnetic forces during the current pulse. Sized to meet stress requirements, the tie plates are 15 m long and 108 mm to 65 mm thick. Nitronic 50 was chosen as the base metal for the tie plates based on 295 K and 4 K performance, and for the welded tie plates, 316LMN was chosen as the weld filler metal using the Gas Metal Arc Welding (GMAW) process. The CS tie plate must have acceptable yield strength (> 380 MPa at 295 K and 4 K) and good 4K fracture toughness (Kic > 130 MPa*M^0.5). Testing of the weld exposed a reduced fatigue performance (compared to base metal in S-n fatigue tests). Coincidentally, the weld metal is observed to have anomalous microstructural and fracture surface features. Therefore, an investigative metallography and fractography study of the welded CS tie plate test specimens has been conducted and is reported here. The goal of this research is to document the weld pass microstructure and correlate the microstructure with the fracture morphology and the resulting mechanical properties.

Results and Analysis

Of the four fatigue samples, three exhibited unusual weld pass interfaces at the initiation sites on the fracture surfaces; of the three CT samples, all three exhibited some sort of discontinuous weld passes; however, only one had severe discontinuous weld pass interfaces. Sample 33 exhibited some of the worst weld passes of all seven samples. Sample 35 did not exhibit any unusual weld passes at the fracture surface; however, it did contain substantial voids mid-sample.

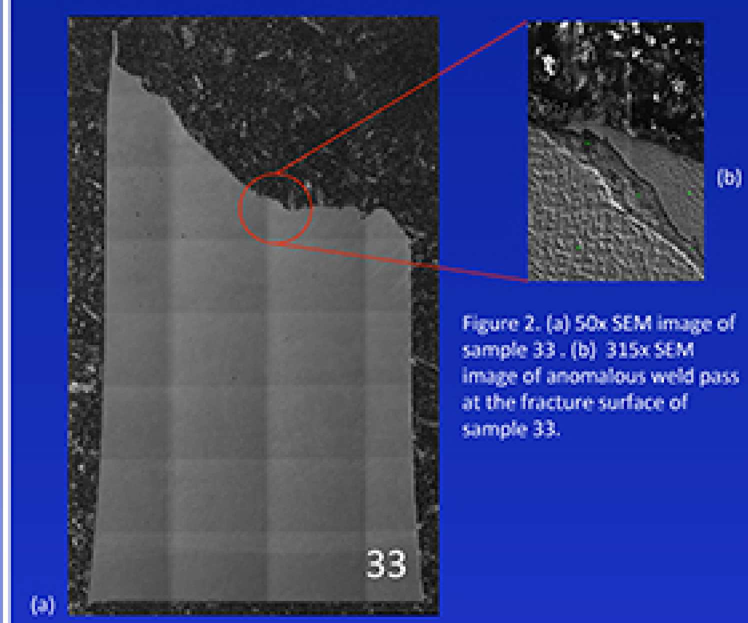


Figure 2. (a) 50x SEM image of sample 33 . (b) 315x SEM image of anomalous weld pass at the fracture surface of sample 33.

