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RESEARCH ARTICLE

REVIEW ON: INFLUENCE OF BP-ECAP ON MECHANICAL CHARACTERISTICS OF ALUMINIUM MATRIX COMPOSITES

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ABSTRACT

In present contest Aluminium based metal matrix composites are rapidly developing group of materials due to their unique combination of properties that include low weight, elevated strength, improved wear and corrosion resistance and relatively good ductility. Obtaining good properties with aluminium as ductile matrix blended with different reinforcement. Generally most common methods for producing this type of metal matrix composites is powder metallurgy since it has many variations and also is relatively low-cost method. A lot of different techniques of compacting aluminium alloy powders have been previously investigated. Among those techniques equal channel angular pressing and powder metallurgy etc. Equal-channel angular pressing (ECAP) is an effective fabrication process for obtaining ultrafine-grained materials. This paper emphasis on aluminum alloy composite processed by ECAP with different passes at room temperature. The factors influencing the mechanical characters are observed, including the die corner angle within the ECAP die and the number of imposed passes. It is shown that good properties may be achieved through ECAP processing when the number of passes in ECAP is reasonably high.(ECAP) stands out due to its beneficial influence on the main problem that arises during powder compaction and that is a non-uniform distribution of reinforcement particles. This paper gives an overview on ECAP method principles, advantages and produced powder composite properties.

INTRODUCTION

In advancement of materials Aluminium matrix composites are a fast developing group of metal matrix composites due to its extensive range of potential applications in different branches of contraction industry, automotive and aerospace (MatejaŠnajdar Musa and ZdravkoSchauperl, 2008). Improving properties of aluminium by introducing different reinforcement is somewhat well accepted idea due to possibility of generating aluminium based material with improved mechanical properties, while trusting properties of aluminium itself like high ductility and toughness. Previously investigated aluminium based metal matrix composites (MMCs) were reinforced with different types of ceramic particles , metals, fly ash, polymers being most common ones (Bharath *et al.,* 2012). It has been shown that using different particles as reinforcements rather than some continuous reinforcement type provides materials with more isotropic properties and relatively cheaper and simpler production process with particle size being key parameter for obtained properties of the composite material (Iwahashi *et al.,* 1996).

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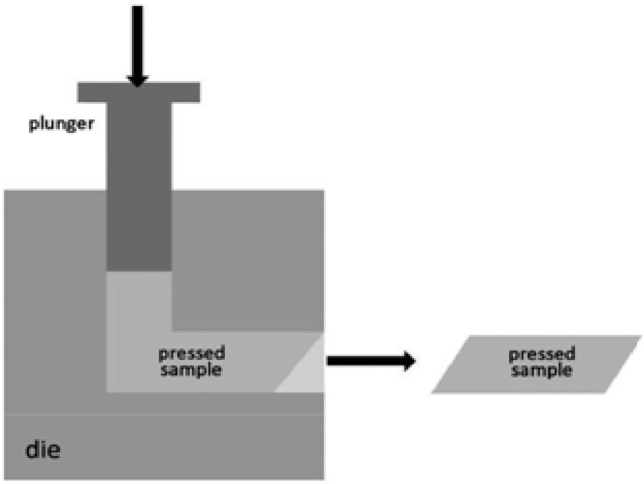
Like with other types of composite materials, properties of MMCs depend strongly on production methods and parameters. Several methods for the preparation of composite structured materials have been developed so far. The methods can be divided into two groups: *top-down* and *bottom-up* (MatejaŠnajdar Musa and ZdravkoSchauperl, 2008). The *bottom-up* methods are based on powder metallurgy (PM) techniques, on the preparation of powders and their following compaction. Major problem of conventional powder metallurgy methods for production of metal matrix composites is tendency of smaller particles especially micro and nanoparticles to form clusters during pressing which overall contribute to increased material porosity and poor mechanical properties. Despite the advances in the development of the powders preparation methods, problems still remain concerning powder purity, residual porosity of compacts, grain growth at compaction, which have not been resolved yet. Other method is severe plastic deformation (SPD), has become attractive in recent years because it provides the capability of achieving remarkable grain refinement, typically to the sub micrometer or even the nanometer level, and thus it often leads to superior mechanical properties. So many investigation carried on the SPD with mechanical character examine. Initial field of interest was using SPD techniques as methods for refining grain size in different metals at room temperature by imposing large shear on the material thus improving their mechanical properties. Most commonly used SPD methods included high pressure torsion, groove rolling, accumulated roll bonding and equal channel angular pressing, ECAP, which proved to be very efficient technique for obtaining ultrafine grain structure.

