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Mechanical Properties Of Commercially Pure Aluminium Subjected To Repetitive Bending And Straightening Process

A. Krishnaiah[*,], U. Chakkingal[***] and H. S. Kim[*,****]**

[*]BK21 Education Center for Advanced Intelligent Components and Materials, Chungnam National University, Yuseong, Daejeon, 305-764, Korea
[**]Department of Mechanical Engineering, University College of Engineering (Autonomous), Osmania University, Hyderabad 500 007, India
[***]Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras, Chennai 600 036, India
[****]Department of Nanomaterials Engineering, Chungnam National University, Yuseong, Daejeon, 305-764, Korea
E-mail: krishnaiah@nano.cnu.ac.kr

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ABSTRACT

The feasibility of using the Repetitive Bending and Straightening (RBS) process to improve the mechanical properties of commercial purity aluminium has been investigated. RBS was carried out by bending with a U-bending die of 10 mm radius followed by straightening between flat dies. The ultimate tensile strength (UTS) and yield strength (YS) slightly increased with increasing number of passes. The maximum UTS of 84 MPa and YS of 68 MPa were obtained after four passes and % elongation to failure decreased from 46% to 35% after four passes. The RBS processed Al showed poor improvement in mechanical properties as compared to other SPD processes. Repetitive bending and straightening process is therefore not an effective process to introduce fine grained structures in metals or alloys.

1. INTRODUCTION

Mechanical properties of ultrafine grained (UFG) bulk metallic materials have become the subject of intensive studies over the few years. It is well known that the yield strength and tensile strength of metallic materials can be increased by decreasing the grain size of materials to ultrafine grain level. Currently a wide variety of severe plastic deformation (SPD) processes are available for producing of ultrafine grained materials, such as equal channel angular extrusion (ECAE)[1,2], accumulative roll bonding (ARB)[3], high pressure torsion straining (HPT)[4], repetitive corrugation and straightening (RCS)[5] and groove pressing (GP)[6-9] etc. Severe plastic deformation techniques can be used to produce ultra fine grain sizes in bulk metallic materials. Some of these techniques were successfully applied to introduce a UFG structure in a variety of pure metals and alloys[10,11]. Of these techniques, only ARB and GP are appropriate to manufacture UFG sheets or plates, which is among the most widely used material shape in the manufacturing. These processes allow a material to accumulate very large strains without changing the initial dimension of the original specimen.

Repetitive bending and straightening (RBS) process is a U-bending process carried out in two steps: bending followed by straightening. Deforming the workpiece to a U-shape by bending is carried out in the first step. In the second step the bent sheet is straightened between two flat dies. The schematic diagram of the RBS process is illustrated in Fig. 1. The deformation mode of the RBS process is bending. Basically the bending strain is dependent on the radius of the die being used. According to Venugopal *et al.*[12] the U-bending strain (ε) is calculated using the following equation (1).

$$\varepsilon = 2\left(\frac{t}{2R}\right) \tag{1}$$

where, t is sheet thickness and R is radius of the die. A true strain of $\varepsilon = 0.4$ ($\varepsilon = 0.2$ in bending and $\varepsilon = 0.2$ in straightening) is imparted to the specimen in RBS process for R-10 die per each pass.

In this study, the feasibility of using the repetitive bending and straightening (RBS) process to improve the mechanical properties of commercial purity aluminium was investigated.

