Dissimilar Weld Failure: A Forensic Analysis to Determine Primary Failure Mechanisms

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Solar receivers are an integral part of a concentrated solar power plant and commonly utilise tubular structures to absorb solar energy and transfer the heat into a heat transfer fluid. These systems often contain dissimilar materials to minimise the cost of the system. These sections, joined through welds, are exposed to frequent cyclic temperatures daily or as weather conditions change throughout the day.. This presentation will focus on the failure of a receiver exposed to 780°C, where cracks were observed near the welded tubing segment of Haynes 230 (Ni alloy) and 253 MA (stainless steel) as shown in Figure 1. A range of analysis techniques have been brought together, , such as Micro Computed Tomography (micro-CT), Scanning Electron Microscopy (SEM) and X-Ray Spectroscopy to understand the root cause of the failure and provide approaches to avoid cracking in the future.

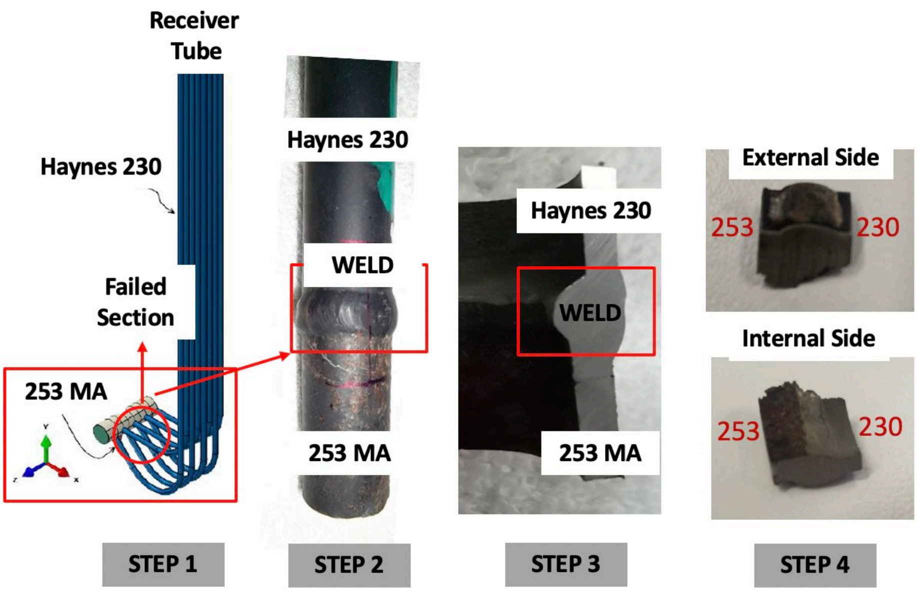

Figure 1. Crack observed on an adjacent weld (Haynes 230 - 253 MA) of a receiver tube. The section was down-sized for further investigation

Analysis showed that the interface between the weld and Haynes 230 is almost defect free. Cracks were observed on both internal and external sides of 253 MA with multiple crack initiation points (Figure 2 (a-f)), regardless of the differnece of air or CO_2. Surface oxidation and de-alloying occured in the near surface region in addition to significant oxidation of grain boundaries which can be seen in Figure 2 (g). Importantly, the area adjacent to weld showed no carbide formation at the grain boundaries on both air and CO_2 sides or any other significant chemical changes that could have been associated with the welding proceses, suggesting that carburisation is not the case causing the alloy degradation. The cracks can be casued by the significant levels of stress that was produced when temperatures were elevated upto 780 °C. Upon such thermal stress, grain boundary oxidation in 253 MA away from the weld can be propergated and the multiple cracks can be ignited, that proporgated along the grain boundaries of 253 MA consistent with brittle failure in the section. The analysis indicates that failure starts when the surface of 253 MA oxidises. The oxidation further develops to the sub–surface regions via the diffusion of oxygen through grain boundaries, in the presence of thermal or mechanical stresses, forms the horizontal cracks. Longitudinal forces then contribute to crack propagation in the vertical direction.

