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A brief overview of the equal channel angular processing approach

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ABSTRACT

A possible method to create an ultra-fine grain microstructure and enhance the material's characteristics is equal channel angular pressing (ECAP). The number of variables, including the processing route, die angle, number of passes, and operation temperature, are critical in order to analyze the mechanical behaviour and microstructure of the material deformed by the ECAP process. The development of the Mg alloy microstructure and its mechanical characteristics following the ECAP approach have received particular attention. It was found that producing finer microstructure with superior mechanical properties at lower temperatures, more passes, and a smaller die angle is possible. The impact of equal channel angular pressing parameters on the mechanical characteristics and microstructure of Mg alloys is thus briefly summarised in this review paper.

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1. Introduction

One of the widely used methods of severe plastic deformation (SPD) is equal channel angular pressing. In order to improve the super plastic and mechanical behaviour of the material, severe plastic deformation (SPD) is a practical approach that is frequently employed to produce ultra-fine-grained metal and nano-grained microstructure [1–3]. Dimic et al. obtained that the nano-grains lies in the range of below 100 nm, whereas the ultra-fine-grains lying in between 100 and 1000 nm obtained by the SPD approach [4]. According to the research studies, the ECAP approach can strengthen metals and alloys. A high dislocation density and small grain size obtained in the process of ECAP are attributed to the high strength of metals and alloys [5–10]. Severe plastic deformation (SPD) techniques come in a variety of forms and are used in a variety of contexts [11–14]. Accumulative back extrusion, constrained groove pressing, accumulative roll bonding, high-pressure torsion, equal channel angular pressing, and tubular channel angular pressing are the various techniques used in the SPD processes. In the ECAP approach, an aluminum sample is forced through a die where two intersecting channels attribute to the formation of shear strain. Its microstructure and mechanical properties may change as a result of the strain introduced [17–19]. The HPT technique combines torsional straining and high pressure. The drawback of the HPT technique is the small and coin-shaped sample size that it uses. The zero-shear strain at the axis of rotation entails the unchanged geometry of the workpiece. But the shear strain subsequently increases in the radial direction. It results in the material properties of the sample that is positioned close to the axis of rotation remaining unchanged [19]. Equal-channel angular pressing (ECAP) is a processing technique in which a metal is put through a simple shear without experiencing a commensurate change in the sample's cross-sectional dimensions [20]. The introduction of an ultrafine grain size into polycrystalline materials is possible using this approach. Examining the distortions that a sample experiences as it travels through an ECAP die and, in particular, the impact of rotating the sample between successive presses, the

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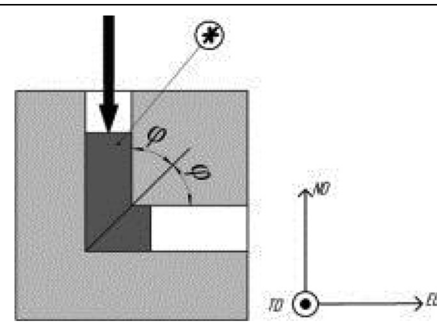
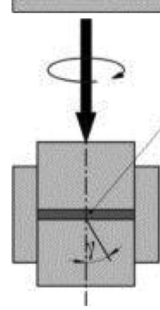
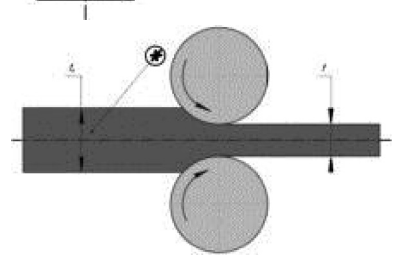
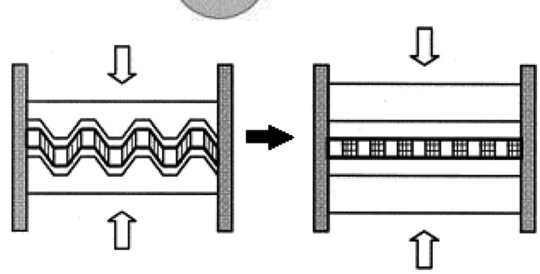
fundamentals of the ECAP process is reviewed. Research studies are shown to demonstrate the super plastic ductility that can be reached at extremely high strain rates as well as the microstructure that ECAP introduces [13–15]. The grain refining procedure used in the equal-channel angular pressing (ECAP) method has been shown to be particularly effective in increasing the strength of metallic alloys handled as ingots. The ECAP technique makes it very simple to refine the microstructure of strong metallic materials [4–13]. To obtain a desirable ultrafine-grained microstructure, materials must undergo numerous runs of ECAP processing. In pure aluminium, homogeneity levels are higher than in Al6061 alloy, and fewer passes are necessary [16]. In comparison to pure materials, the homogeneity of alloys grows more slowly [2]. By using SPD processes, materials can be created that have higher performance and characteristics.

