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ARTICLE

Significant Difficulties in Achieving Equal Channel Angular Pressing in Aluminum Metal Matrix Composites

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ABSTRACT

The technique known as Equal Channel Angular Pressing (ECAP) has gained prominence as a transformational method for improving the mechanical characteristics of metals and alloys by subjecting them to intense plastic deformation. This study explores the significant difficulties that arise when using Equal Channel Angular Pressing (ECAP) on Aluminium 2024-Beryl Metal Matrix Composites (2024-BMMCs), providing a detailed analysis of the complex interaction between the reinforcement particles and the aluminium matrix. This work aims to provide a thorough examination of the challenges, root causes, and possible approaches to address the issue of producing consistent deformation in 2024-BMMCs using ECAP. By doing so, this research contributes to a better understanding of the intricate nature of this process.

Keywords: Types of die materials; Process parameters; ECAP; Aluminum metal matrix composite

1. Introduction

SPD improves metal mechanical characteristics and grain structure. This process yields nanocrystalline, ultrafine-grained metals [1-3]. ECAP, high-pressure torsion, and ARB achieve SPD. High strain is delivered to metal by twisting and rolling [4-7]. SPD increases metal strength and hardness without affecting ductility. SPD produces high-strength materials for numerous purposes [8]. SPD requires specialised equipment and may cause material faults like cracking or delamination [9]. It may also be expensive and time-consuming. Researchers are creating and optimizing severe plastic deformation techniques to increase metal characteristics [10,11]. For decades,

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researchers have studied severe plastic deformation (SPD) to improve metal mechanical characteristics. SPD's recent breakthroughs include twisted extrusion. Twist extrusion stresses metal at a preset angle. This approach is comparable to ECAP but needs fewer tools. Due to its fine-grained structure, TE improves the mechanical characteristics of aluminium and copper. Cryogenic SPD: Cryogenic SPD involves SPD at low temperatures, usually below the metal's dynamic recovery temperature. This approach enhances titanium and magnesium mechanical characteristics and produces finer grain sizes than SPD methods. HPT-GD is a modified variant of HPT that rotates a metal between two flat surfaces to provide high pressure and shear. Grooved discs replace surfaces in HPT-GD, creating more complicated deformation routes. This method produces ultrafine-grained structures with good mechanical characteristics in aluminium and copper. Repetitive corrugation and straightening (RCS) involve repeatedly bending and straightening metal under compression. This method creates ultrafine-grained copper and aluminium structures. Constrained Groove Pressing (CGP): CGP presses metal via a confined groove to provide high pressure and shear. This method creates ultrafine-grained titanium and magnesium structures. SPD's novel methods provide great prospects for creating high-performance materials with unique microstructures and characteristics. ECAP SPD forces a metal billet through an inclined channel at the same rate of force, particularly in engineered intersections, causing repeated shear deformation without substantial size changes. This treatment decreases grain size and enhances characteristics.

ECAP has numerous steps. First, ordinary casting or deformation creates a metal billet. The deformation temperature is then set for the billet. Next, the billet is put in a die with two channels intersecting at 90 degrees. The billet is rammed into the channel, causing substantial shear distortion. The billet may be reinserted into the channel and treated again to distort further. Nanocrystalline structures are created by reducing grain size with each die run. The finished product may be treated for desired qualities. Aluminium, copper, magnesium, and titanium are among the ultrafine-grained materials ECAP makes with superior mechanical qualities. The procedure is easy and can be done using standard lab equipment, making it appealing for high-performance material R & D. However, the ECAP approach requires specialised dies and may fracture or delaminate billets during processing. For bigger billets or hard-to-deform materials, the procedure is time-consuming and costly. ECAP is still a viable approach for making high-performance materials with unique microstructures and characteristics [12-17].

Aluminium metal matrix composites include aluminium and one or more reinforcing phases, such as ceramic particles or fibres. These composites have several uses due to their strength, stiffness, and wear resistance [18-20]. Aluminium MMC grain structure may be enhanced using ECAP [21,22]. The treatment boosts strength, hardness, and wear resistance. Grain refining improves ductility, fracture toughness, and crack resistance [23]. ECAP allows reinforcing particles or fibres to be added to the Aluminium matrix for more homogenous reinforcing phases. More effective stress transmission between matrix and reinforcing phases improves composite mechanical characteristics [23].

