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Original Article

Frictional angular rolling extrusion of interstitial-free steel sheets☆

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ABSTRACT

Interstitial-free steel sheets were processed using a novel severe plastic deformation technique – frictional angular rolling extrusion (FARE), in order to produce ultrafine grained structures. The deformation was carried out at room temperature and individual sheet specimens were repeatedly processed to various passes. An overall grain size of 200 nm was achieved after eight passes (or an equivalent total strain of 5.3). The present paper reports the evolution of microstructures during deformation, which were examined and characterized using electron backscatter imaging and high resolution EBSD in a field emission gun SEM. The mechanisms of grain refinement are discussed.

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1. Introduction

In the last two decade or so, extensive research has been carried out in order to develop and optimize severe plastic deformation (SPD) techniques for commercial utilization. So far, of all the SPD techniques, equal channel angular pressing (ECAP) has attracted the most attention, due to its effectiveness of grain refinement and capability of producing UFG structures at scales large enough for structural applications [1–3]. However, the ECAP technique in its original form has disadvantages for commercial employment, such as limited scalability, high scrap rate and high load requirement. These limitations, plus its batch nature, result in low productivity and high material waste. Several attempts have been made to transform ECAP into a continuous process. For example, continuous constrained strip shearing (C2S2) [4] and ECAP-Conform [5] are methods for continuously processing sheets and rods to produce UFG structures. Although these techniques exhibit some useful features, they all use a long confined feeding passage for building up pressure on the work-piece to generate frictional extrusion force. This causes several problems and a major one is that the work-piece undergoes a reduction in thickness, or shape change, before entering into the die's shear zone. Consequently, the material experiences a complicated deformation path and redundant strains. This results in reduced grain refinement effectiveness and excessive requirement for torque, imposing practical limitations for scale-up.

Frictional Angular Rolling Extrusion (FARE) was developed to overcome the above-mentioned problems [6] and has been successfully applied to process UFG aluminum sheets [7]. The

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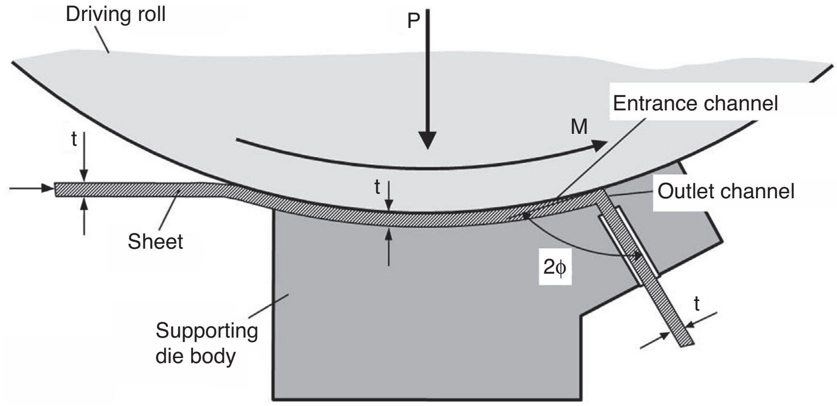

Fig. 1 – (a) Schematic diagram of the FARE setup and (b) the configuration of the die assembly and the reference system (ED, extrusion direction; ND, normal to the sheet; and TD, transverse direction).

FARE technique, as schematically shown in Fig. 1a, involves the use of an ECAP based die assembly combined with several innovative steps, including the use of a frictional driving roll, which applies a normal pressure to the work-piece without plastic compression. Thus, processing can be done continuously, like rolling, and plastic deformation occurs by simple shear as it does in ECAP. The main benefits that the FARE technique offers include the capability of processing large volumes of material in various forms, high productivity, low scrap rate, and reduced extrusion force requirement, etc. The present paper reports the result of a feasibility study on the application of the FARE technique in the production of UFG steels, focusing on the microstructure evolution and mechanisms of grain refinement during the processing of an interstitial free steel (IF steel).

2. Experimental

Fig. 1 illustrates the principle of the FARE setup established for the present investigation. The driving roll rotates to provide a torque (M) and at the same time applies a pressing force (P) to the work-piece against its supporter. The first extrusion channel is virtually formed between the driving roll and the workpiece supporter whose working surface is made to match the curvature of the sheet on the driving roll. The second extrusion channel was a short slot, to minimize friction, in the stationary die assembly. The die angle was 120° and the configuration of the die assembly and the reference coordinates used in this paper are shown in Fig. 1b.

IF steel sheets, with dimensions of 2 mm × 20–50 mm × 1000 mm, were used for the FARE processing. The material was cold rolled and annealed 820 °C for 40 min, giving a fully recrystallized starting microstructure of an average grain size of 67 μm. Deformation was carried out at room temperature and at a rate of 0.6 m/min. The sheets were processed to a various accumulative number of passes of up to 8 following route A, i.e., the sheet orientation maintained constant throughout, giving a maximum equivalent true strain of 5.3. The driving roll was mechanically roughened to enhance friction and an MS_2 spray was employed to lubricate the interface between the workpiece and its supporter, the working

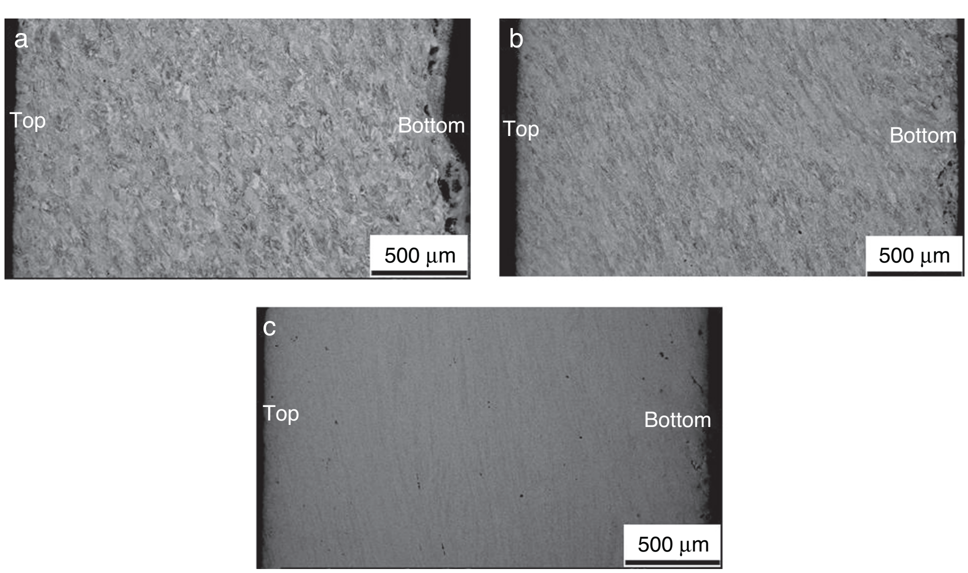

Fig. 2 – FEGSEM backscattered images, showing the effect of friction and strain (FARE pass) on the sheet surface quality: (a) 1 pass (true strain ~0.66), (b) 2 passes (1.33), and (c) 8 passes (5.3).

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