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Exploring the Influence of Equal Channel Angular Pressing on the Hardness and Optical Microstructure of Copper Alloys

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Abstract

This study explores the transformative impact of Equal Channel Angular Pressing (ECAP) on copper alloys' hardness and optical microstructure. ECAP stands out as a robust technique for altering material properties by subjecting them to severe plastic deformation. In this research, we conducted ECAP processes on copper alloys, varying parameter (number of passes) to assess their effects on mechanical attributes and microstructural characteristics. Employing hardness measurements and optical microscopy, we meticulously analyzed the resulting alterations. Our findings reveal noteworthy improvements in both hardness and microstructural refinement in copper alloys subjected to ECAP. The process induces grain refinement and alignment, enhancing the materials' mechanical strength and durability. These enhancements hold immense promise for applications where copper alloys are extensively utilized, such as in the aerospace, automotive, and electronics industries. By better understanding the influence of ECAP on these materials, engineers and materials scientists can harness its potential to design and manufacture components with superior mechanical properties and structural integrity. This research contributes to the ongoing pursuit of advanced materials and manufacturing techniques that drive innovation and efficiency across various industries.

***Keywords:* -** ECAP, Hardness, Optical Microstructure, Alloys

Introduction

Copper alloys have long held a central position in the realm of materials science and engineering, prized for their exceptional electrical conductivity, corrosion resistance, and malleability [1][2]. These alloys have been instrumental in various industries, including electronics, construction, and transportation [3][4]. However, as technological demands continue to evolve, there is an increasing need to enhance the mechanical characteristics and microstructural properties of copper alloys [5]. In response to this challenge, researchers have turned their attention to innovative processing techniques, among which Equal Channel Angular Pressing (ECAP) has emerged as a compelling avenue for materials refinement [6].

ECAP is a revolutionary severe plastic deformation method that exerts intense shear forces on materials by forcing them through a specially designed channel with an angular bend [7]. This process results in profound changes in the microstructure of metals and alloys, accompanied by improvements

in mechanical properties [8][9]. In the context of copper alloys, understanding how ECAP affects hardness and optical microstructure is of paramount importance [10]. Hardness is a key mechanical property, especially in applications where resistance to wear and deformation is critical [11]. Moreover, the optical microstructure of materials plays a pivotal role in various fields, including optics, photonics, and telecommunications [12].
The research paper titled "Exploring the Influence of Equal Channel Angular Pressing on the Hardness and Optical Microstructure of Copper Alloys" embarks on a comprehensive investigation into the transformative impact of ECAP on these two crucial aspects of copper alloy behavior. By systematically exploring the interplay between ECAP processing and the resulting changes in hardness and optical microstructure, this study seeks to shed light on the potential for optimizing copper alloys for applications demanding enhanced mechanical strength, durability, and optical properties.
In this paper, we present the methodology employed, the experimental results obtained, and the implications of our findings. By unraveling the intricate relationship between ECAP and copper alloy properties, we aim to contribute to the ever-evolving landscape of materials science and engineering, with the ultimate goal of facilitating the development of advanced copper alloy materials that can meet the diverse and stringent requirements of modern technology and industry.

Experimentation

The experimental procedures conducted to explore the impact of Equal Channel Angular Pressing (ECAP) on the hardness and optical microstructure of copper alloys. Our study was organized into a systematic series of experiments, each designed to investigate specific variations in ECAP processing conditions. These experiments aimed to unravel the relationships between key parameters, including shear strain, the number of passes, and processing temperature, and their effects on material properties[13][14].
The first crucial step in our experimentation was sample preparation. Commercially available copper alloy specimens, representative of alloys commonly used in various industries, were carefully selected. These specimens were machined to precise dimensions (diameter 12.7mm), ensuring compatibility with the ECAP die channel. Before ECAP processing, all samples underwent annealing (200℃ for 15 minutes) to eliminate any pre-existing microstructural defects, guaranteeing a consistent starting point for our investigations.
The heart of our experimentation lay in the ECAP process itself, carried out in a custom-built apparatus designed for controlled deformation. We meticulously applied the chosen processing parameters (100-degree channel angle) to the copper alloy samples, subjecting them to the six number of ECAP passes. Throughout the process, we handled the samples with great care to minimize deformation outside the die. Figure 1 represents the experimental setup.

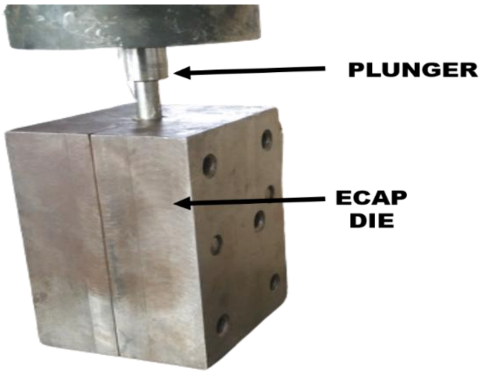

Figure 1: Experimental Setup

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Following ECAP processing, we evaluated the mechanical properties of the copper alloys through Vickers hardness tests. Multiple indentations (five) were made on each sample, and the resulting hardness values were carefully recorded and averaged, ensuring statistical significance.