ECAP uses several reinforcing materials, including ceramic grit: alumina, silicon carbide, and titanium dioxide increase metal matrix mechanical properties. These round or irregular particles are disseminated throughout the matrix during ECAP. Carbon fibres: Strong and stiff carbon fibres increase metal matrix mechanical characteristics. These fibres are placed in a metal matrix with a predefined orientation during ECAP. Copper, nickel, and titanium particles in the metal matrix improve mechanical characteristics. Particles increase composite material heat conductivity, wear resistance, and corrosion resistance. The mechanical characteristics of the metal matrix may be improved by adding organic fibres like aramid or carbon. These fibres are placed in a metal matrix with a predefined orientation during ECAP. Different reinforcing materials will be utilised depending on the composite material's usage and mechanical qualities. These reinforcing elements may be added to the metal matrix using ECAP to improve MMC mechanical properties. Aluminium metal matrix composites manufactured via Equal Channel Angular Pressing (ECAP) might help in several areas. ECAP-processed Aluminium MMC components are versatile [23]. Air Commerce: ECAP-processed Aluminium MMCs offer a high strength-to-weight ratio and better mechanical characteristics for aeronautical applications. These items might be used in aircraft frames, wings, and engines.

Due to improved mechanical qualities, ECAP-processed Aluminium MMC brake, suspension, and engine blocks may last longer and perform better. ECAP-processed Aluminium MMCs have improved thermal conductivity, making them useful for heat sinks and PCBs [23]. Strong and strong, ECAP-processed Aluminium MMCs are perfect for baseball bats, tennis racquets, and bicycle frames. Biomedical applications for ECAP-processed Aluminium MMCs include biocompatibility and improved mechanical characteristics. These materials can make orthopaedic and dental implants. ECAP-processed AMM'C has several uses because of its improved mechanical characteristics, biocompatibility, and thermal conductivity. These materials might improve performance and lifespan in a variety of components across industries. ECAP may lower AMMC grain size, however, the number of passes depends on many factors. Multiple die passes are needed to reduce grain size. The ideal (N) depends on beginning grain size, goal grain size, and strain hardening throughout each pass [23]. Aluminium MMCs typically need 8-10 passes before becoming excessively hard and brittle. The optimum passes depend on the matrix, reinforcement type, and processing circumstances. ECAP Routes A, B, and C process aluminium MMCs. The ultimate composite material's grain structure and mechanical characteristics will determine the course. Process A presses the material through the die forward-backwards-forward, resulting in consistent deformation and a generally homogenous grain structure. Route B rotates the die 90 degrees between passes instead of pushing the material forward, backwards, and forward as in Route A. A more complicated deformation pattern and finer grain structure arise. Method C presses the material through the die without back-and-forth action. More severe deformation and finer grain structure from this approach. The maximum ECAP passes for Aluminium MMCs vary on material and procedure. The final composite material's grain structure and mechanical qualities determine the ECAP technique [23]. Let's imagine a reinforced aluminum-ceramic composite.

Through ECAP, we intend to get 1-2 micrometer grains. Research reveals this material can travel through the ECAP and die 10 times before becoming brittle. Route B processes material by moving forward, backwards, and forward with a 90-degree rotation between passes. The material is put through the ECAP die 10 times with a 90-degree rotation between passes, commencing with a 50-micrometer grain size. We measured grain size before and after each pass and found that it almost halves [23]. After 10 passes, we reach 1-2 micrometres. The enhanced grain structure and reinforcing particles increase the final product's mechanical characteristics. There are various materials and grain size reduction objectives that need varying numbers of passes and ECAP pathways. This is one of several outcomes. Here is a typical Aluminium series used to make Al-ceramic composite particle reinforcement. Ceramic particles called silicon carbide are utilised to strengthen aluminium matrix composites. SiC, a strong and brittle substance, improves aluminium's hardness, strength, and wear resistance. SiC-reinforced AMC is made from aluminium alloys like 6061, 6063, and 6082 in the 6xxx range. High formability, weldability, and corrosion resistance make these alloys suitable [23]. Silicon Carbide particles are usually added to molten aluminium alloy via stir casting or powder injection moulding. Traditional casting procedures include sand or permanent mould casting shape and size of the mixture. The material is ECAPed after casting to increase mechanical characteristics and grain size. The composite material's grain structure and mechanical qualities determine the number of ECAP passes and routes. SiC-reinforced aluminium matrix composites are used in aerospace, automotive, and structural materials. The materials' increased mechanical characteristics make them suitable for high-performance and high-stress applications [23].

This article will benefit the following groups and fields:

Readers: The challenges and advantages of MMC ECAP will be discussed in this article. MMC users and ECAP innovators will benefit from this knowledge.

Researchers: This website gives scholars a detailed description of MMC ECAP research. This information may help researchers plan similar investigations.

Industries: This document will help firms identify ECAP's MMC property enhancement prospects. This data might be used to generate new MMC products or improve existing ones.

