EFFECT OF SEVER PLASTIC DEFORMATION IN CHANGING MECHANICAL PROPERTIES AND PRODUCTION OF NANOSTRUCTURED MATERIALS

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ABSTRACT

In the last few years the mechanical properties of materials of nanocrystalline structure and of ultrafine grain (UFG) size, in the range of 100 nm to less than 1 μm, have received considerable scientific attention and technological interest. It is now well established that the grain size of metallic alloys may be substantially refined to the submicrometer or even nanometer range, through the application of severe plastic deformation (SPD) .

Among various SPD processes, Equal Channel Angular Pressing (ECAP), High pressure Torsion (HPT) and Accumulated Roll Bonding (ARB) have been widely used for a large range of metals and alloys. Equal Channel Angular Pressing (ECAP) is one of the most diffuse SPD techniques since it is able to induce a refined microstructure, virtually maintaining the billet shape. In the present work, we present an overview of the most used methods of severe plastic deformation with the objective of assessing recent advances in the production of nanostructured materials with very significant enhancement in their mechanical and functional properties.

The aim of this work is to present an overview of the most used methods of severe plastic deformation for production of nanostructured materials with significant enhancement in their mechanical and functional properties. In order to examine the potential for using ECAP to refine the grain size and improve the mechanical properties, two commercial 5754 Al and AA3004 alloys, were selected for study Processing by ECAP through up to 6 passes gives a very substantial reduction in the grain size from ~70 μm to ~ 0.3-0.4 μm This reduction in grain size gives an increase in the 0.2% proof stress by a factor of at least three times.

Keywords: *Nanostructured materials; Severe Plastic Deformation; Equal Channel Angular Pressing (ECAP); Mechanical properties.*

INTRODUCTION

Grain size reduction is one of the most attractive ways for improvement of mechanical properties of metallic materials [1-4]. The strength of all polycrystalline materials is related to the grain size, d, through the Hall-Petch equation which states that the yield stress σy, is given by

$$\sigma_y = \sigma_0 + kd^{-1/2} \qquad (1)$$

where σ_0 is termed the friction stress and k is a constant of yielding. [4] It follows from Eq. (1) that the strength increases with a reduction in the grain size and this has led to an ever increasing interest in fabricating materials with extremely small grain sizes.

Nanostructured materials, in which the structural features (e.g., grains and/or domains separated by low-angle grain boundaries) are smaller than 100 nm in at least one dimension, have attracted worldwide research interest for more than a decade because of their unique properties. For example, the combination of high strength with high ductility has been reported for some nanostructured metals and alloys: this is a rare, if not impossible, combination of mechanical properties for coarse-grained metals and alloys [5,6]. Among the many techniques available for producing nanostructured materials, severe plastic deformation (SPD) is the most popular and most rapidly developing one. Specifically, SPD processing is defined as any method of metal forming in which a very high strain is imposed on a bulk solid without the introduction of any significant change in the overall dimensions of the sample, having the ability to produce exceptional grain refinement [3-9] .

The aim of this work is to present an overview of the most used methods of severe plastic deformation for production of bulk nanostructured materials with significant enhancement in their mechanical and functional properties. In order to examine the potential for using ECAP to refine the grain size and improve the mechanical properties, two commercial 5754 Al and AA3004 alloys, were selected for study.

METHODS FOR NANOSTRUCTURED MATERIALS BY SPD

There are three major procedures now being developed in SPD processing. The first, known as High Pressure Torsion (HPT), involves subjecting a sample, in the form of a thin disk, to a high pressure and concurrent torsional straining (Fig.1).

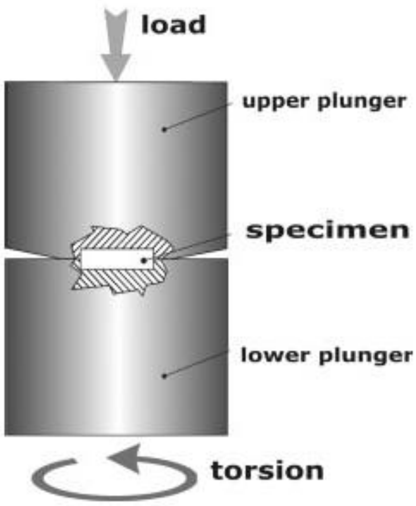


Fig. 1:Schematic, HPT set-up

The second is Accumulated Roll Bonding (ARB), where a sheet is rolled, cut in half, stacked to double the height, rolled again, cut in half again, etc. (Fig.2)