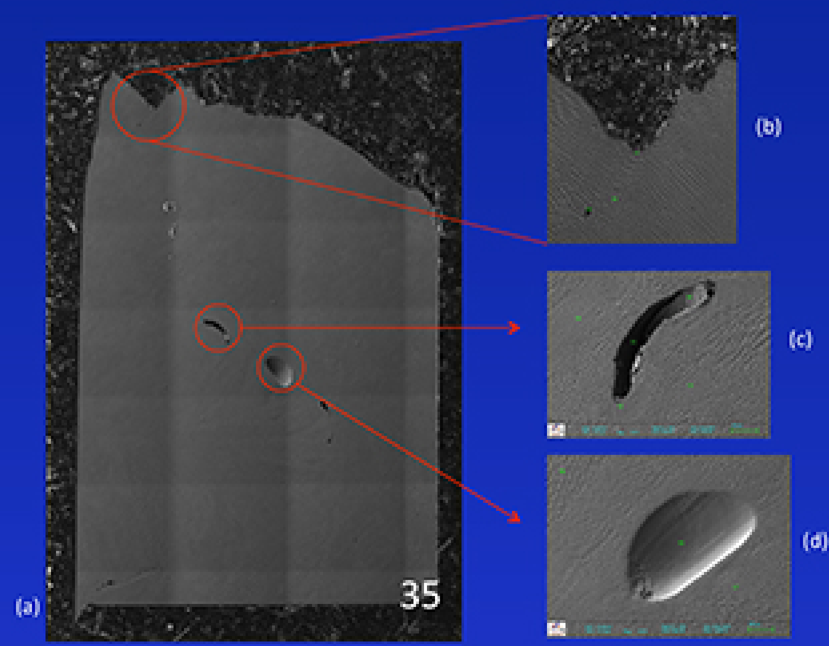


Figure 4. (a) 50x SEM image of sample 35. (b) 87x SEM image of the initial fracture surface of sample 35 which does not contain an unusual appearing weld pass like the other samples. (c) 137x SEM image of a mid-sample void in sample 35. (d) 116x SEM image of a mid-sample deep void in sample 35.

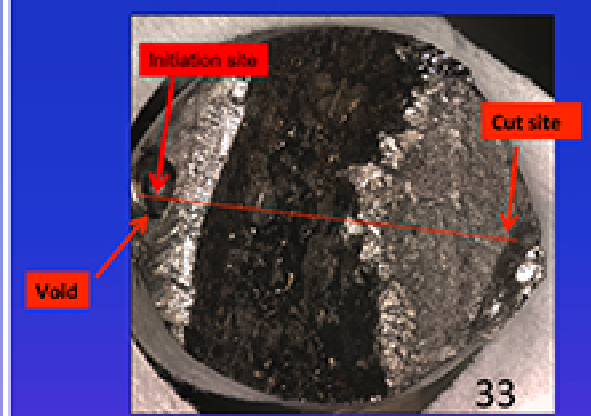


Figure 3. Fracture surface of sample 33 with initiation site, cut line, and a void marked. Anomalous weld pass material is visible around the initiation site.

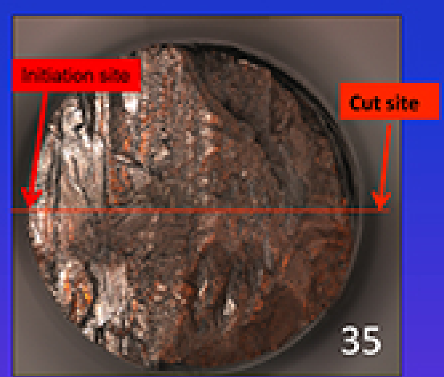


Figure 5. Fracture surface of sample 35 with initiation site and cut line marked. Anomalous weld pass material is not present as compared to Figure 3.

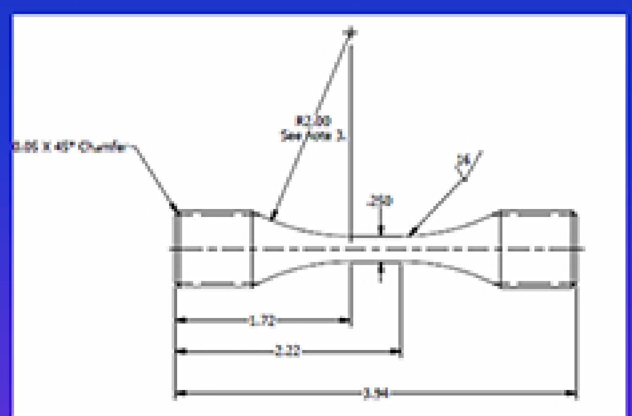
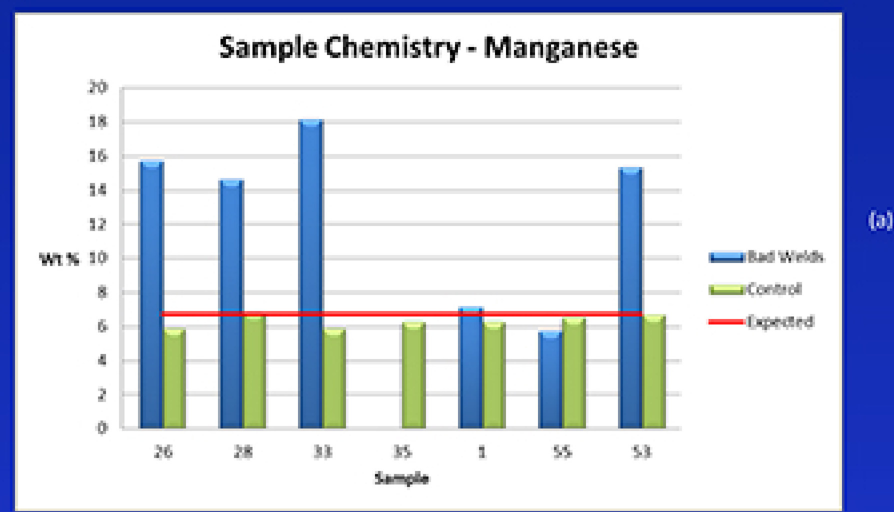
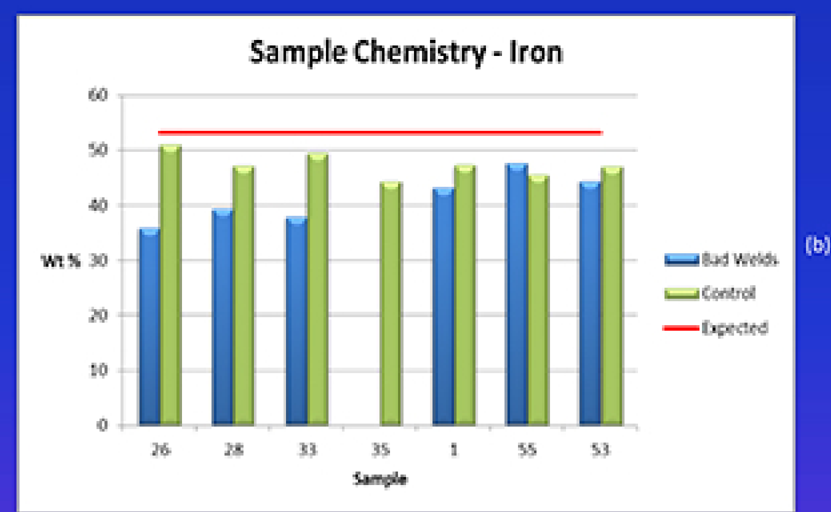