2. Materials and methods

2.1 Materials

Aluminium 2024, known for its strength-to-weight ratio and corrosion resistance, was the matrix material in this investigation. Its mechanical qualities and aeronautical compatibility make it a good research candidate. The reinforcing material was natural beryl $Be_3Al_2Si_6O_{18}$, the chemical formula of beryl, is a mineral made of beryllium aluminium silicate, which is durable, thermally stable, and compatible with aluminium. Beryl's ceramic nature might improve Aluminium 2024's mechanical characteristics [21].

2.2 Methods

A crucible or furnace melts aluminium 2024 alloy at regulated temperatures. After reaching the correct temperature, the molten metal is fluid enough for casting. Once aluminium 2024 is molten, preweighed beryl particles are added. Powder or particulate beryl particles. A homogeneous composite requires proper beryl mixing and dispersion in the molten matrix. A mechanical stirrer or impeller stirs the molten aluminium 2024 and beryl combination. The churning mechanism evenly distributes reinforcement particles throughout the melt. Warmed graphite or other refractory mould casts the mixed mixture. Proper mould preparation ensures filling and solidification. The molten mixture hardens in the mould as it cools. The regulated cooling rate prevents beryl particle segregation and enhances uniformity. Heat treatment may improve composite microstructure and mechanical performance, depending on material qualities [21].

3. Results and discussions

3.1 Die wear

ECAP requires a die with intersecting channels to deform the material. The repeated deformation process can cause significant wear on the die, which can affect the quality and consistency of the final product. This issue can be mitigated by using high-quality dies and monitoring their wear over time [23].

Figure 1 shows the heating coil for ECAP dies. **Figure 2** shows the ECAP dies. When pressing the specimens, the dies wear off many numbers of times. The glass acts as an insulator heating coil wirings die wear. **Figure 3** shows the pin type ECAP die, while **Figure 4** shows its another half.

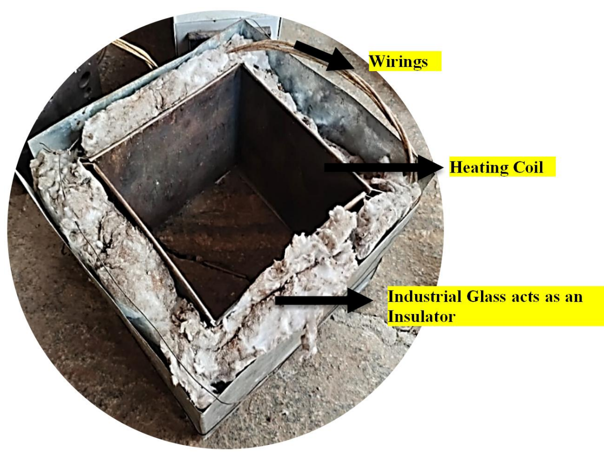

Figure 1. Heating coil for ECAP die.

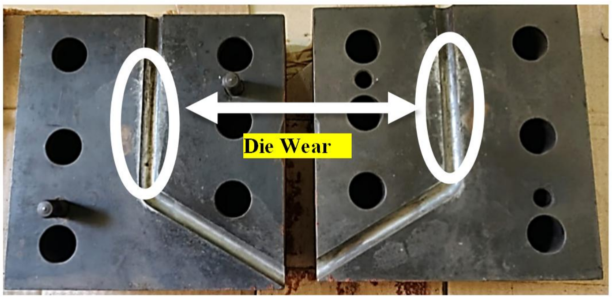

Figure 2. ECAP die.

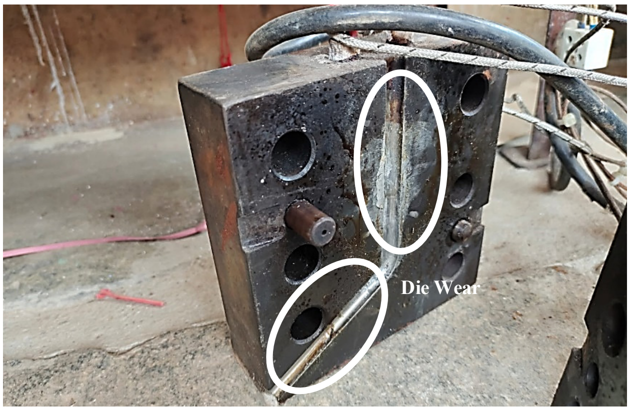

Figure 3. The pin type ECAP die.

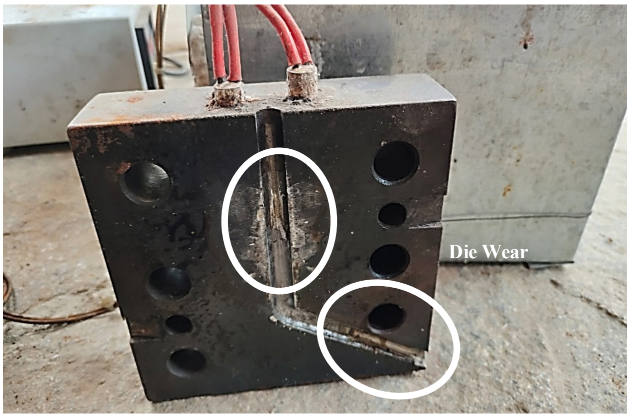

Figure 4. Another half of the same ECAP die.