Accumulative roll-bonding is another SPD technique (ARB). The sheet may experience significant strain during rolling, cutting, brushing, and stacking. Metal-matrix composites can be created using this technology [19]. In the CGP process, a grooved die is used to press the sample, and then a flat die is used after that. The distorted region yields a strain value of 0.58 at initial pressing, and 1.16 upon subsequent pressing. The procedure is carried out once more by 180° rotating the sample [20]. Table 1 depicted severe plastic deformation processes. Mg offers a wide range of possible uses in mechanical goods due to its low ductility and outstanding machinability behaviour [21]. Because of its excellent strength-to-weight ratio and ability to reduce both vehicle weight and fuel consumption, magnesium is widely used in the automotive sector [22–23]. Magnesium's HCP structure does have a limitation on ductility at room temperature, though [24,25]. The impact of various process parameters of ECAP including temperature, curvature, and channel angle, pressing route and speed, the number of passes through the die, etc., were analyzed by Roodposhti et al. relating to the titanium alloy [26]. The impact of ECAP parameters on specific materials has not received much attention in the media. The effects of ECAP processing settings on the microstructure and mechanical properties of magnesium alloy are thus briefly described in this review work. A die and curvature angle, the number of passes, the processing path, and temperatures are some of the ECAP parameters that are described. Five steps were required to obtain the ultra-fine grain microstructure depicted in Fig. 1.

Table 1
Depicted severe plastic deformation processes.

Process	Schematicand diagrammatic illustration
ECAP	
HPT- High pressure torsion	
ARB – Accumulative roll bending	
CGP- Constrained groove pressing	

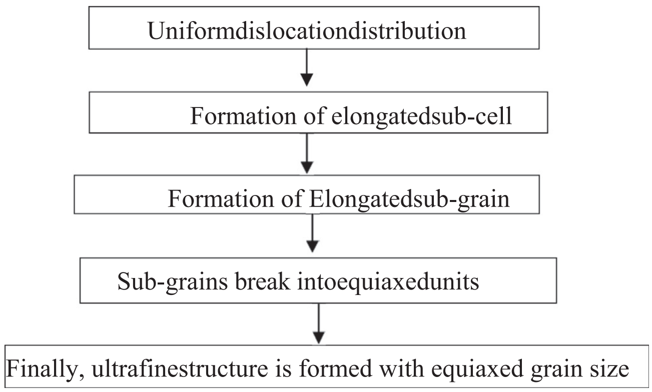


Fig. 1. Sequential stage of the process of ecap.

2. ECAP: Processing approach

ECAP has long been recognized as a method that aims to create a microstructure revealing the ultra-refined grain size [27–29]. There have been numerous methods for metals and their alloys that have successfully completed the ECAP process in the past, including steel [30–31], copper and its alloys, magnesium alloy, and aluminum and its alloys [32–35]. The majority of study focuses on how ECAP processing affects materials' mechanical behaviour and microstructures in particular. Table 2 lists different investigations on the materials following the ECAP approach completed by the researchers. The general schematic diagram of the ECAP approach is shown in Fig. 2. Utilizing the die with a channel (bent) that cuts through an acute angle close to the die's centre, the process is carried out. The angles between the two channels that are connected together are the channel angle and curvature angle. To evaluate the length and diameter to fit the channel diameter, firstly the sample is machined. The billet is forced into the die under intense pressure by a plunger (P). It is possible to obtain extremely high stresses by repeating the operation because the cross-sectional dimensions are fixed. To achieve the appropriate microstructure, the pressing procedure is done numerous times [30–43].

