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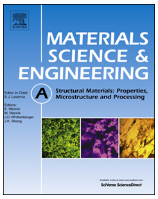

Multiscale characterisation of the mechanical properties of austenitic stainless steel joints

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ABSTRACT

A multiscale investigation was pursued in order to obtain the strain distribution and evolution during tensile testing both at the macro- and micro-scale for a diffusion bonded 316L stainless steel. The samples were designed for the purpose to demonstrate that the bond line properties were equal or better than the parent material in a sample geometry that was extracted from a larger component. The macroscopic stress-strain curves were coupled to the strain distributions using a camera-based 2D – Digital Image Correlation system. Results showed significant amount of plastic deformation predominantly concentrated in shear bands which were extended over a large region, crossing through the joint area. Yet it was not possible to be certain whether the joint has shown significant plastic deformation. In order to obtain the joints' mechanical response in more detail, in situ micromechanical testing was conducted in the SEM chamber that allowed areas of 1x1 mm^2 and 50x50 mm^2 to be investigated.

The size of the welded region was rather small to be accurately captured from the camera based DIC system. Therefore a microscale investigation was pursued where the samples were tested within an SEM chamber. Low magnification SEM imaging was utilised in order to cover a viewing area of 1 mm × 1 mm while high magnification SEM imaging was employed to provide evidence of the occurrence of plastic deformation within the joint, at an area of just 50 μm × 50 μm. The strain evolution over the microstructural level, within the joint and at the base material was obtained. The local strains were highly non-homogeneous through the whole test. Final failure occurred approximately 0.2 mm away from the joint. Large local strains were measured within the joint region, while SEM imaging showed that plastic deformation occurs via the formation of strong slip bands, followed by the activation of additional slip systems upon further plastic deformation which end up in additional slip bands to form on the surface. Plastic deformation occurred by slip and twinning mechanisms. Upon necking, significant out of plane deformations and slip deformation mechanisms were observed which suggested that plastic deformation was also happening at the last stages of damage evolution for the specific alloy. This was also evident from the large difference between the 600 MPa UTS stress value and the low stress values before final failure (which in many cases was below 30 MPa).

1. Introduction

Joining technologies have been intensively studied for over 70 years now, in many cases it is within the neighbourhood of the joints that engineering structures fail. It is due to the effect and alterations that these processes cause to the parent material that final failure may occur within, or close to the welded region. Microstructural changes to the parent material, such as grain growth and diffusion of elements to grain boundaries, as well as defects within the weld pool, like inclusions, porosity and lack of penetration, together with the development of residual stresses and (hot and cold) cracking; all these mechanisms can lead to final failure of the component [1,2].

Numerous joining processes have been developed due to the complex engineering geometries, the use of new materials and technological developments. Processes such as laser welding, electron-beam welding, Gas Metal Arc Welding and Plasma Arc Welding as well as Diffusion Bonded, Self-Pierce Riveting and

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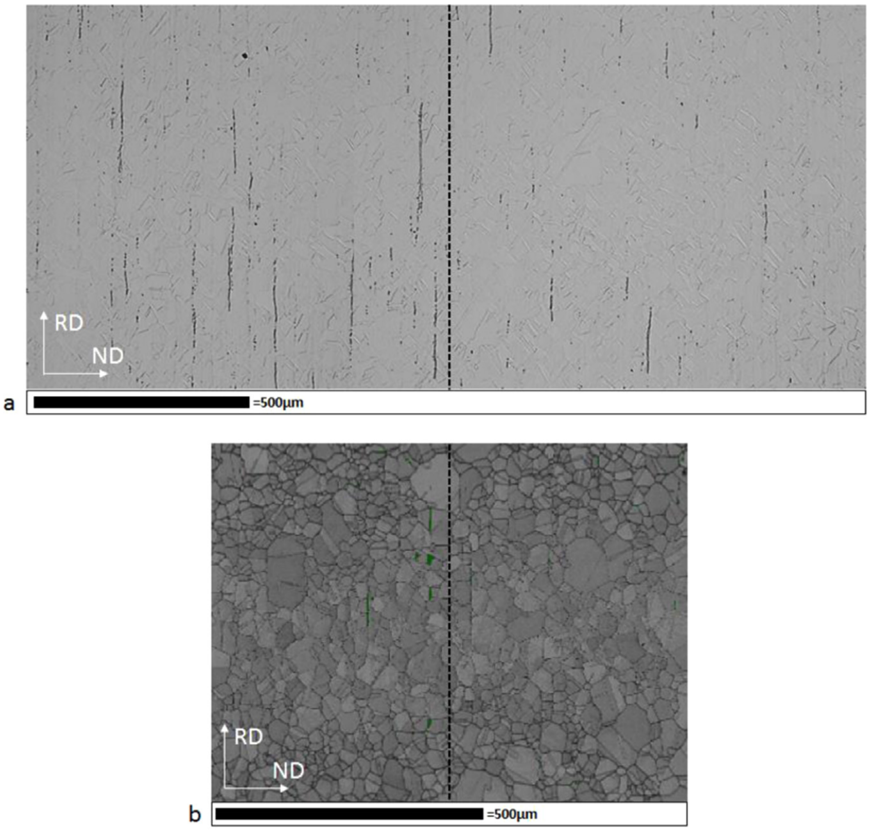

