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Cracking Failure in a 253 MA – Weld – Haynes 230 Concentrated Solar Power Receiver

Raihan Rumman[1*], Yanting Yin[1], Egon Perilli[2], Sophie Rapagna[2], David A. Lewis[1], Madjid Sarvghad Moghaddam[3], Theodore A. Steinberg[3], Gunther G. Andersson[1]

[1]Flinders Institute for Nanoscale Science and Technology, Flinders University, Adelaide SA, Australia,
[2] College of Science and Engineering, Flinders University, Adelaide SA, Australia,
[3] Science and Engineering Faculty, Queensland University of Technology, Queensland,

Concentrated solar power (CSP) systems have shown great presence in power industry for their successful generation of electricity or thermal energy from renewable sources [1]. The reliability of such systems is long term, and they are known for their flexibility in working with a wider temperature range as opposed to traditional isothermal systems. As a state-of-the-art sustainable energy technology, CSP has been globally promoted and is proliferating. A typical design of a CSP unit consists of a set of mirrors, lenses, storage modules and receivers. More recently, thermal energy storage (TES) is being incorporated with CSP to allow for more effective use of the power by storing excess energy, and later discharging when required. The receiver is also considered to be a critical component, as it processes the cycling stress and temperatures in different operating environments [2]. However, while this technology is seen as beneficial for future energy requirements, the high cost of CSP compared to other forms of generation has limited its uptake. In an effort to reduce the cost of energy generation, global research focuses on increasing operating temperatures and materials selection that are sustainable while ensuring higher overall efficiency in such systems.

Research work at the Australian Solar Thermal Research Institute (ASTRI) and Commonwealth Science Innovation and Research Organisation (CSIRO) focuses on such integrated and high functioning CSP systems, including development of all individual components. Due to occasional failure of the receiver modules attributed to their design and operational defects, further investigation is required to identify the mode of failure and to suggest mitigation strategies. Material analysis of failed sections is the primary focus of such studies, where the component is investigated from a fracture point of view. Several microstructural techniques, such as Micro Computed Tomography (micro-CT) [3], Scanning Electron Microscopy (SEM) and X-Ray Spectroscopy are employed to investigate the defected regions or areas of failure. Being a non-destructive characterization method capable of providing three-dimensional images, X-ray micro-CT can provide internal details on the materials morphology, identifying the presence of cracks, their propagation and how they can eventually cause materials to fail. This complements SEM analysis, which further identifies the grain structure, orientation and how cracks propagate in their presence. The combination of such techniques to investigate and validate failure modes is still relatively new, but have shown great success in many metallic alloys, such as steel [4].

This paper aims to investigate the cracking failure in a 253 MA – Weld – Haynes 230 section of a receiver module. The welded section connects two steel components, which as an overall unit, is occasionally seen to fail structurally. The study will look deeply into the crack initiation points with propagation and failure mechanisms.

Tube-shaped samples were water-jet cut into 10×10 mm^2 plates with a thickness of 3 mm, in preparation for analyses. The plates were cut out to have a welded section in the middle the two different materials, Haynes 230 and 253 MA. Elemental composition of Haynes 230 and 253 MA is detailed in table 1.

Table 1: Elemental composition of Haynes 230 and 253 MA.

	C	Fe	Ni	Cr	Si	Mn	W	Mo	Co	Al	Density (g/cm^3)
Haynes230	0.1	3	60	22	0.5	0.65	14	0	0.4	0.3	8.97
MA253	0.075	65	11	21	1.5	0.6	-	-	-	-	7.8

Fig. 1 shows an SEM cross-section image of the 253 MA section, which was welded to Haynes 230. SEM analysis shows presence of multiple cracks, propagating primarily through grain boundaries of 253MA, which is a clear indication of a brittle failure in the section. It can also be seen through the analysis that cracks are formed on both internal and external sides of 253 MA with multiple crack initiation points. The exact spot where a crack was first generated is not clear as it appears that there are multiple sections affected by the stress conditions. Some cracks are seen on both sides of the welded section, confirming possible initiation sites. Some grains seem to also demonstrate a planar separation along grain boundaries. This can indicate that a mechanism of expansion and contraction played a role, due to varied thermal coefficients between the materials. It was also found through the EDAX analysis that Cr was primarily oxidising at the cracks, which, due to its brittle nature, has the potential to cause further generation and propagation of cracks, reducing the fracture toughness of the overall material. In our micro-CT studies, we were able to see multiple, up to few mm long and irregular cracks, some generating from the welded section propagating into 253MA.

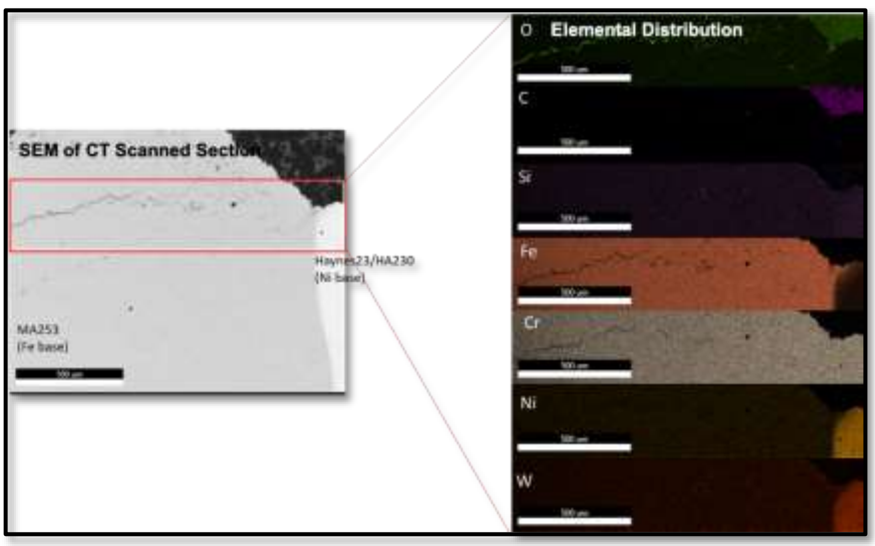

Fig. 1: SEM image showing presence of cracks and propagation along grains boundaries in 253 MA.

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