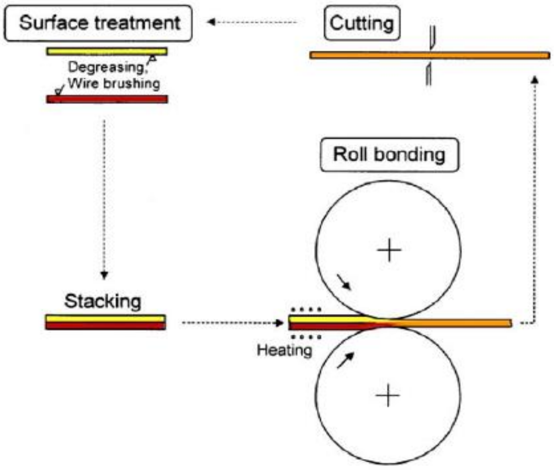


Fig. 2:Sketch of ARB technique

The third procedure known as Equal Channel Angular Pressing (ECAP), involves pressing a bar or rod through a die within e channel bent into an L-shaped configuration (Fig.3)

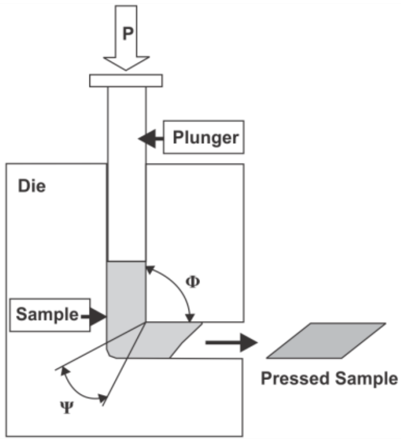


Fig. 3:Schematic view o of an ECAP die

AL ALLOYS PROCESSED BY ECAP
EXPERIMENTAL

The experiments were conducted on two light-weight commercial aluminum alloys: Al-5754 alloy having the following composition in wt.%: 2.4-2.6 % Mg, 0.1-0.6 % Mn, 0.4 % Cr, 0.4 % Fe, 0.4 % Si, 0.2 % Zn in the overall Al . The mentioned alloy was used for producing automotive parts. Observations by optical microscopy revealed grain size of about 70 μm in the as received condition. The other studied alloy was AA3004 whose composition (wt.%) is as follows: 1.09Mn, 1.08Mg, 0.55Fe, 0.20Si, 0.19Cu, 0.01V, 0.01Ti, in the overall Al. The 3004 aluminium alloy is widely used in the container, packaging, and automobile industry, because of its excellent specific strength, corrosion resistance and formability. Observations by optical microscopy revealed grain size of about 50 μm in the as received condition.

The samples in the forms of cylinders with 10 cm in length, and with diameter of 10 mm, were subjected to ECAP at room temperature.

EXPERIMENTAL (CONTINUE...)

Each sample was repetitively pressed to ECAP up to a total of 6 passes, for AA 5754, equivalent to an imposed strain of ~ 6, and up to 6 passes for AA 3004.

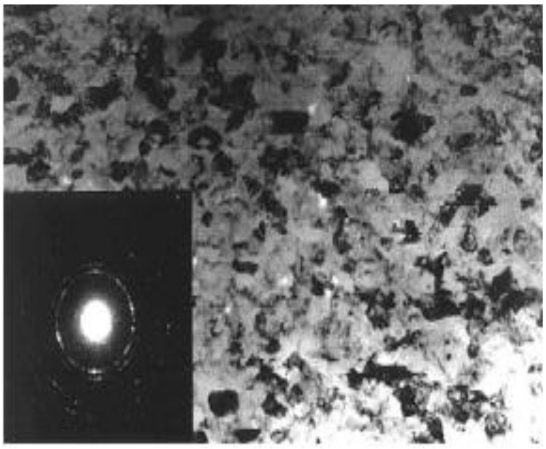
Small pieces were cut from the as-pressed cylinders. Each of these pieces was polished and then subjected to the Vickers microhardness (HV) measurements, using a load of 300 g, applied for 15 s.

Microstructure inspections for AA 5754 were carried out using a TEM (a Philips CM-200 at 200 kV); Specimen preparation: twin-jet polishing

Tensile tests were performed parallel to the ECAP pressing and were conducted to failure at room temperature, using a testing machine, with an initial strain rate of 3 x 10^{-3} s^{-1}, for AA 5754.

RESULTS AND DISCUSSION

AA 5754: Microstructural examinations of samples pressed through 2 to 6 passes revealed an array of reasonably equiaxed grains having average sizes of < 1 µm. An example of the as pressed microstructure is shown in Fig.4, after 4 passes through the ECAP die. Measurements indicated average grain sizes of ~ 0.3-0.4 µm, in the as-pressed condition, demonstrating that ECAP is an effective procedure for attaining an ultrafine grain size.



