Through thickness non-destructive residual stress-mapping of friction stir welds in Aluminium using neutron diffraction

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Abstract

While x-ray diffraction is widely used to non-destructively screen residual stresses at the surface, deeper investigations are often carried out in a destructive manner. Neutron diffraction offers the unique possibility to map the whole stress tensor in the bulk and near the surface of a given component. Friction stir welding (FSW) is of particular interest for joining of space and aircraft components made from high strength aluminium alloys because it provides high-quality joints with low distortion. We present here a work started with OHB-System company regarding FSW on Al plates. Near-surface to bulk residual stress were measured and stress-maps are shown.

1. Introduction

The non-destructive determination of residual stresses within engineering components using laboratory equipment is limited to the surface (X-ray) or near surface regions (Barkhausen-noise) but with limited spatial resolution. Bulk stress investigations are often carried out using destructive methods. Examples are deep-hole drilling, slicing or the contour method. The destructive methods are based on the relaxation of stresses and therefore limit further materials investigations.

Neutron stress determination conquers these shortcomings. It is a **non-destructive** technique, applicable to mock-ups as well as realistic sized engineering components. It allows mapping of stress fields from the bulk of the work piece to its near-surface and provides the full stress tensor for each measuring point. The technique is based on diffraction at (poly-) crystalline material, comparable to x-ray diffraction, but provides much higher penetration. Neutron techniques are well suited for in-situ or in operando investigations, using even complex sample environment. Examples are tensile testing, fracture dynamics or casting. The non-destructive character allows the investigation of complete development cycles since the same sample can be measured repetitively, after it has received further treatment or aging tests.

SALSA, which stands for “Stress Analyzer for Large Scaled engineering Applications”, is a stress diffractometer dedicated to engineering sciences and industrial R&D (1). SALSA provides a maximum of flexibility in terms of sample size and shape, allowing laterally resolved stress- and texture determination. The resolution is variable between 0.8 and 6 mm and allows stress mapping with penetration depths of 60 mm in steel, 70 mm in Titanium alloys, 40 mm in Nickel and 300 mm in Aluminium, to give some examples. It is as well possible to obtain depth profiles from 40 microns below the surface into the bulk. SALSA can host samples from 0.5 mm up to 1.5 m length and a weight of 700 kg.

2. Investigation of Friction Stir Welds

As an example we present a result of a test series with OHB-System regarding FSW of aluminium. OHB-System (2) is one of the leading space companies in Europe, delivering satellites and high-tech components for the space sector.

Aluminium plates (2XXX series) of 250 x 700 mm^2 and 6 mm in thickness were investigated using the set-up shown in Figure 1. The scattering vector q indicates the particular strain component investigated: in this specific geometry the transversal to the weld. Special interest lied on the stress field across thickness within nugget and heat affected zone (HAZ). The sample is then positioned and scanned through the gauge volume with the help of the hexapod stage.