Figure 6. Schematic of the S-n fatigue samples used for these experiments.

Sample Chemistry





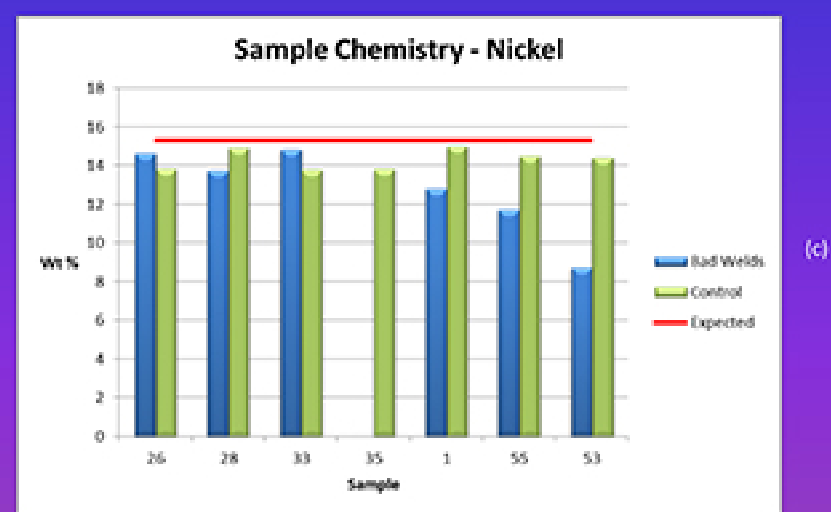
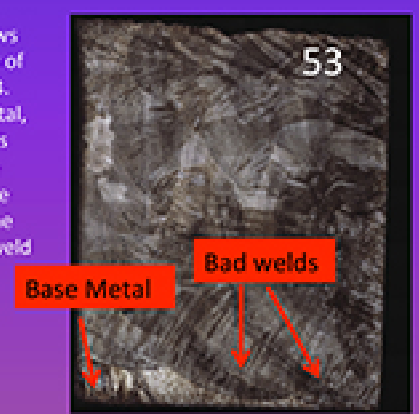


Figure 9. (a) Average sample chemistry of manganese. It is clear that the anomalous welds (blue bars) had higher Mn than the controls (green bars) and the expected values (red line). (b) Average sample chemistry of iron. The anomalous welds contained lower Fe content than the controls and the expected. (c) Average sample chemistry of nickel. The samples generally had lower Ni content than the control and the expected; although, it is not as pronounced as Fe and Mn.

Figure 7 shows the end view of CT sample 53. The base metal, Nitronic 50, is visible at the bottom of the image and the anomalous weld passes are labeled.



