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A preliminary study on the feasibility of friction stir back extrusion

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The feasibility of producing fine-grained tubes via the novel concept of friction stir back extrusion was investigated. A rotating tool is plunged into aluminium round bar specimens at a selected feed rate, forcing the processed material radially outwards and thus forming tubes. Preliminary results show that the process is capable of producing structurally-sound, void-free tubes; optical microscopy clearly shows the presence of a stir zone, and grain size measurements indicate significant refinement in the microstructure of the starting material.

Keywords: Severe plastic deformation; Extrusion; Aluminium alloys; Grain refining; Friction stir back extrusion

Two decades ago, The Welding Institute in Cambridge, UK developed the novel, energy-efficient, solid-state joining technique known as friction stir welding (FSW) [1]. The technique uses a rotating non-consumable tool to weld two sheets or plates together by “stirring” the material surrounding the parting line. Ever since, FSW has attracted a great deal of attention due to its advantages over traditional joining techniques. Of particular importance is the technique’s ability to join hard-to-weld metals, such as aluminium and its alloys. It is now commonly acknowledged that FSW is an attractive technology for joining lightweight metals (aluminium, magnesium and titanium alloys) [2–5], a variety of high strength steels [6], and even a wide range of dissimilar metals and alloys [7,8].

Interestingly, the severe plastic deformation associated with the stirring action in FSW was found to produce a material with fine, equiaxed grain structure in the weld zone. Rhodes et al. [9] reported a weld zone having a 2–4 μm grain size in a friction stir welded 7075-T6 aluminium alloy plate. Mahoney et al. [10] observed a grain size of 3 μm in a 7075-T651 aluminium alloy. This inspired Mishra et al. to propose adopting FSW as a processing technique that can be used to refine the microstructure of the material; thus the term friction stir processing (FSP) was first coined in Ref. [11]. FSP shares the same set-up as FSW, but the stirring tool traverses across a single sheet/plate with the intention of refining/homogenising the microstructure in the processed zone. In that early work, Mishra et al. [11] suggested exciting possibilities for using FSP to enhance the grain-size-dependexnt properties of the material. In a series of works, the authors showed what a large impact the FSP technique could have on improving the superplastic behaviour of several materials [11–14]. FSP has since been recognised as an exciting technique, attracting a lot of attention from a wide variety of researchers to further explore its potential. Additionally, FSP spurred multiple other exciting concepts based on the “friction stirring” phenomenon, including friction stir casting modification [15], friction stir microforming [16] and friction stir channelling [17].

Recently, the author has developed a new concept that is generally based on the friction stirring phenomenon and is referred to as “spiral friction stir processing” (SFSP). While FSP has been predominantly applied to sheets or plates, with the tool traversing in a direction perpendicular to its axis of rotation, SFSP targets the processing of bulk material by moving the stirring tool in the axial direction [18]. The combined rotational/axial motion of the stirring tool causes the processed material to follow three-dimensional spiral motion paths – hence the name. In this work, a form of SFSP that aims to produce tubular structures, in a process called “friction stir back extrusion” (FSBE), is introduced. The process is shown schematically in Figure 1.

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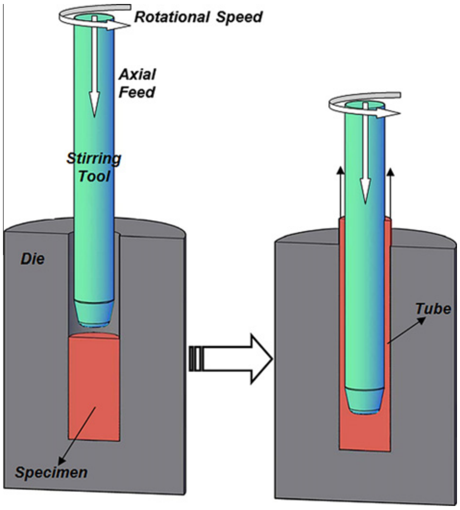

Figure 1. Schematic demonstrating the SFSP technique. Shown here is a particular configuration utilising a straight stirring tool with a tapered end, for producing tubular structures via FSBE.