2. EXPERIMENTAL

The chemical composition of the commercial purity Al used in the present study is given in Table 1. The microstructure of the starting material, annealed at 500°C for 4 h before pressing, exhibited equiaxed grains of about 38 μm. The schematic diagram of the RBS process is illustrated in Fig. 1. Aluminium specimens with dimensions of 58×20×2 mm^3 were pressed using U-bending die[14] with bend radius of 10 mm (here after referred to as R-10). The tooling (die and punch) was fabricated using H11 die steel in normalized condition. A basic RBS process consists of two steps: bending followed by straightening. Deforming the workpiece to a U-shape by bending is carried out in the first step. In the second step the bent sheet is straightened between two flat dies. This bending and straightening cycle was repeated 4 times (one

Table 1
Chemical composition of the Al used in this work (in wt. %)

Elements	Fe	Si	Mn	Cu	Mg	Al
Composition	0.437	0.124	0.129	0.026	0.004	Balance

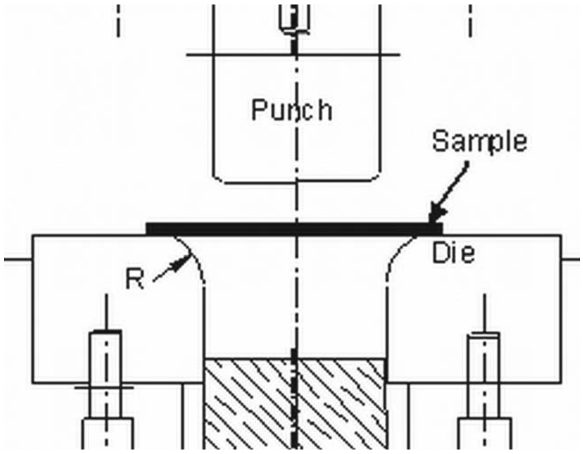

Fig. 1 : Schematic of repetitive bending and straightening process.

free bending, one die bending and one straightening is called one cycle) with 180° rotations along the longitudinal axis lying on the plane of the sheet between consecutive cycles. All experiments were conducted using a 1000 kN LUKAS hydraulic jack at room temperature with a cross head speed of 0.33 mm/s. The free bending and die bending loads were measured using 5 ton DARTEC proving ring during testing. Straightening force required was also measured during the straightening of the sheet between the two flat dies.

Figure 2 shows the configuration and dimensions of RBS specimen[13]. In order to examine the homogeneity of the deformation, Vickers microhardness measurements were made at double hatched (hardness measured at only one end because of symmetry) and cross hatched (middle) regions of the specimens. A 1 kg load applied for 15 s was used for these measurements. The hardness values were taken as the average of a minimum of 10 measurements. Tensile testing was carried out on specimens with gage length 20 mm, width 5 mm and thickness 2 mm using a 50 kN tensile testing machine at a cross head speed of 0.12 mm/s. Three tests were carried out for each condition. Data acquisition system and 500 kg load cell was used to record the tensile data for all passes. The ultimate tensile strength (UTS) was determined from the load-displacement graphs recorded during the testing. The yield strength (YS) was measured by the 0.2% offset method. The difference in gauge length before and after fracture was measured by using digital vernier and the percent elongation to failure was reported.

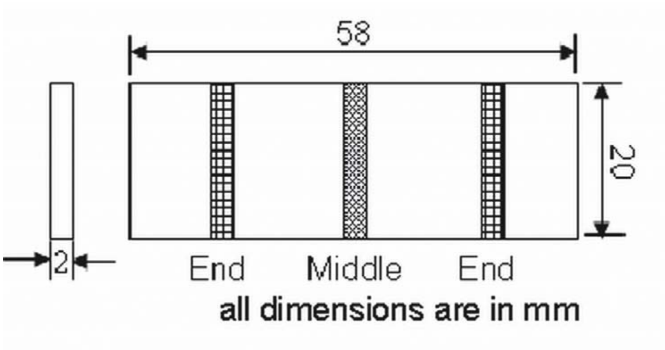

Fig. 2 : Configuration and dimensions of RBS specimen (showing deformed regions: Ends and middle).

