A Cyclic Forward-Backward Extrusion Process for Production of Nano-Grains Materials

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ABSTRACT

A cyclic forward-backward extrusion (CFBE) process was presented as a severe plastic deformation (SPD) technique to produce nano-grained aluminum rods. According to transmission electron microscopy (TEM) and electron backscatter diffraction (EBSD) results, the average grain size was reduced from 120μm to about 100 nm after four cycles of CFBE. Yield strength and tensile strength of the specimens increased after four CFBE cycles. Compared to conventional SPD techniques, the structure produced by CFBE was more homogenous, containing nearly equiaxed grains.

Keywords: severe plastic deformation, aluminum alloy, nano-grained rods, mechanical properties, TEM, EBSD.

1 INTRODUCTION

Nano-graine (NG) materials with the grain size less than 100nm exhibit superior mechanical properties compared to their coarse grain counterparts. [1]. One practical and effective approach to produce the UFG materials is severe plastic deformation (SPD). Equal channel angular pressing (ECAP) [2], high-pressure torsion (HPT) [3] and accumulated roll bonding (ARB) [4] are the most commonly used methods Among the SPD processes Extrusion-based SPD techniques have recently interested more attention because they achieve even more extreme grain size reductions. Consequently, new extrusion-based SPD methods, such as twist extrusion [5], cyclic extrusion and compression [6], simple shear extrusion [7] and torsion extrusion [8], have been developed. However, not all of these methods are efficient enough for large scale production.

In this paper, we suggested a new cyclic forward-backward extrusion (CFBE) method to produce NG materials [9]. The initial grain size of 120 μm of specimen made of an aluminum alloy was refined to ~100nm after four cycle of CFBE.

2 EXPERIMENTAL PROCEDURES

The prencipal of CFBE used in the present study is illustrated in Fig. 1. In order to carry out the CFBE, the workpiece is first placed into the die cavity, followed by the BE of workpiece into the gap between the punch and the die. This is the end of step 1 or a half cycle of process. Then, the workpiece is extruded back, but this time by the tow outer punch, as shown in the step of Fig. 1. This results in moving the inner punch upward. The required force to push the inner punch upward is provided by the workpiece being deformed by the outer punch. The step ends when the workpiece gets flattened, i.e., turning back to its initial shape again. At this stage, the first cycle is over . Finally, after n-cycles of CFBE, the process is ended by conventional forward extrusion, resulting in the product's final shape, such as the circular rods in this work.

The AA1050 aluminum was used in this study. The initial grain size was about 120μm .Specimens with dimentions of Ø30*50 mm were machined from AA1050 billets. They were then annealed at 600°C for 2h. The CFBE process was carried out using a extrusion press with the speed of 5mm/min at room temprature. The produced rods had diameter of 10mm and length of 20cm. Tensile specimens were prepaerd from the CFBEed rods in the extrusion direction according to ASTM B557. Tensile tests were carried out by an Instron machine at the strain rate of 2.6×10-3 s-1. Vickers microhardness tests were carried out under a 1kg load applied for 15s. The microstructures of CFBEed rods were characterized by TEM using a Philips CM200 model operated at 200kV. The specimens for TEM analysis were prepared with a twin-jet polisher, and a solution of 66% methanol and 33% nitric acid was used for etching. The EBSD technique was used to study the microstructure in the areas of approximately 600 μm2 [10].

3 RESULTS AND DISCUSSION

The microstructural evaluations after the CFBE were characterized using transmission electron microscopy (TEM). Fig. 2(a) and (b) show TEM micrograph and the selected area diffraction (SAD) patterns after conventional extrusion (CE) and after four cycles of CFBE. Fig. 2(b) Obviously, the CFBE led to significant grain refinement. That is because the initial grain size of about 120 μm are broken down to the grains ~100nm. The SAD for this case indicates a sharper pattern [11-12]. Besides, the microstructure exhibits a homogeneous distribution of grain. It should be considered that such a microstructural refinement and homogeneity are achieved by four cycles of CFBE. The shear forces play the main role in grain refinement during severe plastic deformation via CFBE[10-

12]. The dominant mechanism for grain refining is the shearing and/or the subdivision of the elongated grains. Again, these results are comparable with those obtained for processing of AA1050 by other SPD methods such as ECAP [12] and friction stir process [13].