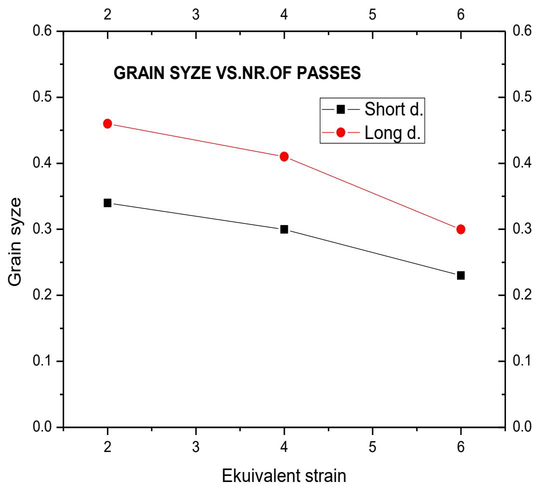


Fig.4.Microstructure observed TEM after ECAP through 4 passes. Grain size vs nr. of passes

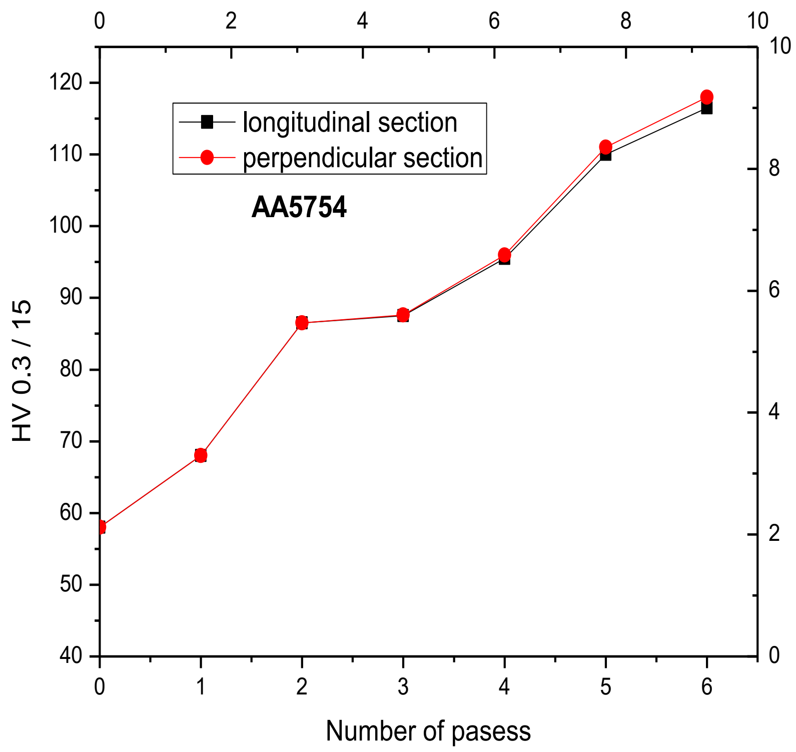


Fig.5 AA 5754
Microhardness Hv versus number of passes in ECAP

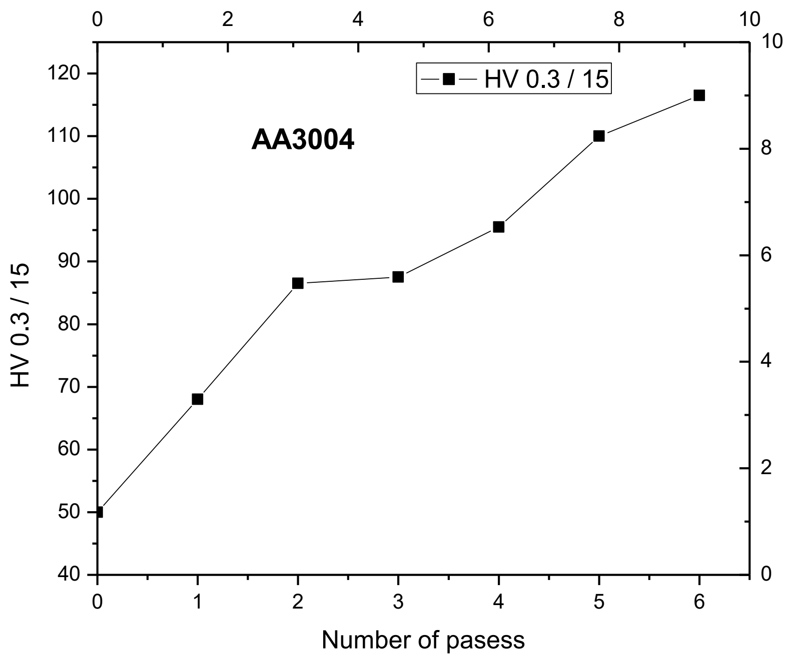


Fig.6 AA 3004
Microhardness Hv versus number of passes in ECAP

Fig.5 shows the variation of the microhardness with the number of passes, where measurements were taken on 2 orthogonal planes and the first point (zero passes) refers to the unpressed alloy (Al-5754), while Fig. 6 shows the variation of the microhardness with the number of Passes for AA 3004.

Two main conclusions may be drawn from the graph at Fig.5. Firstly, the micro-hardness is essentially independent of the plane of sectioning. Second, the value of HV increases abruptly after a single pass, but thereafter increases slowly with the progress of the pass number. A similar behavior has the AA 3004 alloy.

Strength and ductility are two key mechanical properties for structural materials. Nanostructured metallic materials produced by severe plastic deformation techniques usually have high strength but relatively low tensile ductility, which is mainly attributed to their low strain hardening ability [4].

The results from the tensile testing are shown in the Fig.7, where the stress is plotted against strain for a sample in the as received conditions and for samples after pressing from 1 to 6 passes.

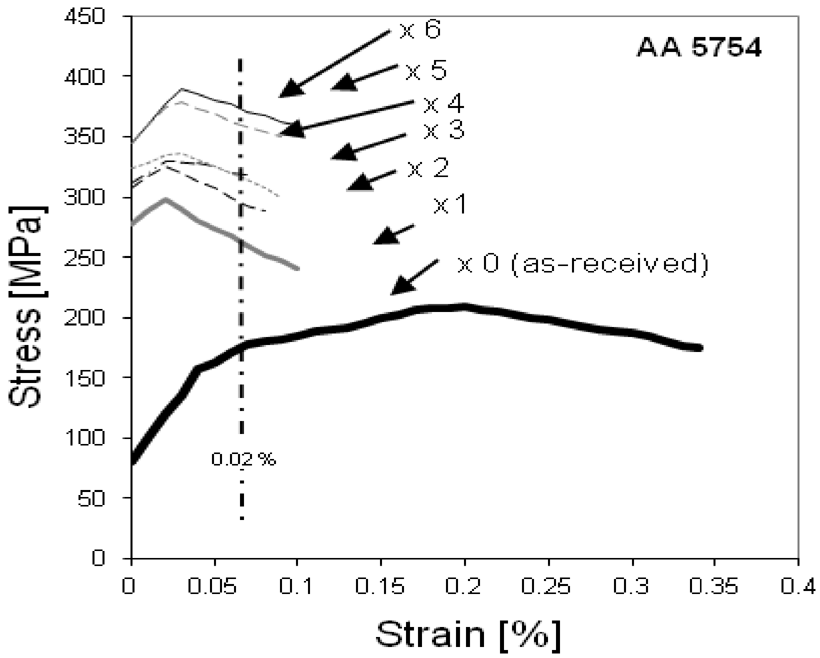


Fig. 7 Tensile test: stress versus strain of the AA 5754 at room temperature.