Equal Channel Angular Pressing (ECAP):

One promising compaction technique is the back pres-sure equal channel angular pressing (ECAP-BP) as a severe plastic deformation (SPD) method (Bharath *et al.,* 2012), where a rod is pressed through a die constrained within a channel which is bent through an abrupt angle, and with a corner curvature angle'Φ' (90^o to 135^o), as shown schematically in Figure 1 (Iwahashi *et al.,* 1996). There are two distinct advantages in using ECAP processing. First, it has the potential for producing large bulk samples, sufficient for industrial applications, without the introduction of any porosity or contaminants. Second, it is a simple processing technique that has the capability of being developed into a continuous processing procedure (Goussous *et al.,* 2009). Processing by ECAP leads to significant strengthening of the material at ambient temperatures (Gupta *et al.,* 2012; Djavanroodi and Ebrahimi, 2010) and, provided the ultrafine grains have a reasonable thermal stability, to the occurrence of superplastic ductility at high strain rates at elevated temperatures (Filho *et al.,* 2011; Yoon *et al.,* 2007).



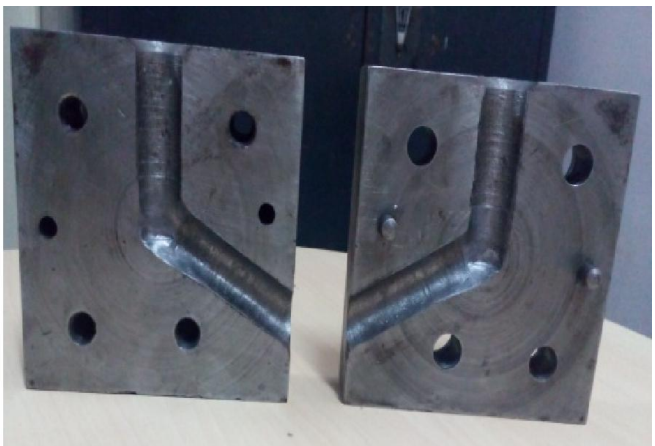


Figure 1.ECAP die, general principle and two part ECAP die

Channel and curvature angles of the die

Curious and large interest has focused on the homogeneity of materials and mechanical properties processed by ECAP, primarily on the effect of the die configuration and especially the die angle 'Φ' (90^o to 135^o) and the corner angle(Y = 20°, 30°, 13°, 10°). It is well established that the strain achieved through a single pass of ECAP is related only to the die angles and corner angle under ideal conditions (Yoshinori Iwahashi *et al.,* 1988). Therefore, it is important to evaluate the effect of the corner angle because most of the investigations conducted to date use a die with a channel angle of Φ= between 90^o to 135^o, where this angle is selected because it is most effective in achieving an ultrafine grained microstructure (BabakManafi and Mehdi Saeidi, 2016). It is well established that the use of an ECAP die with a sharp corner having an arc of curvature of zero (Y = 20°, 30°, 13°, 10°) leads to the occurrence of a ''dead zone'' at this outer corner where the billet is no longer in contact with the die wall (Andreyachshenko and Naizabekov, 2011; Athreyam *et al.,* 2012; RazaviHesabi *et al.,* 2007; Kollo *et al.,* 2012; Kainer, 2006; Derakhshandeh *et al.,* 2011). Although the problems associated with these dead zones can be alleviated or removed through the use of dies having movable die walls, the construction of these dies is not easy and therefore their use tends to be inconvenient and time-consuming. In practice, therefore, conventional dies where the die walls are fixed are generally more practical for use in ECAP processing. Come to corner angle, practically the difference may be due to the larger contact area between the sample and the die walls for the die with the sharp corner. However, it is introduces additional in homogeneity into the sample during the ECAP procedure. This finding is not fully reliable with some earlier calculations where it was predicted that a sharp corner die is preferable to a round corner die in producing a homogeneous shear strain distribution over the cross-sectional plane (Mohseni, 2006; Athreya *et al.,* 2012).