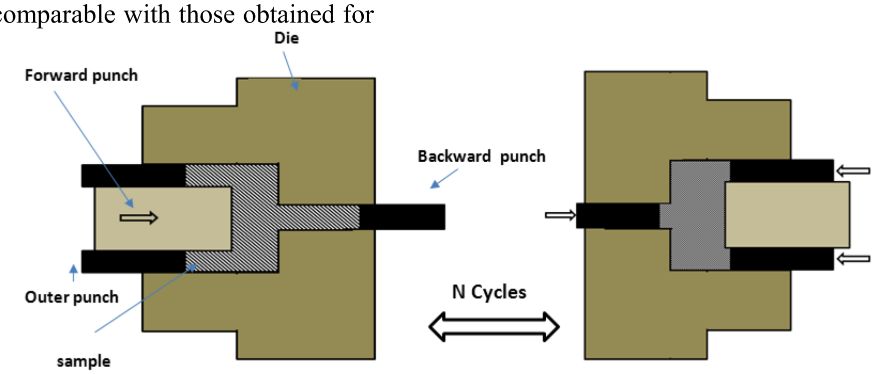

Fig.1. Schematic of the experimental cyclic forward-backward extrusion (CFBE) setup.

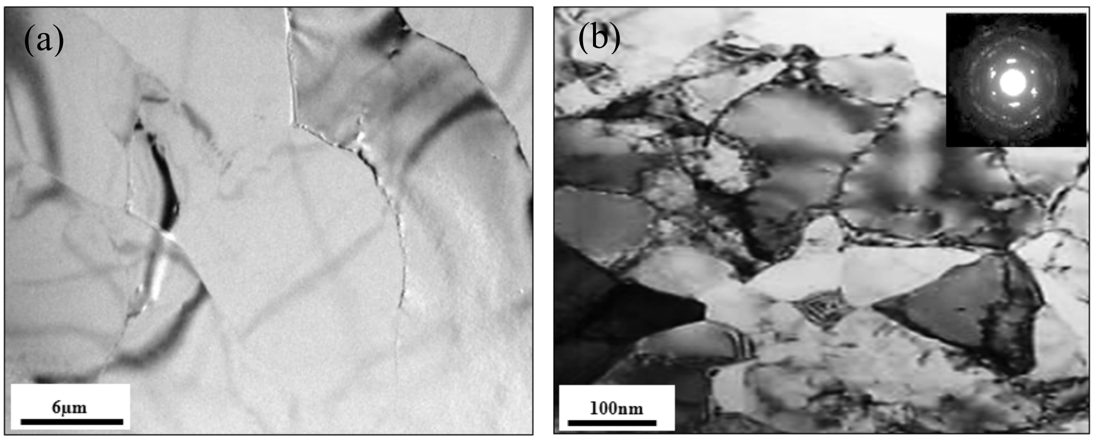

Fig.2. TEM micrographs and corresponding SAD patterns: (a) after conventional extrusion (CE), (b) after four cycles of CFBE.

The distribution of crystallographic orientations was evaluated through inverse pole figure (IPF) by using EBSD. In Fig. 3(a), colors correspond to different orientations in the IPF of AA1050 after four cycles of CFBE (extrusion direction (ED) and normal direction (ND)). The texture has more equiaxed grains distribution after four cycles of CFBE, and grains are broken down to nano grains. In addition, the orientation of each grain became more miscellaneous.

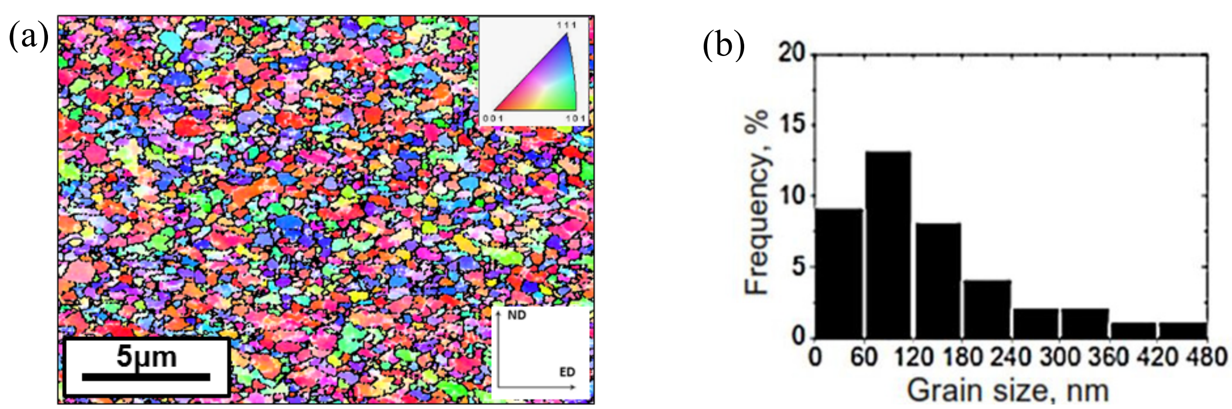

Fig. 3. A specimen after four cycles of CFBE: (a) EBSD inverse-pole-figure map (b) histograms of distribution of the grain sizes.

Fig. 3(a) also illustrates the random texture since various grains with wide color spectrum from the three angles and even from the central regions of IPF can be observed.