Fig. 1. a) Optical microscopy image of the microstructure of the two sheets within the region of the diffusion bond, b) EBSD map at the area of the joint. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

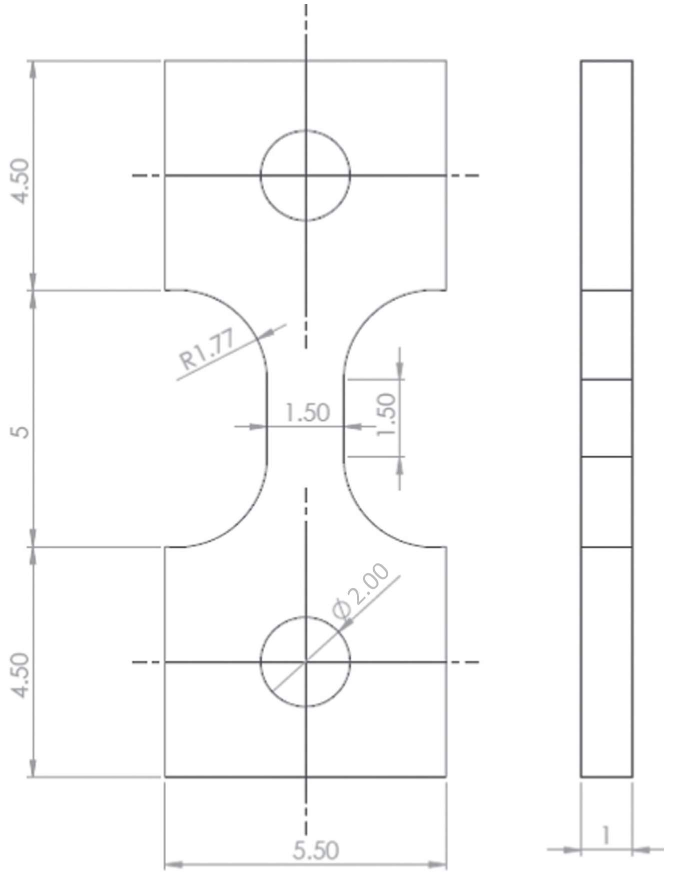

Fig. 2. Specimen geometry for room temperature tensile testing and b) Microstructure at the centre of the sample.

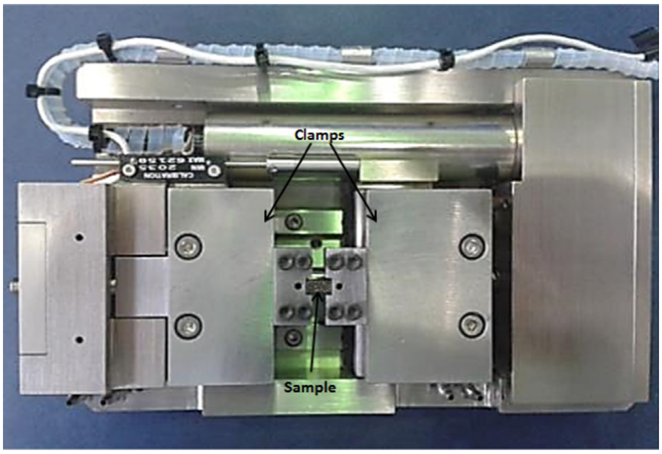

Fig. 3. 5 kN capacity micro-mechanical tester, with a painted specimen clamped.

Friction Stir Welding; as well as numerous others have been developed. All these processes allow engineers to join versatile types of materials, thicknesses and geometries [1–3]. In the first family of joining processes, considerable amount of heating is generated in the material with high heating rates, and due to the fast inhomogeneous cooling rates in the nearbourhood of the weld combined with the low temperature of the base metal lead to microstructural variations (such as grain growth), defects, distortions and residual stresses in the weld. In the later family of the processes relatively lower heating is generated at slower rates which decreases in return the cooling rates and minimises the residual stresses developed within the structure [1,2]. In this study the primary interest is on the joints made by diffusion bonding in