3. RESULTS AND DISCUSSION

Aluminium specimens which were annealed at 500°C for 4 h before bending exhibited equiaxed grains of approximately 38 μm (Fig. 3). The Vickers hardness variation with number of passes is shown in Fig. 4(a). The annealed aluminium had a hardness of 26 VHN. The hardness slightly increased with increasing number of passes and reached a maximum of 33 VHN after four passes. The hardness is more at the ends compared to the middle of the sample due to the localized deformation. The tensile properties of aluminium are shown in Fig. 4(b). The sheet in the annealed condition had an ultimate tensile strength of 80 MPa and yield strength of 61 MPa. The tensile strength did not improve significantly even

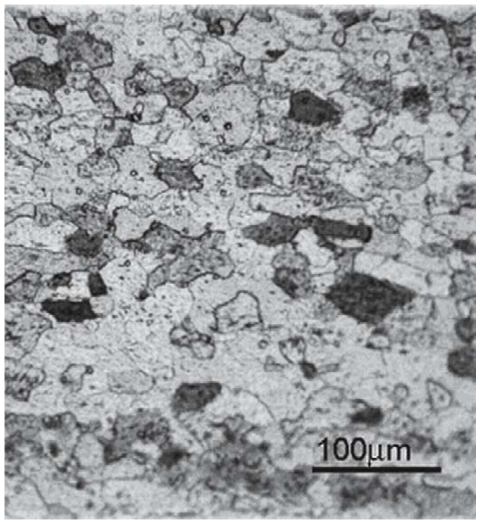

Fig. 3 : Optical micrograph of the starting material (CP-aluminium) annealed at 500°C for 4 h.

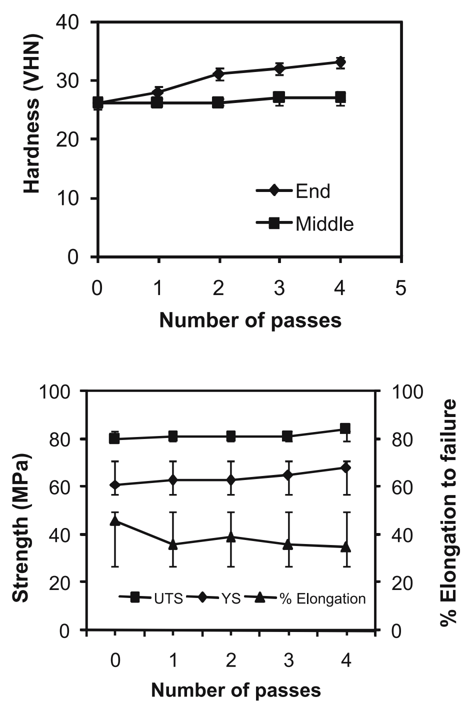

Fig. 4 : Mechanical properties of RBS processed CP aluminium using R-10 die, as a function of the number of RBS passes (a) Vickers hardness and (b) tensile properties.

though the applied strain after four passes was high (ε = 1.6 for R-10 mm die after four passes). The ultimate tensile strength (UTS) and yield strength (YS) slightly increased with increasing number of passes. The maximum UTS of 84 MPa and YS of 68 MPa were obtained after four passes and % elongation to failure decreased from 46% to 35% after four passes. The RBS processed Al showed poor improvement in mechanical properties as compared to other SPD processes because of strain localization and micro cracks that are developed. According to the Hall-Petch relation[15] strength of the metals and alloys depends on the grain size. It is therefore expected that there is no significant decrease in grain size in the RBS process. There is not much scope for producing higher strength and ultrafine grained microstructures in the sheet specimens using this process. So, repetitive bending and straightening process for Al is not an effective process. Therefore, further investigations like optical microscopy and transmission electron microscopy (TEM) were not carried out after processing. Research to enhance the mechanical properties and achieve the deformation homogeneity by modifying the process and the die designs are underway.

4. CONCLUSIONS

Annealed aluminium specimens were subjected to RBS process to study the feasibility of improving mechanical properties using U-bending die with radius of 10 mm at room temperature. Repetitive bending and straightening (RBS) did not lead to significant increase in strength and in grain refinement. So RBS is not an effective method for producing ultrafine grained microstructures.

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