Processing routes

There are four basic routes for ECAP processing based on billet rotation between individual ECAP passes. Every of these routes are attributed to different slip system and strain value. During route A there is no rotation of the billet, while during route C the billet gets rotated for 180° between each pass. For routes BA and BC rotation of 90° in the same and opposite direction occurs between passes (Goussous *et al.,* 2009). Figure 2 shows described basic routes of ECAP. Route $B_c$is an optimal pressing route since single route involves specific slip systems (Filho *et al.,* 2011; Yoon *et al.,* 2007).

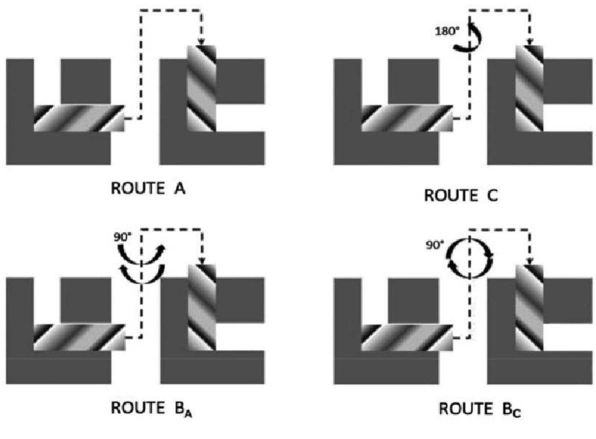


Figure 2. Fundamental routes for ECAP pressing

Pressing speed

The ECAP technique is always conducted using high-capacity hydraulic presses that operate with relatively high ram speeds. The influence of pressing speed was investigated using samples of pure aluminium and a range of pressing speeds from 10-2 mm/s to 10 mm/s. The results showed that the speed of pressing had no significant influence on the equilibrium grain size, at least over the range used in these experiments, and that the nature of the microstructure was dependent on the pressing speed, because recovery occurred more easily at slower speeds, resulting in more equilibrated microstructures. There was also indirect evidence for the advent of frictional effects when the cross-sectional dimensions of the samples were 5 mm or less (MatejaŠnajdar Musa and ZdravkoSchauperl, 2013; Bharath *et al.,* 2012).

Pressing temperature

Pressing temperature in ECAP is a key factor in microstructure development. Yamashita (Bharath *et al.,* 2012) studied the effects of pressing temperature using pure aluminium and aluminiumalloys and reported that an increase in the deformation temperature resulted in an increase in grain size and a decrease in the miss-orientation of strain induced boundaries. It has also been shown that the proportion of high angle boundaries evolved in a 5052 Al alloy decreased with an increase in pressing temperature and reached only 14% during ECAP at 573 K[15]. The effect of pressing temperature on fine grain formation during hot ECAP is currently a matter of debate and is still unclear

ECAP for Production of Aluminum composites

Numerous investigations of ECAP have shown that it is necessary to process materials by ECAP up to multiple passes in order to achieve satisfactory ultrafine-grained microstructures. Thus, the development of homogeneity and mechanical properties as a function of the number of passes is a critical question in ECAP processing. In last couple of years ECAP was also used as a method for production of rapidly solidified metallic powder alloys having amorphous structure and outstanding mechanical properties (Djavanroodi and Ebrahimi, 2010; Filho, 2011). During powder consolidation raw powders have to be diffused in solid phase at temperatures below materials' melting point. The surface of powder particles is covered by oxide layer which acts as an obstacle during particle bonding. In order to consolidate powders that barrier needs to be broken so clean particle surface can interact with each other. ECAP as a method proved to be efficient in doing since it generates severe plastic deformation through high pressure which imposes high shear stress on powder mixture thus enabling particle consolidation. This can be performed with rather low forces applied, making this potential production process for wide range of industrial applications (Yoon *et al.,* 2007). First attempts of reinforcing ductile materials like aluminium and copper with ceramic particles have been made research for automotive industry purposes. This type of new materials would possess best of both materials ductility of metal matrix with increased strength of ceramic reinforcement particles (Cheng Xu *et al.,* 2007). In modern years research in that area has been expanded on aluminium composites production as a method to substitute production of such composites by in situ formations of reinforcement particles in melt which were very complex and limited procedures. Many analyses conducted by Mohseni, Balog, Athreya etc. of Al based MMCs consolidation characteristics and their obtained properties showed ECAP to be a good method for solving consolidation problems (Ahmadi *et al.,* 2015; Yoshinori Iwahashi *et al.,* 1998). These investigations showed similar densification behaviour of powder composite materials and regular metallic powder materials. Composite powder materials were shown to have lower strength and density due to mentioned cluster formation and need for extra pressure in order to enable softer metal particles to fill voids between hard ceramic particles (Andreyachshenko and Naizabekov, 2011). Applying back pressure in the outlet channel during pressing proved to have very positive effect on reducing particle clustering and increasing density thus enabling more uniform structure of produced composites.