3.2 Scale-up

The ECAP process is typically performed on small-scale laboratory samples. Scaling up the process to produce larger quantities of material can be challenging, as it requires specialized equipment and may lead to increased costs.

3.3 Material defects

ECAP can induce defects such as cracking (**Figure 5**), delamination, or shear banding. These defects can compromise the mechanical and tribological properties of the final product and can be difficult to control or eliminate. **Figure 6** are the ECAP plunger damaged pictures.

3.4 Process parameters

The success of the ECAP depends on the appropriate selection of process parameters, such as temperature, strain rate, and number of passes. optimal process conditions can result in inconsistent or poor-quality products.

3.5 Limited material applicability

The ECAP process works best for materials that exhibit a high degree of plastic deformation, such as aluminium and copper. The technique may not be as materials with low ductility, such as brittle ceramics or intermetallic.

3.6 Particle segregation mitigation

One potential approach to mitigate the challenges related to particle segregation is the meticulous management of process parameters. The achievement of a moderate channel angle and precise management of the deformation temperature might potentially enhance the uniformity of particle dispersion in the process of Equal Channel Angular Pressing (ECAP). The use of suitable die shape and lubrication may also contribute to the facilitation of uniform particle dispersion.

3.7 Strain localization management

The phenomenon of strain localization is intricately linked to the spatial arrangement of particles and the manner in which material flows within a system. Modifying the channel angle to promote enhanced material flow and optimising the deformation temperature may contribute to effective strain localization management. The use of a multi-pass equal channel angular pressing (ECAP) technique has the potential to provide a more uniform distribution of accumulated strain across the advanced metal matrix composites (AMMCs).

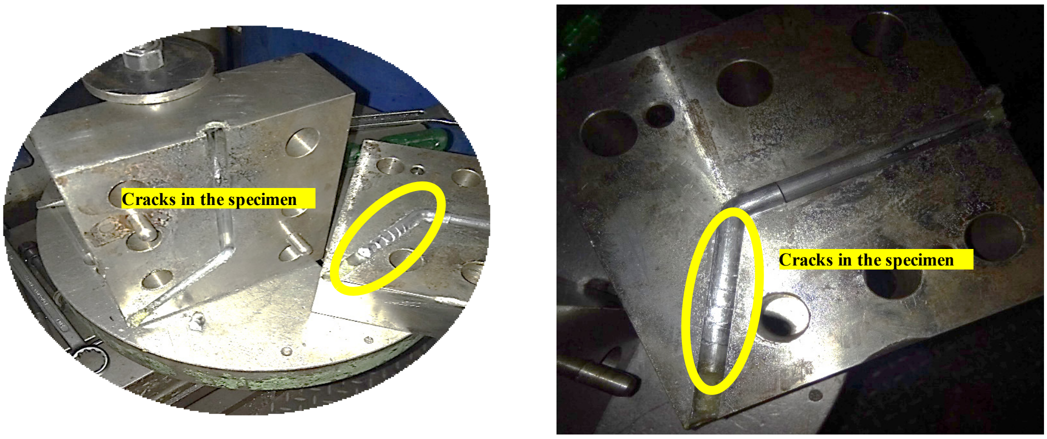

Figure 5. The cracks in the specimens.

Figure 6. The ECAP plunger damaged photographs.

3.8 Parameter optimization

The results obtained from this discourse highlight the need to optimise process parameters to tackle the challenges faced in equal channel angular pressing (ECAP) of advanced metal matrix composites (AMMCs). By using a systematic approach including testing and modelling, researchers may determine the most effective combination of channel angle, deformation temperature, and number of passes to minimise particle segregation and strain localization.

3.9 Advanced modeling and simulation

The use of numerical modelling and simulations may be advantageous in the prediction of material flow patterns, stress distribution, and particle behaviour during Equal Channel Angular Pressing (ECAP) under different process parameters. These tools provide valuable insights into the fundamental dynamics at play and assist in the process of selecting appropriate parameters.

4. Conclusions

Comprehending and effectively resolving the challenges associated with attaining consistent equal channel angular pressing (ECAP) in advanced metal matrix composites (AMMCs) is of paramount importance in order to fully harness their capabilities. Through the development of effective solutions aimed at mitigating these problems, researchers and companies may effectively use the advantages offered by both AMMCs and ECAP, hence facilitating the creation of enhanced materials possessing customised mechanical characteristics.

Conflict of Interest

There is no conflict of interest.

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