In summary, it is likely that the oxidation processed being promted by thermally induced stresses caused the igniion of the cracks on the 253 MA sdie, and also provided the driving force for the crack propagation. It is probably that the failure related due to thermal cycling and therefore cyclic stresses following severe oxidation and metallurgical damage to the 253 MA in particular, resulting in the mechncial failure of the tube eventually.

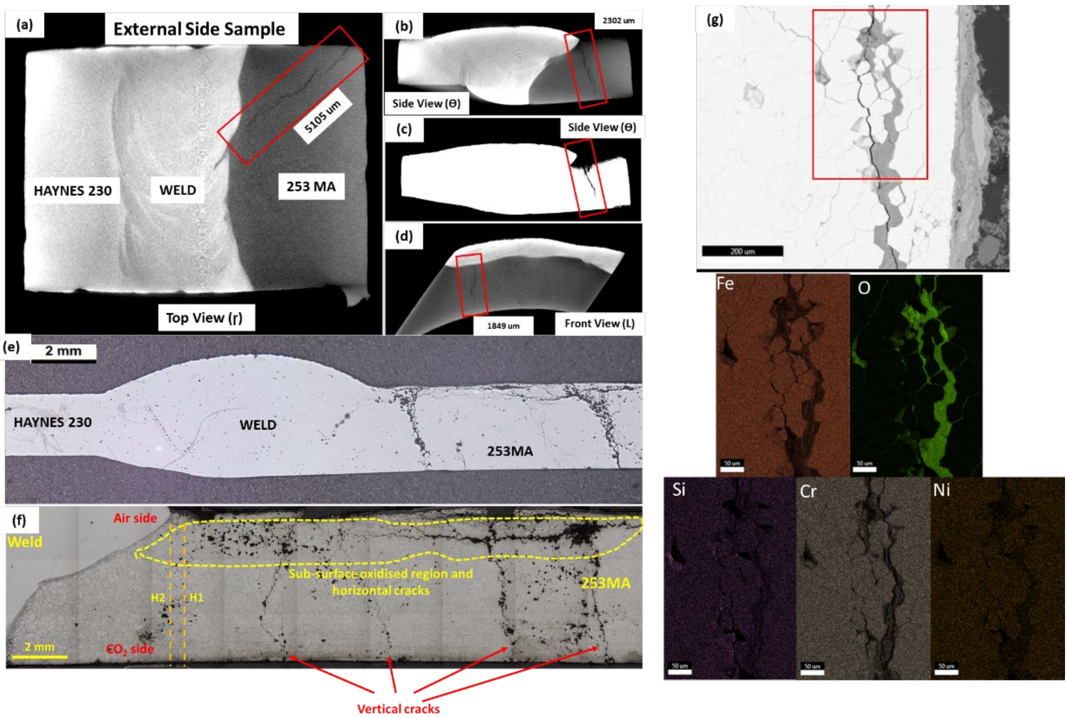

Figure 2. Micro–CT cross-section images showing (a) top view, (b) side view, (c) side view (binarized image), with pixels representing metal segmented as solid (in white colour), (d) front view (grey-scale image) of a main crack distributed inside 253 MA bulk. Optical Microscopy of cross-section tube at crack locations (e) Haynes 230 weld and 253 MA and weld; (f) higher magnification of the weld and 253 MA. (g) Element mapping showing a region enriched with oxygen compounds along the main crack propagation.

References

Yin, Y.; Rumman, R.; Sarvghad, M.; Bell, S.; Will, G.; Clegg, R. E.; Perilli, E.; Rapagna, S.; Lewis, D. A.; Steinberg, T. A.; Andersson, G. G., Dissimilar weld failure: A forensic analysis to determine primary failure mechanisms. Engineering Failure Analysis 2022, 139.