Thermal Analysis of Equal Channel Angular Pressing Process by Taguchi Method

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Abstract: Equal Channel Angular Pressing (ECAP) is a metal forming process widely recognized for its ability to refine the microstructure of metals and alloys, thereby enhancing their mechanical properties such as strength, hardness, and ductility. This review presents an in-depth examination of the state-of-the-art advancements in ECAP, highlighting recent developments and research trends in the field. The review covers various aspects of ECAP, including its principles, process parameters, and their effects on material properties. Additionally, the review discusses the latest progress in ECAP-related technologies, such as hybrid processing techniques and innovative die designs, which have expanded the applications of ECAP to a broader range of materials. The review also addresses the challenges and opportunities in implementing ECAP at industrial scales, offering insights into potential avenues for future research. Overall, this comprehensive overview provides a solid foundation for researchers and practitioners interested in leveraging ECAP for materials development and processing in various industries.

Keywords: Equal Channel Angular Pressing, material, development, plastic deformation.

I. INTRODUCTION

High-strength, light-weight metallic materials are in high demand to meet a wide range of market requirements. This goal is attainable through the employment of both novel and traditional resources. Improved processing methods are required to advance currently available materials. SPD processing techniques significantly enhance the grain's refined and mechanical qualities [1-6]. ECAP, HPT, ARB, "Cyclic Extrusion and Compression (CEC), and RCS (Repetitive Corrugation and Straightening)" are only some of the several metal forming processes featured in SPD [3]. All SPD methods involve applying a hydrostatic pressure to a bulk material in order to induce a large shear strain with a low plasticity index and little size change.

ECAP [2- 5,7- 8,9] is a technique that shows promise for use in SPD processing of metallic materials. When the idea for ECAP was first conceptualized in the 1980s, [1] [8] ECAP is a widely used processing method at research facilities throughout the globe. ECAP is anticipated to be a very promising technology [3,5] for the foreseeable future. By pushing the metal through an ECAP die, which consists of two tubes with the same cross-sectional area but which meet at an angle (), large plastic shear stresses may be created in the metal [9]. Because ECAP permits an infinite number of pressing passes to obtain very high strain due to the development of shear strain in the specimen [2,3,5,7], the high imposed shear strain leads to grain refinement, which in turn enhances mechanical properties. After each ECAP pass, rotating the specimen around its longitudinal axis can introduce new slip systems and lead to significant grain refinement [5,7].

Critical processing factors that impact the final microstructure and attributes of ECAP-ed products include die design, lubrication, deformation rate, and temperature. [8] Recent years have seen a surge in interest in ECAP among academics from all over the world. Few research have looked at the design and production methods for an ECAP die, but several have looked at how ECAP processing factors affect material structure and properties [1, 3-9]. It's not common to learn about the ECAP's downsides, which include: Thus, there are a great deal of challenges to be dealt with before ECAP may be employed in industry.

II. SEVERE PLASTIC DEFORMATION

Severe plastic deformation (SPD) is a process used to refine the grain size of metals and alloys, making them suitable for use in ultrafine grain (UFG) applications. The following are examples of structural shifts brought about by SPD: Metals' yield stress and hardness, among other mechanical qualities, have improved in recent decades. Goals in the production of ultra-fine grain structure are attained via the application of equal-channel angular pressing and high-pressure torsion. [1]. [1] It is challenging to obtain high plastic stresses in metallic materials without causing volumetric defects like cracks. It is common practice to do common industrial operations like forging, rolling, extruding, etc., at moderate to high temperatures if significant stresses need to be imparted. If significant strains are applied uniaxially at room temperature, imperfections are going to be created. Extreme plastic deformation occurs when hydrostatic pressures are injected in addition to the shear stresses required for plastic deformation. The shear stresses supply the required plastic strains to the specimen, while the hydrostatic pressures keep the sample from cracking. In addition, the process should be designed so that the overall shape is preserved at the end of each "pass" (or the start of the subsequent pass). By doing so, plastic tension may be built up over time. Some tried-and-true methods for inducing substantial plastic deformation will be discussed below.

By simultaneously pressing in the same direction on all channels, ECAP is now the most often used SPD method. The ECAP has the benefit of being reusable, allowing for maximum pressure to be transmitted into the granules without altering the cross-section of the bulk material [2]. During the ECAP process, a sample is placed in between two channels of the same form but opposite orientation. Outside corner angles and die channel angles are both present in these segments.