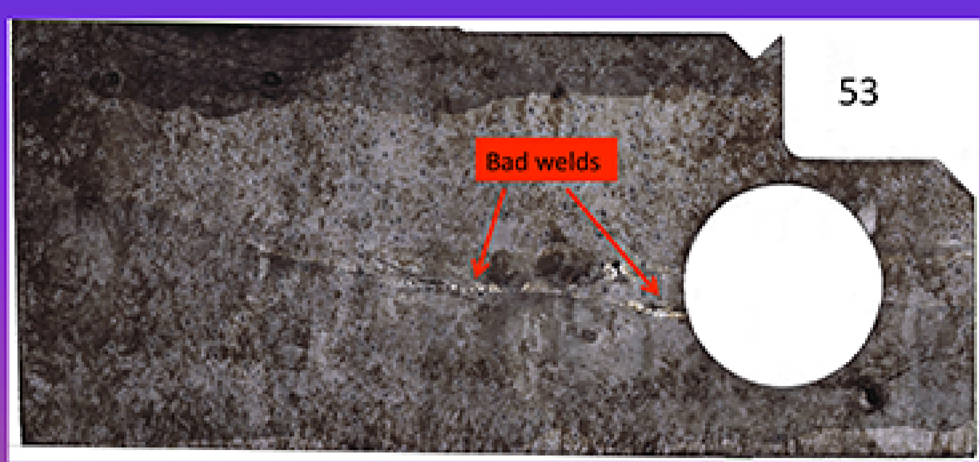


Figure 8. Side view of CT sample 53 with the anomalous welds labeled. Weld pass lines are visible at the top and middle of the sample; however, the anomalous weld pass only appears in the middle of the sample .

Conclusion

The results of the investigational metallography with optical microscopy and with an SEM provide visual evidence of the anomalous weld pass interface microstructure in 3 of the 4 fatigue samples and to some degree in all 3 of the CT samples. Correlating the anomalous weld pass interface to the fracture surfaces shows that there was some unusual appearing weld passes associated with these samples that may have initiated cracking at the dark brittle region on the fracture surface. Because the only sample that did not exhibit the anomalous weld passes (sample 35) also did not exhibit the brittle features on the fracture surface, it seems that the dark, brittle-appearing region is related to the anomalous weld pass. For the tie plate to be welded together from smaller forgings, instead of forged as a solid piece, which is the more expensive option, the room temperature yield strength and 4 K fracture toughness of the welded joints must meet or exceed the performance of the base metal. The 316 LMN welds exhibited good tensile and fracture toughness properties at both room temperature and at cryogenic temperature. However, the 316 LMN welds showed reduced fatigue performance and scattered/inconsistent results compared to the base metal.

One possible explanation for the reduced fatigue performance in the 4 K fatigue tests may be associated with the presence of a Mn-rich, Ni-poor phase at the inter-pass boundaries between adjacent weld passes. The presence of large voids within the small diameter of the fatigue samples may have contributed to early failure, both by a stress-concentration effect and by reducing the amount of cross-sectional area of weld metal to elevate the actual stress above the nominal stress in the gage-section of the sample. Localized chemical analyses of both types of samples show that the composition of the unusual-appearing weld passes contain a higher concentration of manganese than the expected value of manganese for 316 LMN. It also revealed that the unusual-appearing weld passes exhibited lower concentrations of iron and nickel than the expected values. It is thought that the anomalous weld pass interface microstructures are regions where undesired segregation and oxidation occurred during weld pool solidification. A possible remedy for this type of problem is better surface prep between consecutive weld passes. It appears that the chemical segregation results in a secondary phase material with a varied composition that exhibits brittle fracture behavior and reduced 4 K fatigue and fracture performance.

References

1 Freudenberg, K. D., & Myatt, R. L. (2011). ITER Central Solenoid Support Structure Analysis. *Fusion Engineering (SOFE)*, 1-6. doi: 10.1109/SOFE.2011.6052298
2 Walsh, R., McRae, D.M., Dalder, E., Litherland, S., Goddard, R., Han, K., Trosen, M., & Kuhlmann, D. "Welded tie plate feasibility study for ITER Central Solenoid structure." *Presentation* ICMC 18Jun2013.
3 Walsh, R.P., McRae, D.M., Han, K., & Goddard, R. (2012, December). "CS Tie Plate Structure Materials Characterization Update." *Presentation* ICMC 6Dec2012.

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