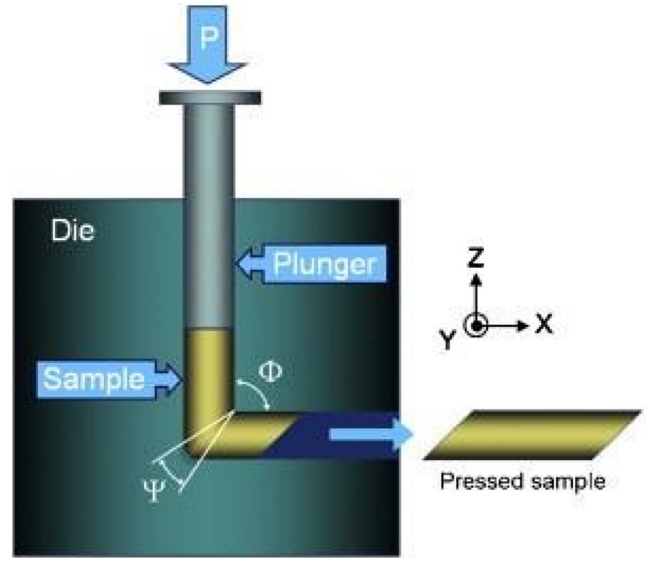


Fig. 2. . Processing technique of ECAP approach[31].

Table 2
Lists different investigations on the materials following the ecap approach.

Researcher	topic	Objectives
Kim et al. [36]	Impact of channel angular pressing routes on the ultra-fine grained Mg alloy's high strain rate deformation behavior	• To examine how ultra-fine grained aluminum alloy fractures and how its HSR deforms following 1P and 8P ECAP along various pathways. • To investigate the influences on the tensile and torsional characteristics as well as the possibility of adiabatic shear band formation.
Suh et al. [37]	AZ31 alloy sheets formed via ECAP have improved cold formability	• To look at mechanical characteristics and microstructure development. • To compare the findings with the cold forming behavior.
Torre et al. [38]	Copper microstructures and characteristics after 1–16 passes of equal channel angular extrusion.	• To use TEM and XRD analyses to examine the microstructure from 0 to 16 passes. • To research the material's mechanical characteristics following the treatment.
Eddahbi et al. [39]	The mechanical characteristics of the ECAP-processed EUROFER 97 steel and its texture	• To investigate whether warm ECAP may help temper EUROFER 97 to stabilize grain structure that will improve its mechanical behavior within the operational temperature range.

3. Effects of ECAP processing parameters

The numerous aluminium processing options in ECAP are depicted in Fig. 3. The popularity of the ECAP approach raises questions about and interest in homogeneity development. The characteristics of ECAP process in terms of different attributes are shown in Table 3. To acquire a desirable ultrafine grained microstructure, materials must be processed by ECAP up to multiple passes. After a single pass of ECAP, materials initially become inhomogeneous, but as more passes are added, they form a homogeneous microstructure with the exception of a very tiny region close to the bottom surface. The microstructure of aluminium is found to become relatively homogeneous after four ECAP passes using routes A, BA, BC, and C [6], which represent scenarios in which the sample is not rotated between passes (route A), rotated by 90°in different directions between each pass (route BA), rotated by 90°in the same sense between passes (route BC), and rotated by 180°between passes (route C). The research studies provide conclusive evidence that the ECAP parameters are crucial in defining mechanical and microstructural behaviour. The temperature, number of passes, processing path, and angles, are among the parameters. The abbreviations 1P, 2P, and 4P stand for 1, 2, 3, and 4 passes, synchronisingly. Avvari et al. conducted research on the impact of ECAP on wrought Mg alloys in 2013 [40]. The goal of the study was to assess the size of grains of wrought AZ31 alloy produced by ECAP using a die with a channel angle of 120° and a curvature angle of 30°. Jahadi et al. [41] conducted research to assess the impact of the ECAP process on the as-extruded AM30 magnesium alloy, comparable to AZ31B alloy.