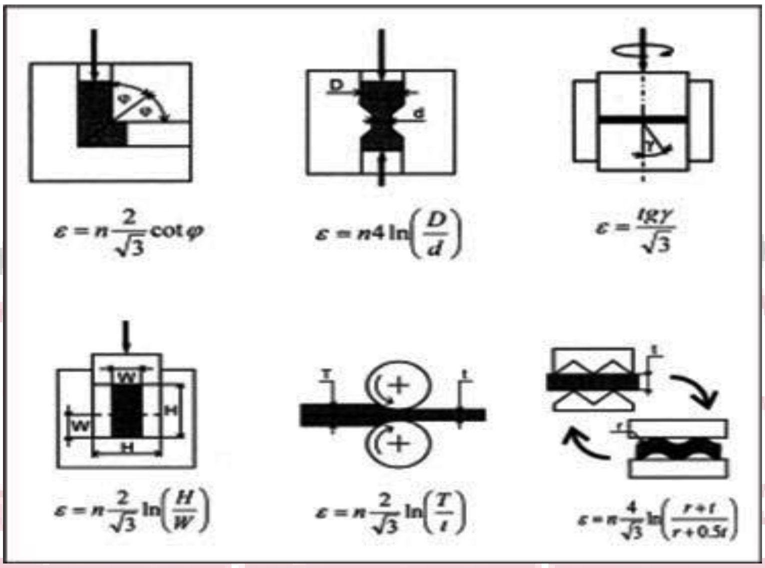

Fig. 1: Severe plastic deformation

There are a number of factors that might affect the ECAP procedure. The most crucial aspect of achieving uniform deformation is the angle, represented by the inner and outer curvature radii (R and r, respectively). Die channel shapes that influence strain uniformity and flow, which impacts mechanical features and microstructural changes, may be used to regulate microstructural changes in deformed materials. [3]. "Only a few studies on the curvature radii r and R. have been conducted by Tyagi and coworkers (Tyagi et al., 2020). [4]." The ECAP process was simulated in DEFORM-3D using a 3D FEM model with several channel angles (90o, 105o, 120o, and 135o) and corner angles (0o, 10o, 20o, and 30o). Increasing the channel and corner angle decreases the shear strain, as seen by the data. "Strain distribution and material flow properties, such as a smaller corner space and a narrower deformation zone, were found to be related to the inner corner radius of the ECAP die (Ghazani and Moslemi, 2018). [5]. There is a greater damage factor in the top parts of the sample than in the lower parts.

The force exerted was boosted by increasing the radius of the inner corner. The effect of varying the outer corner radius of an ECAP was studied in (Jabur 2020) [6]. The results show that die geometry has a major effect on pressing force and related plastic strain as the channel angle and outside corner radius increase. Both the plastic strain and the pressure applied to it decrease. According to the results of this investigation (Abioye et al. [7] This parameter has been discovered to significantly impact strain uniformity, making it a crucial piece of simulation data. The effective strain can be increased by extruding the outer corner at an angle between 22.5 degrees and 45 degrees. [8] According to Zhang (Zhang, 2017), the strain is lessened at both the inner and outer corners as the radius of the inner fillet is larger. This causes the compression stress to be released outside the zone of shear deformation (Hans Raj et al. 2018, 9). The deformation is substantially more uniform without any strain accumulation because to the ECAP dies' 30° outer arc angle and 5 mm radius" fillet radius for all materials. With a larger corner angle, the strain is distributed more evenly across the specimen because "the strain concentration changes from the bottom to the top layer of the" sample.

Multiaxial forging (MAF) (or forging) consists of repeated pressing followed by rotation by 90 degrees and squeezing along three orthogonal axes. This technique, which was developed in the later 1980s, has recently seen widespread use. Repeated uniaxial compression in all three axes is used in the simplest form. Grinding the sample after each pass of uniaxial compression to create flat faces is necessary for further compression. Use a channel die, either an open die [49] or a limited die, to avoid the grinding process. Here, we show that if a sample is pushed to a 50% reduction in size, it may be rotated, reinserted, and pressed again in any of the three orthogonal directions. For the same height reduction as in uniaxial compression, a greater effective strain is achieved with the channel die. The open channel die bulges one pair of faces at the end of a cycle, leading to nonuniform deformation and premature cracking. If the die is limited, the sample will conform to its shape, which may result in a flattering of a bulging face.

