Journal of Materials Processing Technology 241 (2017) 54–63

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Applying electron backscattering diffraction to macroscopic residual stress characterisation in a dissimilar weld

K. Abburi Venkata[a,*], C.E. Truman[a], H.E. Coules[a], A.D. Warren[b]

[a] University of Bristol, Solid Mechanics Research Group, Department of Mechanical Engineering, Bristol BS81TR, UK
[b] University of Bristol, Interface Analysis Center, HH Wills Physics Laboratory, Bristol BS81TL, UK

ARTICLE INFO

Article history:
Received 16 September 2016
Received in revised form 3 November 2016
Accepted 4 November 2016
Available online 6 November 2016

Keywords:
EBSD
Dissimilar weld
Phase volume fractions
Phase dependent residual stresses
Neutron diffraction

ABSTRACT

Dissimilar metal welds are complicated in nature because of the complex microstructure characteristics in the weld fusion zone. It is often necessary to know the phase distribution in a dissimilar metal weld especially at the interface such as fusion zone and heat affected zone to be able to predict the behaviour of the joint and its fitness for service. In this paper, a dissimilar metal weld made between ferritic/martensitic modified 9Cr-1Mo steel (P91) and austenitic AISI 316LN stainless steel using autogenous electron beam (EB) welding was analysed. The weld fusion zone has a local segregation of bcc and fcc phases. The EBSD technique was applied to determine the volume fractions of each of these phases in the weld fusion zone. This information was incorporated into the analysis of neutron diffraction data from the weld zone, and the macro-scale residual stresses were calculated from phase-specific stresses arising from the welding process. The results indicate that the overall macroscopic residual stress distribution in the weld centre is predominantly compressive in nature driven by the solid-state phase transformation of the weld pool during rapid cooling, with tensile peaks pushed adjacent to the heat affected zone (HAZ)/Parent boundaries on both sides of the fusion zone.

1. Introduction

Dissimilar metal welds are often used in industrial applications and usually create a complex fusion zone that is essentially different from the parent materials. Dawson (2012) in his research has studied the interfaces in transition joints made between ferritic steels of different Cr percentages. Significant microstructural changes were reported between the base metals and the weld interface in his work. Mvola et al. (2014) have examined dissimilar joints in various steel families including case studies and concluded that the microstructure at the interface and HAZ has a major influence on the mechanical properties and performance of joint in service. Sun and Karppi (1996) have outlined the advantages of EB welding as a potential joining mechanism for dissimilar metals. However the need for extensive joint characterisation in terms of microstructure and suitability to service has been stressed. Barnhouse and Lippold (1998) researched the effects of weld microstructure on toughness and corrosion resistance in dissimilar welds between stainless steels and carbon steels. Shahid et al. (2015) observed through their studies on dissimilar friction stir welds that the microstructure of the weld can affect the tensile strength of the component due to the formation of intermetallic compounds which aid in crack initiation and propagation. Chatterjee et al. (2016) summarised through their findings that the physical and chemical dissimilarities between parent materials influence the formation of microstructure in a dissimilar metal weld. Ueji et al. (2013) based on their research on dissimilar welds concluded that the interface of the joint contained a multi-phased microstructure different from base materials. According to a case study conducted by Hajri et al. (2015) on dissimilar metal weld joint in a superheater tube, indicated that failure occurred on alloy steel side rather than stainless steel side because of decrease in creep strength and increase in hardness at the weld interface on alloy steel side as a result of the microstructure. Bala Srinivasan et al. (2006) described that the welded joint of a dissimilar metal weld between a duplex stainless and low alloy steel was significantly inferior compared to both base materials in corrosion resistance.

Another crucial and unavoidable consequence of welding process is the development of residual stresses in the welded structure arising from the differential expansion and contraction of the weld pool. This effect is even more pronounced in dissimilar metal welds, because of the significant differences in the thermo-physical and mechanical properties of the parent materials. As these residual stresses exert a strong influence on the mechanical response of

* Corresponding author.
E-mail address: k.abburivenkata@bristol.ac.uk (K. Abburi Venkata).

http://dx.doi.org/10.1016/j.jmatprotec.2016.11.003
0924-0136/

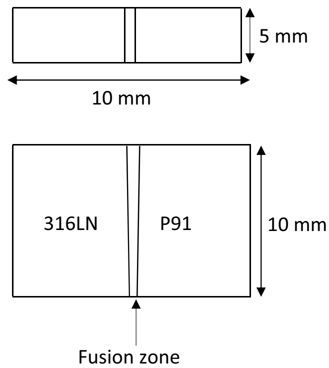

Fig. 1. Schematic representation of EBSD sample.