Through grain refinement, the equal-channel angular pressing (ECAP) approach has been shown to be extremely helpful in enhancing the strength of metallic alloys produced as ingots. In a variety of metallic materials, strong microstructure refinement

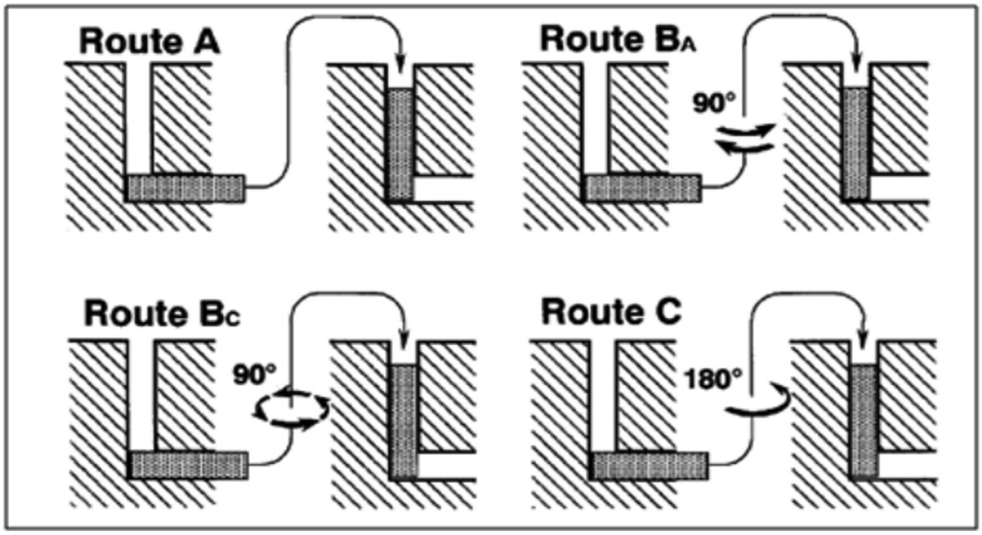


Fig. 3. Indicate the ecap processing route[18].

Table 3
Characteristics of Equal channel Angular Pressing Technique.

Attributes	Characteristics
Grain Precision The primary priority of the ECAP	operation is to strengthen the material's crystalline structure. Repeated shearing and deformation of the object through the channel causes a significant decrease in grain size as well as a rise in the quantity of grain boundaries. As a consequence, the mechanical properties are improved, including resilience, stiffness, and toughness.
Low Strain Rate	The Multi - pass process generally runs at low strain rates, that either decreases the probability of material flaws and cracks. The material can deform evenly without creating localised deformation zones thanks to the low strain rates, which also leads to a homogeneous microstructure.
High Strain	The ECAP process has the ability to generate a high strain, usually greater than 4. Inducing extreme plastic deformation and fostering grain refinement require a high strain, which is essential.

via the ECAP technique is fairly simple to achieve. To obtain a desirable ultrafine-grained microstructure, materials must be processed by ECAP up to multiple passes [38]. Compared to Al6061 alloy, pure aluminium has a greater homogeneity level and fewer passes are necessary. Compared to pure materials, alloys achieve homogeneity more slowly. Materials created with SPD processes can be specifically designed to have higher performance and characteristics [39]. Yamashita et al. [42] research focused on using severe plastic deformation to enhance the mechanical characteristics of magnesium and magnesium alloys. The goal of the study was to examine the mechanical behavior of these materials at room temperature and analyze the efficacy of pure Mg and diluted Mg-Al in refining grains. A study conducted in 2013 [33] by Minarik and his colleagues examined how the AE21 alloy's microstructure, mechanical characteristics, and corrosion resistance changed as a result of ECAP. The study focused on corrosion behavior in addition to microstructure and mechanical behavior. Recently, Minarik et al. [43] evaluate the mechanical characteristics of LAE442 alloy produced by ECAP with an emphasis on biodegradable magnesium implants.

Additionally possessing the biodegradable and biocompatible qualities required in implant material, LAE442 Dumitru and his colleague's [44] research examined the ECAP procedure on the material ZK60. The great strength but reduced flexibility of the material led to its selection. Poggiali et al. analyzed the behavior of Mg material under rolling and as-cast conditions [32]. ECAP technique was then applied to various routes and numbers of passes. In contrast to a material treated by ECAP alone, the article sought to introduce a new primary step of rolling prior to the ECAP approach to produce improved mechanical characteristics and obtained a reduction in grain size of the material. Avvari et al. [34] examined the effects of the ECAP processing parameters on the mechanical characteristics and microstructure of AZ31 after two passes at 498 K.