III. PRINCIPLES OF EQUAL CHANNEL ANGULAR PRESSING (ECAP)

ECAP is a common severe plastic deformation mechanism that causes nano or ultrafine grained microstructure to grow at low homologous temperatures. ECAP is ideal for industrial materials due to the considerable shear strain created by the repeated extrusion processes. There are several ways to make nanostructured materials, but only severe plastic deformation (SPD) technologies can produce large samples suitable for commercial application. The term "severe plastic deformation" is used to describe metal forming processes that apply a substantial plastic strain to a bulk metal in order to construct nano- or ultrafine-grained structures at low temperatures (usually below 0.3 of the melting temperature).

To get the smallest microstructural measurements, plastic stresses of above 600 to 800 percent are necessary. Such extreme plastic deformation is possible because a single sample may be subjected to SPD several times to accumulate the full amount of plastic strain.

One of the most frequently utilized Severe Plastic Deformation (SPD) processes, ECAP may be used to a broad variety of metals and alloys to create ultrafine grains with desirable mechanical and physical characteristics. The creation of ultrafine grains and the mechanisms that generate the high levels of strength displayed have attracted a lot of attention in recent studies, two important components of SPD technologies. SPD-ECAP experiments have used titanium, which is alloys of titanium (Cu and Ti), and aluminum for orthopedic implants.

Large quantities of high-quality, industrial-grade material may be produced by equal channel angular pressing (ECAP). High shear strain is applied to the workpiece by driving it through two channels that meet at an angle as it is pressed into the die. Since the cross-sectional area of both channels is the same, the product may be reinserted into the extruder and forced through again. By repeatedly extruding through the ECAP die, the microstructure is degraded and the grain size is decreased to an ultra-fine level.

The ECAP idea is shown graphically in Figure 1.1. Figure 1.1 depicts two angles, one at the point where the internal channel and the external arc of curvature connect. Samples are often produced as rods or bars that may be inserted into a channel and then pushed through a die using a plunger.

The billet suffers a simple shear deformation as it is squeezed through the die. SPD processing, in contrast to conventional metalworking operations like rolling, extruding, and drawing, keeps the cross-sectional area the same while subjecting the material to extremely high pressures. In terms of SPD processing, this is crucial. Since the billet's cross-sectional area remains the same throughout pressing, it is possible to repeatedly crush the material to obtain extremely high strain.

