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Characterisation of fatigue fracture surfaces of friction stir channelling specimens tested at different temperatures

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ABSTRACT

The fatigue fracture surfaces of friction stir channelling specimens tested at room temperature, 120 °C and 200 °C were observed in a scanning electron microscope (SEM) in order to analyse their morphology and the crack propagation mechanisms. Three different friction stir channelling conditions were tested and analysed. For all specimens tested the developing fatigue-crack has always initiated at the advancing side, namely on the boundary between the nugget and the thermo mechanically affected zone (TMAZ) into the interior of the specimen. The crack has propagated through the channel nugget with a path tangential to the advancing side. After the crack has reached the processed surface, a second crack initiated at the channel bottom. The fracture surfaces have shown a semi-elliptical shape crack front. This second crack has propagated uniformly through the base material. Fatigue crack propagation on the TMAZ was mainly characterised by fatigue striations. It was found, on most of the surfaces observed, a clear coexistence of the intergranular fracture mode and the transgranular fracture mode. A relationship between the fatigue testing temperature and the roughness of the fracture surfaces was found. The fracture surfaces roughness was considerably lower at a testing temperature of 200 °C for the three friction stir channelling conditions analysed.

1. Introduction

Friction Stir Channelling (FSC) is an innovative process within solid-state manufacturing technologies able to produce continuous, integral channels in a monolithic plate in a single step that was firstly proposed and patented by Mishra as a method of manufacturing heat exchangers [1]. FSC was initially based on the concept of converting the cavity defect, an internal defect in friction stir welded joints, into a stable manufacturing technique where all the material extracted from the metal workpiece is laid on the processed zone below the tool shoulder, within a clearance between the tool shoulder and the metal workpiece. In 2011, a new concept of the FSC technology was developed and patented by Vidal et al. [2]. In fact, the authors have re-invented the process. The developments carried out enable to promote a distinct material flow, where a controlled amount of viscoplasticised material from the metal workpiece flows out from the processed zone producing the internal channel without any gap between the tool shoulder and the solid metal workpiece. Thus, the material flowing from the interior of the solid metal workpiece is not deposited on the processed surface but directed outside of the

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processed zone in the form of self-detachable flash. The scrolls on the tool shoulder enable this material flow from under the shoulder centre to the periphery of the processed zone. The position and size of the channels can therefore be controlled and the processed surface can be left at the same initial level. To perform the FSC process a non-consumable rotating tool with a specially designed threaded cylindrical probe and a scrolled shoulder is plunged into the solid metal workpiece to be stirred channel and subsequently traversed along a predetermined linear or curved path keeping the tool shoulder scroll in contact with the solid metal workpiece as shown in Fig. 1.

As in other friction based manufacturing technologies, during FSC a viscoplasticised solid-state region is generated and processed into a new shape and properties. Although this region remains in solid-state, it presents a three dimensional material flow pattern that enables the channel formation. This phenomenon, described by Thomas [3], is generally referred to as the third-body region concept. In the particular case of aluminium alloys this third-body region is mechanically characterised by a relatively low flow stress and thermally by temperatures above the recrystallisation temperature but below the melting temperature of the workpiece material. Being the FSC process governed exclusively by the introduction of mechanical energy, it relies not only on the frictional heat generated between the tool and the metal workpiece, but mainly on the heat energy generated from dissipation during plastic deformation and internal viscous dissipation during the material flow, similar to heat generation during the Friction Stir Welding (FSW) process. Because the heat generated by friction dissipation tends to zero as the material gets near the fusion temperature, the maximum temperature achieved within processed zone is physically limited by the fusion temperature and thus all the deformation is restricted to solid-state condition. Therefore, it is not possible that a metal reach fusion based on its own plastic deformation.

Fig. 2 shows a schematic representation of a typical cross-section macrograph of a friction stir channel produced with a cylindrical threaded tool probe according to the concept presented by Vidal et al. [2]. The dashed lines represent the material flow path during the channelling process. The horizontal dashed lines illustrate the microstructural regions whose grains did not suffer visible size and orientation modifications.

Moreover, the ability of FSC technology to manufacture conformal channels with any desirable path has the potential to open a wide range of applications in the moulds industry. Cooling channels for normal size moulds or even for prototypes can be manufacture by FSC, which signifies the capability to replace rapid prototyping in the mould production procedure. However, the performance of a conformal cooling channel affects the quality of the moulded parts and the productivity of the process since moulds are subject to temperature variations during the injection moulding process.

Fatigue strength is one of the most important and demanding design criterion in engineering, therefore assessing the fatigue behaviour and the failure mechanisms of friction stirred channel components is required, foreseeing the future industrial application of this manufacturing technology. Several studies have been published by Vidal et al. [4–7] regarding the fatigue

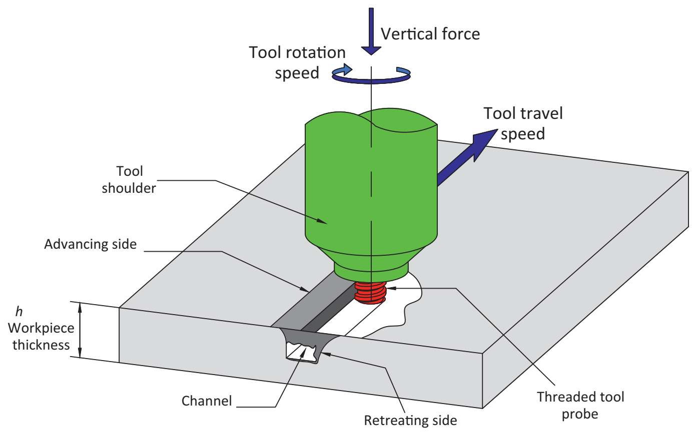

Fig. 1. Schematic representation of the friction stir channelling process and its main parameters and nomenclature.

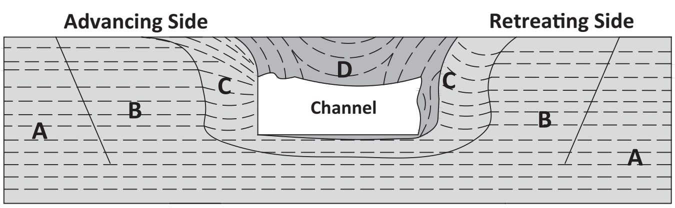

Fig. 2. Schematic representation of a friction stir channel cross-section macrograph showing the main microstructural regions: (A) the base material, (B) the heat affected zone (HAZ), (C) the thermo mechanically affected zone (TMAZ) and (D) the stirred zone – nugget.