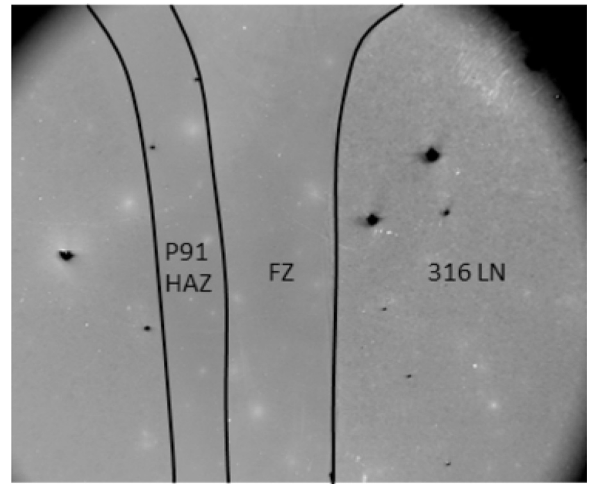

Fig. 2. Fusion boundary after mechanical polishing.

the welded joint during service, it is essential to quantify them. However the quantification is usually focussed on the macroscopic stresses alone. According to Stone et al. (2001), the usual approaches to calculating residual stresses in neutron diffraction involve either using a reflection plane that does not accumulate microstresses or use linearly combined lattice stresses such that the final reflection does not accumulate microstresses. However, in order to quantify the residual macrostress state arising from the welding process, it is crucial to identify the microstructure at the interface i.e., weld fusion zone and HAZ in terms of phase fractions and grain size.

Apart from being essential to the quantification of the macroscopic residual stress state via diffraction-based methods, the microstructure in the weld fusion zone and HAZ plays a critical role in failure. Especially in modified 9Cr steels, the microstructure at the interface has a significant influence on the creep performance of the joint and its susceptibility to Type IV failure. Abson and Rothwell (2013) based on their review on 9–12% Cr steels agreed that the fine grains in HAZ promote failure through void nucleation and/or cracking. Benjamin et al., 2009 carried out detailed microstructure evolution studies in P91 steel during fatigue and creep-fatigue conditions using EBSD. Based on the previous work done on dissimilar welds, it can be established that the joint characteristics in terms of microstructure are ordinarily extremely different from those of the parent materials and therefore need thorough characterisation to understand how these complex joints perform under the applied loads and what failure mechanisms they exhibit.

During the last decade many researchers have examined the residual stresses in welds using experimental and numerical approaches in dissimilar metal welds. Ferro and Berto (2016) attempted to quantify the residual stress state and crack-tip singularity at the weld root, in welded AA-6063 Al alloy, by determining the residual notch stress intensity factors (R-NSIFs) and local strain energy values due to thermo-mechanical loading. This method is an extension to the notch stress intensity factor (NSIF) evaluation method proposed by Lazzarin and Tovo (1998) for stress analysis in welds. Ohms and Martins (2014) investigated residual stresses in a thin slice extracted from a full-scale dissimilar metal piping mock-up using high energy synchrotron and neutron radiation. Ruiz-Hervias et al. (2014) examined residual stresses in ferritic to austenitic steel dissimilar laser weld using neutron and synchrotron radiation and identified that controlling the microstructure of the weld bead can mitigate the residual stresses introduced. Kerr et al. (2013) characterised residual stresses in a dissimilar metal weld nuclear reactor piping system mock-up using neutron diffraction, contour method, hole drilling and finite element predictions as a standardising procedure for determining weld residual stresses. However Lodini (2003) observed that when using diffraction based techniques, in a multiphase material such as the fusion zone of a dissimilar weld, the second order stresses averaged over one single phase are not usually equilibrated. Nevertheless, these stresses when summed over both phases in a bulk material should equal to zero, thereby making the macroscopic stress state as simply the combined macrostresses characteristic of each phase. This can be achieved if the corresponding volume fractions of the representative phases in the weld fusion zone are known.

EBSD is a microstructure investigation technique in the scanning electron microscope (SEM) that is rapidly becoming an extremely useful tool for the analysis of complex microstructures such as weld joints to identify the phases and gather information on the grain size and texture at the interface as stated by Randle (2009) in his

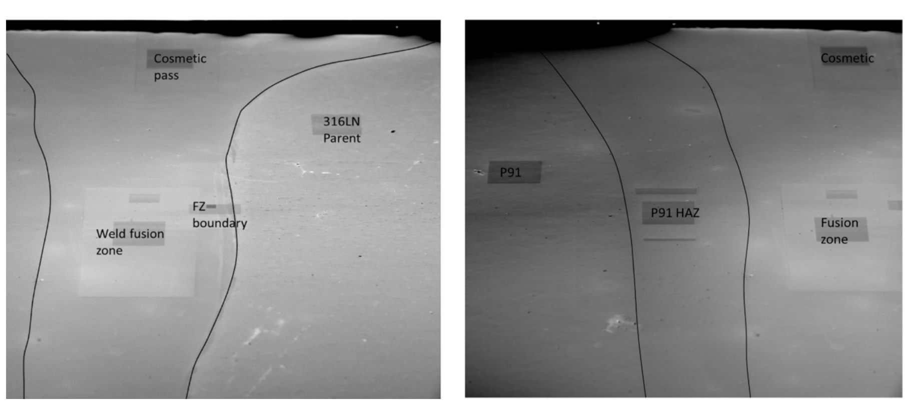

Fig. 3. Sampling area across the weld (a) 316LN HAZ/Parent (b) P91 HAZ/Parent.