Fig. 3(b) illustrates the grain-distribution histogram after four cycles of CFBE. According to Fig. 3, the average grain size after four cycles of CFBE is about 100nm [14].

Figure 4(a) shows the changes in the microhardness of rods for as-recived sample, conventional extrusion and after CFBE. The hardness of specimen before CFBE is a constant value. However, there is almost a three- times increase in the hardness after four cycles of CFBE, i.e., reaching to 80-85 Hv from the initial amount of about 30 Hv.

Fig. 4(b) compares the stress–strain curves of the starting material, a conventional-extruded sample, and CFBEed specimens. The yield strength and tensile strength of the initial sample material were approximately 45MPa and 65MPa, respectively, and its ductility was 18%.

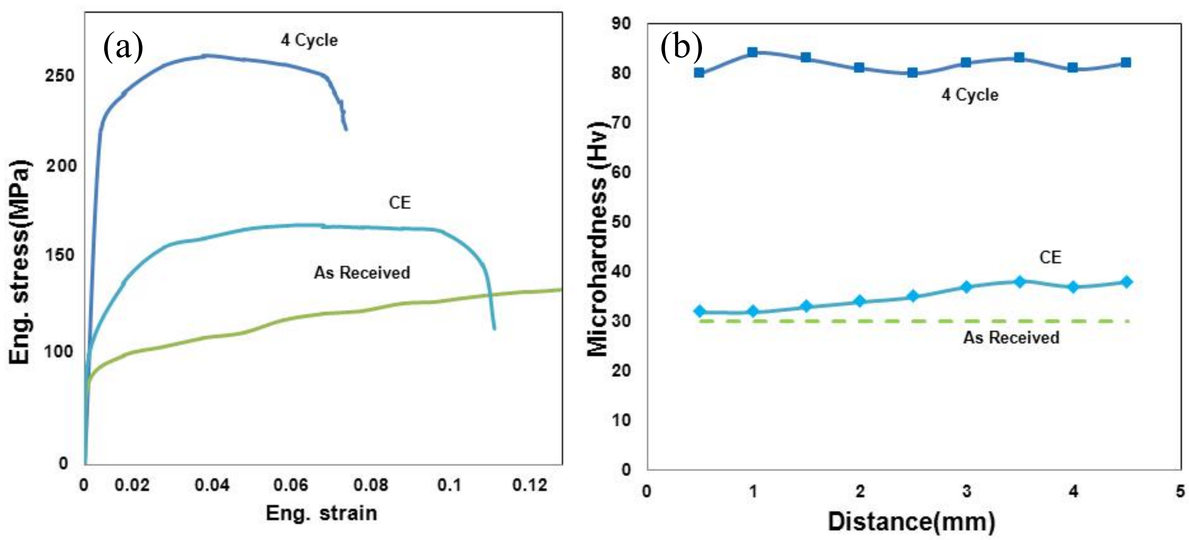

Fig.4. (a) Distribution of microhardness from the center toward the edge of the rod-shape specimens (b) tensile stress–strain curves for AA1050 specimens as-received, after CE, and after different cycles of CFBE.

After four CFBE cycles, both yield strength and tensile strength increased significantly, to 190MPa and 250MPa, respectively, which are about 4 times greater than those of the as-received samples.

Similar to other SPD methods, the increase in strength during CFBE can be attributed to strain and to grain refinement. The same hardening mechanisms were reported by other researchers [15-17], where the dominant hardening mechanism is dependent on the amount of strain.

Notably, the decrease in elongation to break after CFBE, however, does not follow the same trend as the increase in the tensile strength. The same mentioned mechanisms accountable for increase in the yield stress and tensile strength after CFBE cycles can be responsible for a three-fold increase in hardness, Fig.4a. It was also reported that the rapid increase of microhardness can be attributed to the strain hardening as a result of subgrain boundaries/cell wall formation rather than grain refinement [18]. Accordingly, due to the large applied strains, the CFBEed specimen exhibits saturation in strain hardening. This phenomenon has been reported for the cases of UFGed samples produced by other SPD methods such as ARB [16] and ECAP [19]. This saturation occurs because the SPDed materials reach a steady-state in dislocation density.

4 CONCLUSION

The microstructure and mechanical properties of AA1050 subjected to CFBE were investigated. The main results are summarized as follows:

1. CFBE can be considered as a novel method for severe plastic deformation in producing bulk materials with NG.
2. The results showed that after four cycles of CFBE process at room temperature led to significant grain refinement of AA1050.
3. Microstructural evolutions indicated a homogeneous distribution of grain size after process.
4. The initial grains of 120µm were reduced to the nano-grains of about 100nm after CFBE.
5. There was almost a three times increase in the hardness and mechanical properties of workpiece after CFBE.

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