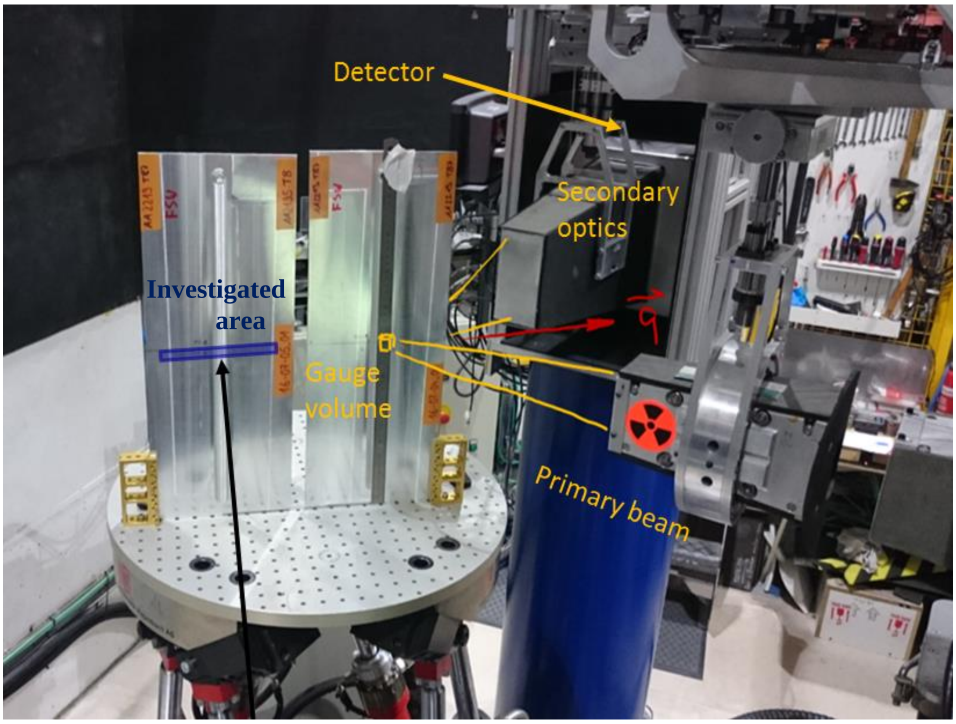

Figure 1 Set-up for measurements in two test welds at the same time. The primary beam is shaped by two radial focussing collimators. A third collimator (secondary optics) in front of the detector defines the third dimension of the gauge volume (here 0.6x0.6x2mm^3).

For each position, the Bragg-diffraction peak Al-311 is recorded. The peak position is a precise measurement of the lattice spacing of the crystallites within the material. Since this lattice spacing changes with the surrounding stress field, stresses can be determined from the peak shift when comparing to a reference unstrained condition.

Figure 2 discloses the 2D maps of the three principal stress components: longitudinal (welding direction), transversal (to the weld nugget) and normal (to the plate) for a 16 mm width and 3 mm in depth of the plate (Figure 2). The 0 origin position is referred to the surface central point of the weld. The normalized 2D stress distribution maps shows the gradient between tensile (+) and compressive (-) regions and their evolution in depth of the weld. As expected, maximum tensile values appear near the HAZ, with a transition to compression state within the weld nugget. This is a typical stress distribution, widely reported for welds. Emphasis is made in the now resolved evolution in depth, where the stresses seem to follow also the microstructural evolution (not shown). Note that stress levels are all referred to the longitudinal component, and so colours are in a different stress scale for the transversal and normal components.

3. Perspectives

There is a growing interest from various industrial sectors in neutron stress mapping because of its unique ability to provide full tensor measurements non-destructively. For instance in the space sector, NASA is investigating welds and additive manufactured parts using several techniques including neutron stress scanning (2, 3).

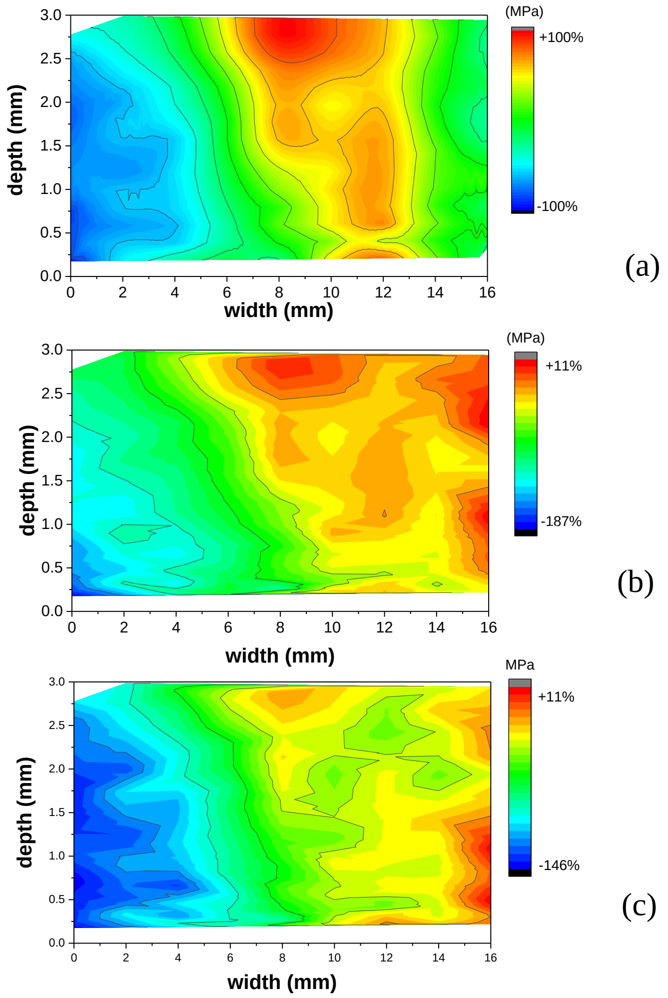

Figure 2 Residual stress 2D mapping and depth profiles of (a) longitudinal (b) transversal and (c) normal components.

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