In FSBE, a rotating stirring tool is plunged into a cylindrical specimen at a selected feed rate, denoted "axial feed" in the figure. The latter motion of the tool simply forces the material radially outwards in a way similar to back extrusion, while friction at the tool–specimen interface generates sufficient heat to soften the material and facilitate its deformation. Beyond that, the stirring action under the relatively high pressure is expected to impose severe plastic deformation on the material, thus refining its grain structure. The net result is a combined radial/peripheral material deformation that forms a tube with a grain size smaller than that of the starting material, as demonstrated by the results of this preliminary investigation.

The set-up used to perform the experiments resembles the schematic in Figure 1. It is simply composed of two core components: the stirring tool and the die. The stirring tool is a polished rod with $\Phi = 12.7$ mm, prepared from H13 tool steel having a surface hardness of ~65 HRC. To ease tool penetration into the material, the end of the tool was tapered by ~10°. Unlike the stirring tools used in typical FSP, a flat stirring surface with no tool pin was adopted here. The second core component of the set-up, the extruding die, was made in two halves in order to ease specimen extraction after testing. The die cavity is a blind hole with $\Phi = 19.05$ mm, thus leaving a 3.18 mm clearance from the outer surface of the stirring tool. The hole was first machined and then honed to a fine surface finish, in order to facilitate the back extrusion (upward material flow) of the test specimen. Pre-hardened P20 tool steel was used in the preparation of the die. The set-up was mounted onto a HAAS VF3 Vertical Machining Center, which was used to perform the experiments, since it provides control of the stirring tool's rotational speed as well as its axial feed.

The material considered in this preliminary investigation is the AA6063-T52 aluminium alloy, received as round bars having $\Phi = 19.05$ mm – the size of the die cavity adopted here. Specimens were prepared by simply cutting the bars into 38–50 mm slugs; no further processing was performed on the specimens before testing. The starting microstructure of the as-received material was examined at multiple locations, in order to estimate its initial grain size. Following a standard grinding and polishing procedure, Baker's etch was used to reveal the grain structure. Though homogeneous grain distribution was generally noted across the material, a few in homogeneities were detected. Measurements across the entire sample revealed an average grain size range of ~60–100 μm with an overall average of ~70 μm. Extreme locations had an average grain size of ~140 μm.

The testing procedure starts by securing the extruding die to the vice of the machining center, and then centring it with respect to the stirring tool in order to ensure axisymmetric deformation conditions. A test specimen is inserted into the die, and then the stirring tool is driven downwards against the specimen while rotating at a selected speed. After reaching the desired depth, the stirring tool is retracted (while maintaining its rotation). The processing conditions were set to 2000 rpm tool rotational speed, 2.12 mm s^{-1} tool axial feed and 4.23 mm s^{-1} tool exit speed. After testing, the extruding die is released, and the produced tubular specimen is retrieved for further examination. Because of the significant heat generated during testing, a sufficient cooling period (no less than 30 min) is allowed before another testing cycle is started. Also, in order to guarantee the repeatability of the performed tests, the stirring tool and the extruding die are lightly polished after each test.

Figure 2 shows a sample of several specimens successfully undergoing FSBE and deforming into tubes. On the left, the image shows a rather prismatic uniform tube, with clear spiral markings on the wall that exposes the processing the material underwent. A small lip is formed at the top end, but this is the insignificant product of the early stages of the tube forming process. The section view on the right clearly shows that the formed tube is structurally sound, with no signs of voids or internal channels. All such specimens were polished,

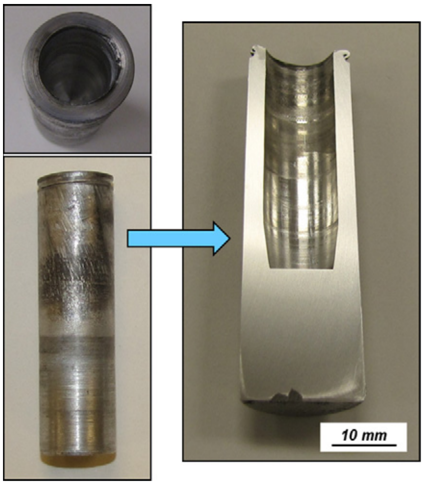

Figure 2. Sample of the AA6063-T52 specimens after processing via FSBE. The image on the right was taken from a section of the specimen after grinding with 400-grit SiC paper, and shows no signs of voids or internal cavities.