Figure 3. ECAP Pressed samples of aluminium

Brief Procedure for obtaining Al MMCs starts with milling of powder mixture which is usually composed of aluminium powder and reinforcement particles such as e-glass, flyash, SiC, Al_2O_3, AlN etc. of different particle sizes. Obtained loose powder mixture is then loaded in copper capsule where it can be heated for some time after which it goes to unheated ECAP die. Then pressing of the capsule through the die is conducted with adequate speed and main and back pressure is applied depending on the material and size of the pressed sample. After several passes of ECAP generally 2, 4 and 8passes recommended, pressed samples of composite are removed from the capsule and prepared for mechanical and microstructure characterization (BabakManafi and Mehdi Saeidi, 2016). In Figure 3 shown that pressed aluminium samples.

Mechanical properties and Microstructure

Mechanical properties

It noticed that ultra-fine grained materials produced by ECAP exhibit good hardness and high strength. It has also been observed that as grain size is reduced through the nanoscale regime, hardness typically increases. The influence of these mechanical properties changes on matrix material is significant and can be described with Hall-Petch relationship between grain size and strength. In terms of yield stress, Hall-Petch strengthening is a phenomenon occurring as a result of grain boundaries and dislocations presenting obstacles for dislocation movement which leads to strengthening effect.

$\sigma_0 = \sigma_1 + (K/d^{1/2})$

Where, σ0 is the yield stress, σ1 is the frictional stress opposing the dislocation motion, K is the Hall–Petch slope and D is the grain diameter.

From this equation it can be seen that strength of material is inversely proportional to grain diameter square root with σo and K being materials constants. Previous studies have shown that there is a critical grain size under which no additional strengthening occurs. Besides Hall-Patch phenomena connected to ECAP processing nature there is another strengthening effect specific for metal matrix composites. The influence of ceramic particles on composite properties can be increases the strength of the composite.

Similarly, a similar equation is obtained for hardness

$H_0 = H_1 + (K/d^{1/2})$

The experimental results of the hardness tests show that the relationship differs when grain size is in the ultrafine range (Athreya *et al.,* 2012; RazaviHesabi, 2007), for example, a positive slope exists when the grain size is less than 20 nm. The materials produced by ECAP also have high wear resistance and fatigue strength, and high biocompatibility and corrosion resistance when in contact with living tissue. Thus, the deformation hardness and strength of ultrafine grained materials are unique. Much work is still underway to understand the unique behavior of these materials.

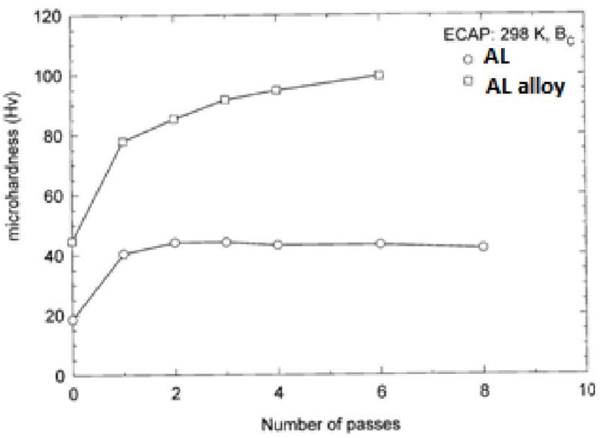


Figure 4. The average hardness, Hv, versus the number of passes in ECAP at room temperature using route B_C

Itcan noticed that the micro hardness for pure Al and the Alalloy composite plotted against the number of passes where the value of the average microhardness for each condition was deter-mined by calculating the average of all microhardness measurements on each cross-sectional planeapparent from Figure 4, that the microhardness of both materials increases dramatically after a single pass of ECAP by a factor of approximately 2·. Thereafter there is a small increase in each additional pass for the Al-6061 alloy up to a maximum value of Hv 99 after 6 passes whereas for pure Al there is saturation after.