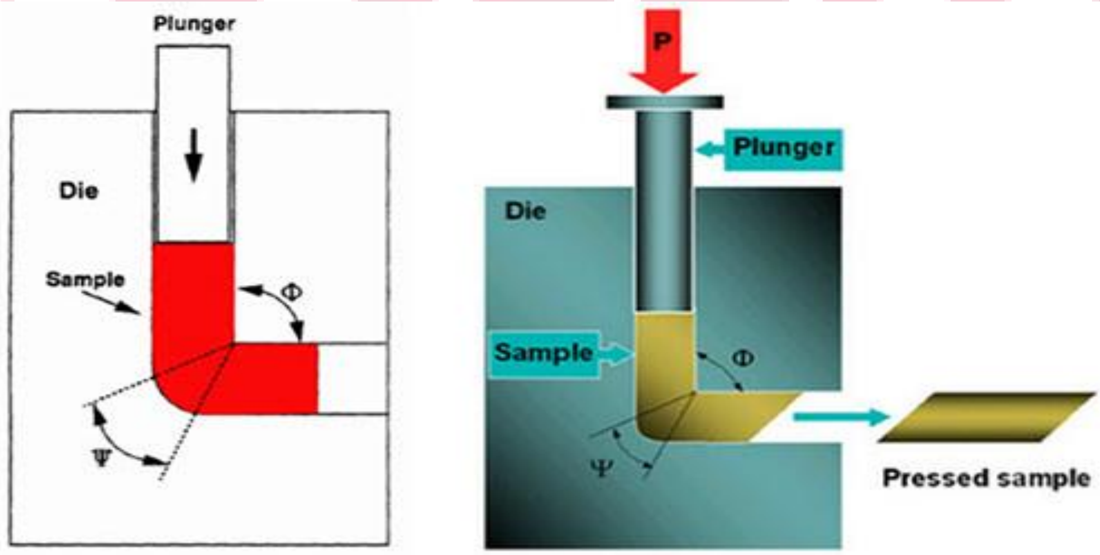

Fig. 2: Principles of ECAP

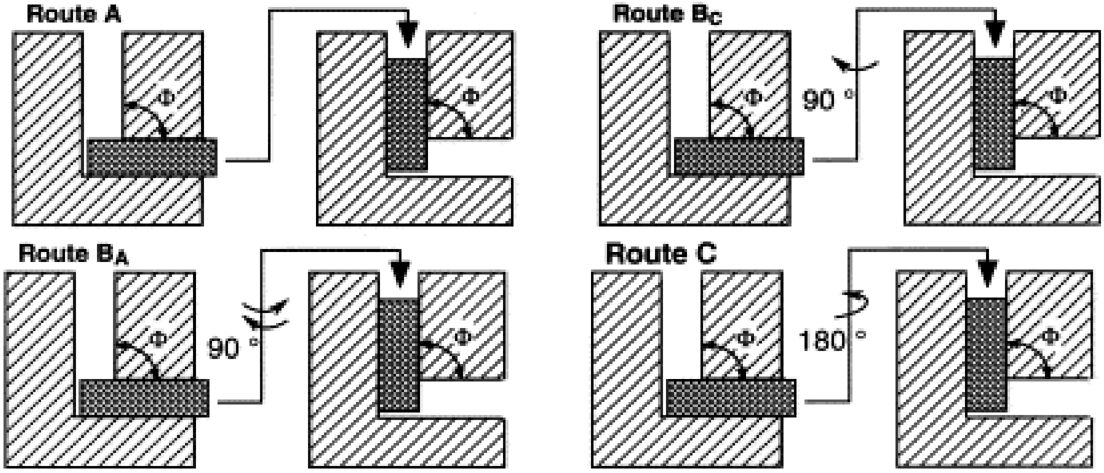

Fig. 3: Grain refinement kinematics during several passes in ECAP.

IV LITERATURE REVIEW

According to **Shuai (2021),** contains a preponderance of equiaxed Zn grains. After eight ECAP cycles, a precipitates-free zone (PFZ) and a precipitates zone (PZ) were developed in the microstructure of the as-cast Zn-1Cu alloy, resulting in a triple heterogeneous microstructure. All PFZs of ECAP alloys are characterized by fine grains (5.4-15.4 m) and a high texture intensity (13.88-21.26). In low-temperature ECAP alloys, PZs are made up of ultrafine CuZn4 precipitates and DRX grains with weak texture (4.90-8.48), whereas in high-temperature ECAP alloys, the DRX grains have substantially greater texture intensity (41.91-42.09).

According to **Liu & Qiu (2021),** "*For the best results in grain refinement and homogeneity of second phases in the AZ91 alloy, high-pass RD-ECAP processing combined with pre-homogenization is the way to go. By optimizing conditions for DRX in future plastic growth, the ductility of the micro grain structure is enhanced, and SPHRR is encouraged*." The PH + ECAP alloy, when subjected to SPHRR, forms a bimodal grain structure with a large number of "coarse un-recrystallized grains" (75.6 m on average) and a small number of "fine recrystallized grains" (3.6 m on average). Mechanical properties such as tensile strength of 420 MPa, yield strength of 335 MPa, and elongation-to-failure of 19% are all attributable to the bimodal grain structure, relatively high SFbasal associated with fine DRX grains, and dynamically precipitated nano-scale second phase particles found in the PH + ECAP + R alloy. (4) The combination of pre-homogenization and RD-ECAP pre-processing has "potential future in industry" because it has the potential to develop a homogenous fine-grain structure that can be utilized to improve the plastic formability of hard-to-deform materials like magnesium alloys.

Garaihy Gara (2021) Corrosion behavior, microstructural development, and hardness values of the AZ31 Mg alloy were studied to see how they were affected by ECAP processing. Electrochemical impedance spectroscopy, open circuit potential, and potentiodynamic and cyclic polarization were used to assess the ECAPed alloy's corrosion behavior.

In the present experimental investigation by Nandakumar (2020), the Al-5052 alloy was subjected to equal channel angular pressing at room temperature. It's been through a variety of processes, from RBC to RC. The Al-5052 alloy was annealed at 420 degrees Celsius for one hour before the ECAP process. In order to analyze the impact of various processing methods, the improved mechanical characteristics of ECA Ped Al-5052 alloys were analyzed. With a maximum value of 120 HV by route RBC, the ECA Ped alloy is harder than the base alloy. The ECAP treatment clearly has an effect, as seen by the tensile test results. The RBC-processed material was found to have a maximum tensile strength of 386 MPa. The testing results showed improved yield, ultimate tensile strength, and hardness compared to the starting material.