These curves show that the elongations to failure are very much reduced after ECAP. Thus, the unpressed alloy pulls out to an elongation ~ 35%, but after pressing from 1-6 passes, the elongations are reduced to ~10%. It is apparent from Fig. 7 that the value of 0.2% proof stress increases by a factor ~ 3 times from ~ 80 Mpa in the as-received alloy to ~ 240 MPa after a single pass in ECAP and thereafter for additional passes the increase is relatively minor.

CONCLUSIONS

In summary, this investigation demonstrates that ECAP was an effective tool for achieving a substantial reduction in the grain size of the commercial 5754 Al and AA3004 alloys. The initial GS of ~ 70 μm in the as received alloy AA 5754, was reduced to ~ 0.3 - 0.4 μm by ECAP through up to 6 passes.

There is an immediate increase in the microhardness at a strain ~ 1 with minor additional increases with subsequent straining. The reduction in grain size gives an increase in the microhardness of the alloys and an increase in the 0.2% proof stress by a factor of at least three times for AA5754. In addition, there is a trend of higher strength accompanied by higher ductility for AA3004, after 4 ECAP pressing. This work demonstrates the possibility of extraordinary combination of high strength and high ductility produced in metals subject to severe plastic deformation (SPD). Materials with such desirable mechanical properties are very attractive for advanced structural applications.

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