Microstructure

RemarkableGrain refinement can be achieved through ECAP for all metallic and intermetallic materials.During ECAP numbers of significant changes of material microstructure occur such as intense grain and second phase particle refinement, formation of structure characterized by equiaxed grains and large angle grain boundaries. The result of a single ECAP pass is a directed shear texture with visible sub grain bands. With following passes matrix structure gets homogenized and low angle grain boundaries after first pass transform to higher angle boundaries. In addition, simultaneous reduction of grain size and additional accumulation of dislocations occur, which finally results in elongated subgrain breakup and formation of equiaxed structure. Mentioned dislocations build-up has similar effect on present reinforcement particle conglomerates which are broken and uniformly distributed in the light metal matrix while porosity of samples is reduced as shown on figure 5.

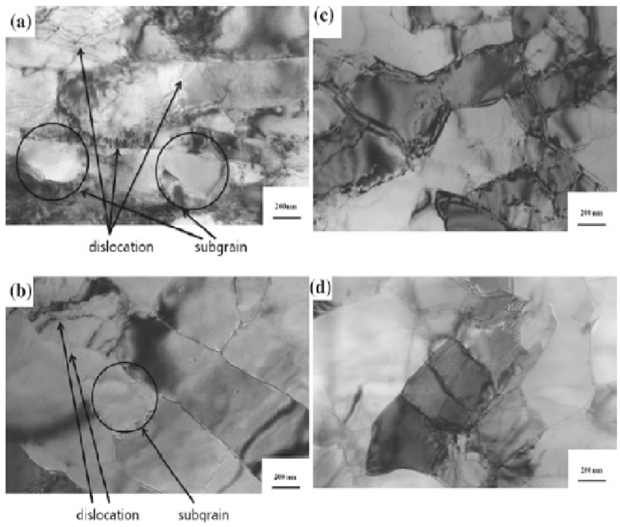


Figure 5. TEM micrographs of aluminum alloy composite, Route Bc; (a) 1 pass, (b) 2 passes, (c) 4 passes, and (d) 8 passes

The number of passes increases the microstructure of Extruded sample in that grain are severely elongated and also fine grains of aluminiumalloy with intermetallic particles could be seen at grain boundaries regions. The increasing homogeneity with increasing number of passes may be illustrated.

Conclusion

Numerous advantages and aspects of using equal channel angular pressing as a powder consolidation method for production of aluminium matrix composites reinforced with ceramic particles have been presented in this paper. ECAP-BP influences the porosity distribution in terms of the severe shear deformation involved and therefore influenced the Microstructure and mechanical properties. The ECAP has a wide range of parameters such as particle size, reinforcement material type and content, pressing routes, speed and die design which all can be specifically adjusted in order to engineer desirable properties of final product such as hardness, strength, wear resistance etc, besides variability.

It can be seen from the above that, Al and an Al alloy composite, are capable of achieving a reasonable level of homogeneity after repetitive passes in ECAP. These results are very encouraging when the ECAP procedure is under consideration for the production of materials for industrial applications. However, it is important to note also that the extent of homogeneity attained in ECAP depends, at least in part, on the hardening characteristics of the material. The homogeneity of material processed by ECAP was inspected by taking hardness measurements, following a regular rectilinear grid pattern, over the cross-sectional planes of samples processed by ECAP. The results are presented in the form of contour maps depicting the values of the individual hardness values at each point on the cross-section and thus the hardness distribution over the entire plane. In order to make it widespread industrial method for fabrication MMCs, future efforts should be directed to automation of the process mostly concerning die geometry i.e. rotation of the sample in between passes for different routes making it a more continuous process.

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