Improving the mechanical and microstructural optimization of the equally channel-angular pressure (ECAP) parameters was the focus of **LuleSenoz et al. (2020)**. For the L9 (33) orthogonal array, three levels of investigation were conducted into the effects of processing temperature, processing route, and number of passes. Using an X-ray diffractometer, an optical microscope, and a Vickers experimental micro-hardness test, we evaluated the effect of these variables on the microstructure properties of Al-Zn-Mg alloy. Grain was reported in the samples evaluated using electron Microscopy, electron backscatter diffraction, and electron transmission microscopy. The optimal micro-hardness and lowest kernel size are achieved with eight ECAP passes in route Bc at 100 °C. Microstructural analyses reveal that passageway and ECAP route size, number, and placement are all significantly affected by temperature. According to the results, the percentage of HABs reduces, grain size increases, and grain equivalents climbs as ECAP temperature rises.

Dumanicet al. (2020) high-pressure molding of a semi-solid A356 aluminum alloy was demonstrated using a moulding simulation tool. High pressure die casting and the viscosity of a semisolid slurry led to the creation of a mold for semisolid aluminum alloy. The three input parameters (liquid % of slurry, plunger velocity of second stage, and mould shape) in half-solid high-pressure die casting techniques were also studied for their impact on casting time, shrinkage, and bubble generation. Taguchi 'grey relation analysis' was performed to identify the best process parameters. In this research, an analysis of variance was used to ascertain the significance of the movable parameter on the performance indicator. 50 percent liquid, 1 m/s plunger speed in the second phase, and 60 degrees of vertical plane-to-cavity angle were found to be the optimal operating conditions.

Liang et al. (2020) heated extrusion procedure utilizing an Al-Zn-Mg plate was studied using both theoretical and experimental approaches. The design of the feeder chamber was improved using a multi-objective optimization strategy. The optimal feeder chamber was also used for an extrusion test. The standard flow rate variation was reduced from 0.827 to 0.499 mm/s after the above study was performed on the feeding chamber. Transportation and extrusion costs have decreased dramatically in the meanwhile. Dynamic regeneration and partial dynamic reprocessing are indicated by the presence of substructures, elongated grains, and multi-micron fine grains on the extruded plate. Recrystallized cubes and warped brass, S, and copper were among the extruded platform textures. Additionally, there was a large disparity between the percentages of the aforementioned texture components in the plate's centre and its edges. The center of the plate was more sturdy, shorter, and less elastic than its perimeter. Tensile property differences at 0 degrees, 45 degrees, and 90 degrees have been used to determine the presence of anisotropy in al-Zn-Mg extruded plates.

Friction stir processing (FSP) was used by **Taghiabadi et al. (2020)** Recycling chips were added to cast A356 Al specimens at several percentages (0, 25, 50, and 75 wt%) to boost their mechanical and quality indices. To achieve this goal, new and improved FSP settings were given, including a rotation speed of 2000 rpm and a travel speed of 12 mm/min for as-cast samples. Both alloys' tensile characteristics and quality index significantly dropped when recycled A356 content was raised, as shown by the findings. When machining chips were added to the alloy at concentrations of 25, 50, and 75%, the quality index dropped by 18%, 42%, and 65%, respectively. According to SEM tensile fractography, oxides and "oxide-related flaws created" are the primary factors affecting quality. The FSPed samples also shown better performance. When comparing as-cast samples with the same number of machining chips to those with 25, 50, and 75% wt recycled chips, the FSPed quality index increased by 50, 100, and 190, respectively. Ultrafine distribution of second phase particles and the formation of ultrafine grains, as well as the elimination of caster defections, especially oxide inclusions, are likely the" driving factors behind quality improvement, as revealed by scanning electron microscopy (SEM) of the microstructure and fracture surface.

Srinivasan et al. (2020) In the present study, an aluminum composite made with VAL12 as the matrix and La2O3 as the dispersoids by liquid metallurgy and the squash casting technique is shown. Frictional characteristics of as-cast aluminum composites are studied using dry sliding wear tests in a variety of operational settings. The produced samples were analyzed for uniform reinforcement distribution using state-of-the-art characterization equipment. Taguchi orthogonal array approach is used for experiment design for detecting wear and frictional coefficient responses. SEM is used to analyze the form of worn surfaces as part of the mechanistic research. High-charge processes like delamination and abrasion are less common in AMMC than low-charge processes like thermal adhesion. For AMMCs, the load and sliding distance are the two most important elements that influence their wear behavior in non-sliding situations.