According to the literature, most experimental studies use an angle between 90° and 120° for their investigation. There is not much research on comparing material qualities using various channel angles. In comparison to a lesser angle, a wider angle may make pressing the sample easier. The ECAP process setting for a study conducted by Murlidhar et al. is shown in Fig. 4 [28]. The research demonstrates that the smaller the angle, the greater the strain and the smaller the grain size. In contrast, as demonstrated by the research of Muralidhar et al. [29], larger curvature and die angles may diminish the die's dead zone. The grain size obtained in the experiment using the higher die angle is not as fine as the grain size obtained in the experiment via the lower die angle (90° and 120°). After one pass, the increased angle has been seen to yield grains measuring 13.3 m, which then shrank to 8 m after four passes [35]. Lower channel angles, however, can result in small grain size, as demonstrated by a study by Jahadi et al. [45], where the grain size was measured at 7.2 m after only 1 pass and might decrease to 3.9 m after 4 ECAP runs. The microstructure of AZ31 using a 120° die and AM30 using a 90° die are shown in Figs. 5 and 6.

4. Conclusion

One key method for creating an ultra-refine grain structure is ECAP. The mechanical characteristics of magnesium alloys could be enhanced through the use of this method. The ECAP parameters have an impact on the material behavior following the procedure. As the number of ECAP passes is increased up to 4 passes, the reduction in the grain size of magnesium alloys obtained. The longer recovery times caused by a rise in temperature result in larger grains. Compared to high-angle grain boundaries, low-angle grain boundaries are produced more frequently. The microstructure of the Mg alloys is significantly impacted by the channel angle of the ECAP die. Smaller grain size and better mechanical characteristics were achieved for the Mg alloys by using a larger

Fig. 4. Set up for equal channel angular pressing at die angles of 120° and 30°[44].

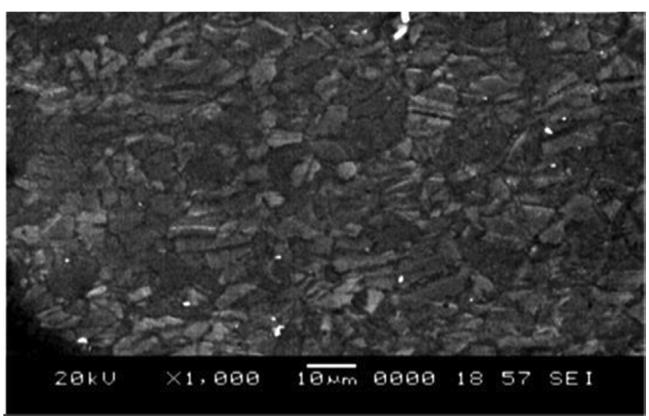


Fig. 5. After four ECAP passes, a 120° channel angle SEM picture of AZ31 was captured [44].

angle die, a lower processing temperature, and more ECAP runs (i.e., four passes).

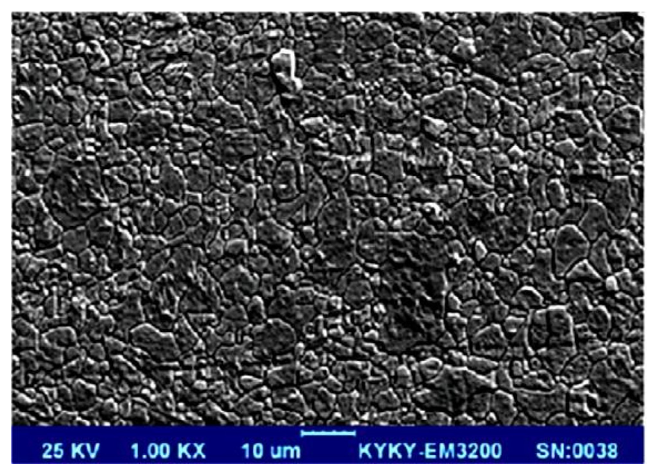


Fig. 6. After 4 ECAP passes, SEM pictures of the AM30 were taken using a 90° channel angle [45].

CRediT authorship contribution statement

B. Chandrasekhar: Conceptualization, Writing – original draft. **Siddheshwar Shirbhate:** Conceptualization, Writing – original draft. **Dalael Saad Abdul-Zahra:** Data curation. **Pravin P Patil:** Data curation. **Dinesh Kumar Yadav:** Methodology. **Gaurav Kumar:** Methodology. **B. Chandrasekhar:** Validation. **Sachin Kumar Sharma:** Visualization, Writing – original draft, Writing – review & editing.

Data availability

No data was used for the research described in the article.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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