.**Kahraman et al. (2019)** *"Surface roughness of materials like aluminum 7075 may be evaluated in three stages during milling. (1) Taguchi-based MNLR modeling, (2) signal-to-noise (S/N) analysis, and (3) Monte Carlo-based probabilistic analysis of S/N as a function of cutting depth, cutting velocity, and feeding rate."* "The optimal cutting conditions, as determined by the Taguchi method, yielded a surface roughness of 0.964 m with a depth of cut of 0.2 mm, cutting speed of 900 m min1, and feed rate of 0.1 mm tooth1." Three tests were performed, and a surface ruggedness of 0.964 m 0.3 percent was achieved to corroborate the area ruggedness predicted by the Taguchi method. The success metric was computed using the best possible MNLR method, which yielded an R2pred (predicted recovery coefficient) of 98.02 percent. Monte Carlo simulations were shown to be very effective in detecting surface roughness uncertainty that cannot be identified using deterministic methodologies.

Angellaet al. (2019). A new strategy for boosting alloy toughness was presented. The high-resistance AA7050 aluminum alloy undergoes a heated working phase in the novel method between the solvent treatment and final ageing. The outcomes demonstrated several advantages, such as grain refinement and a greatly improved KIC toughness of fractures without compromising tensile characteristics. Insight into the improvements in macro properties might be gained by first characterizing the microstructural and precipitation condition.

Azarniyaet al. (2019) The present review provides a comprehensive overview of each of these techniques, in addition to an examination of their potential implications on the microstructure and characteristics of Al-Zn-Mg-Cu alloys, and "examine the most important presenting strategies, such as isothermal ageing, multi-stage ageing, non-isothermal ageing, RRA, or stress ageing (i.e. creep ageing)." New developments and opportunities in this field were also highlighted.

Among the most crucial categories of metallic products to be discussed by **Gloria and colleagues (2019)** will be "Alloys, Ti alloys, Mg alloys, steels, ni super alloys, and metal matrix composites (MMC)"; this discussion will also cover recent developments and place special emphasis on current problems and future possibilities in the field of aeronautical metals.

Sheng et al. (2019) The average kernel size of the fine-grained 5A70 alloy boards shown was 8.48 m, and overall deformations were decreased by 90%. The strain rate sensitivity coefficients are 0.42%, 0.31%, 0.47%, and 0.46%, while the elongation-to-failure values at 400, 450, 500, and 550°C are 205%, 3210%, 3980%, and 4370%, respectively. During superplastic deformation, border sliding and grain rotation likely occurred, as evidenced by the results of electron backscatter diffraction (EBSD), which showed that the huge grain borders are high corners. Based on X-ray diffraction (XRD) and energy dispersive spectroscopy (EDS) analyses, the compositions have been determined to be Al6 (MnFe). Furthermore, at 500°C and 550°C, an unfavorable hardening of something like the pinning action has resulted from uneven grain development. According to transmission electron microscopy (TEM) investigations, the applied tension of precipitated particles and/or grain boundaries had now gone beyond the cavity nucleation favored by the matrix structure. Superplastic divisions and cracks developed as cavities formed, connected, and hardened. As a result of the second phasing of grain boundaries and the formation of Mg-rich oxides, filaments developed on the shattered surface

V .CONCLUSION

Equal Channel Angular Pressing (ECAP) stands as a transformative metal forming process with significant potential for enhancing the mechanical properties of metals and alloys. This review has provided a thorough overview of the state-of-the-art advancements in ECAP, including its principles, process parameters, and their impacts on material behavior. Recent research has demonstrated ECAP's versatility and efficacy in refining microstructure and improving material performance across a range of applications. However, challenges remain in the areas of scaling up the process for industrial use, optimizing parameters for specific materials, and integrating ECAP with other processing methods. Addressing these challenges presents opportunities for further innovation in the field, offering potential for novel applications in industries such as aerospace, automotive, and materials engineering. Continued research and development in ECAP will undoubtedly contribute to the advancement of materials science and engineering, paving the way for the creation of next-generation materials with exceptional properties.

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