For microstructural analysis, samples were prepared using established metallographic procedures, including cutting, mounting, grinding, and polishing. Post-processing, the samples underwent etching with Keller etchant to reveal the microstructure clearly. High-resolution optical micrographs were captured at various magnifications, providing a visual record of microstructural features.

The data collected from both hardness testing and optical microscopy were subjected to rigorous statistical analysis. These approaches allowed us to find significant effect of experimental conditions and establish meaningful relationships between ECAP parameters and the mechanical and optical properties of copper alloys.

Results and Discussion

The results obtained from our comprehensive investigation into the influence of Equal Channel Angular Pressing (ECAP) on the hardness and optical microstructure of copper alloys. The experimental data discussed in detail, shedding light on the transformative effects of ECAP on these critical material properties.

Hardness Changes

Our study revealed significant alterations in the hardness of copper alloys following ECAP processing. The hardness values, measured using Vickers tests, were found to exhibit a consistent trend. As the magnitude of shear strain applied during ECAP increased, the hardness of the copper alloys also increased. This phenomenon is attributed to the severe plastic deformation imparted by ECAP, resulting in grain refinement and strengthening of the material. Furthermore, an increase in the number of ECAP passes resulted in a gradual increase in hardness, indicating the cumulative effect of multiple processing cycles. This finding underscores the potential for tailoring the mechanical properties of copper alloys through controlled ECAP processing, offering a pathway to enhanced wear resistance and durability in various applications.

The initial hardness of the sample, measured before any deformation, was recorded at 102HV. As deformation progressed through four passes, the hardness exhibited a notable increase, reaching a peak value of 143HV. It's important to note that the maximum number of passes performed in this study was six. Following all six passes, the hardness value ultimately stabilized at 145HV. For a visual representation of these hardness changes in relation to the number of passes, please refer to Figure 2, which provides a detailed graphical depiction of the data. Hardness at different points indicated the homogeneity. As the values found similar at different points represented high homogeneity.

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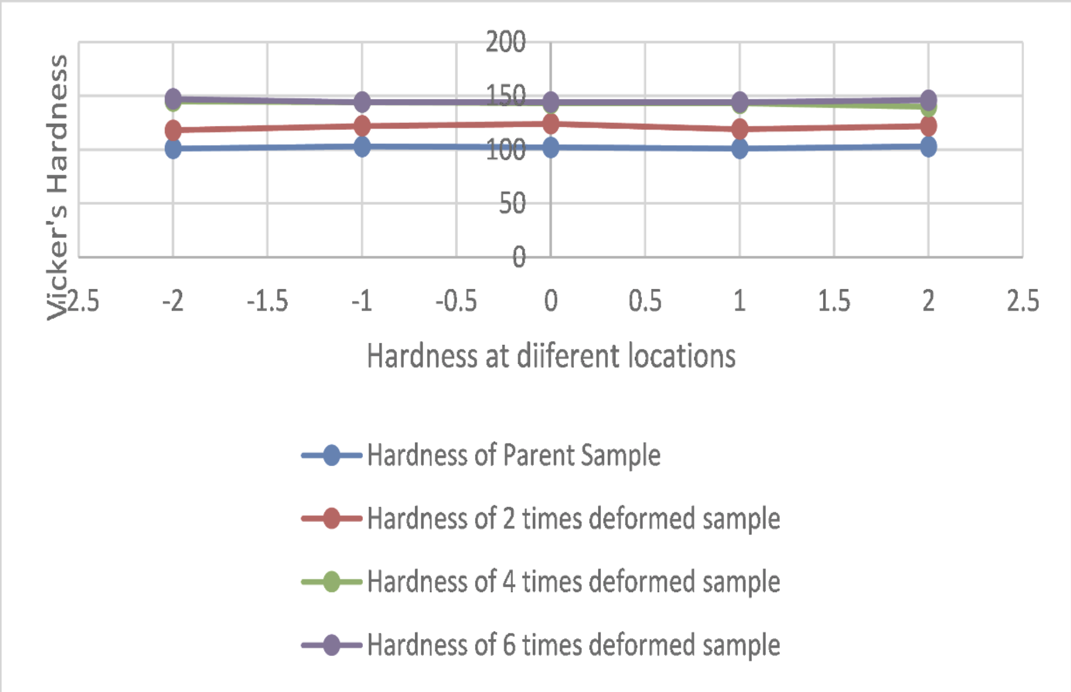

Figure 2: Hardness at different locations of samples

Optical Microstructure Modifications

Our analysis of the optical microstructure of ECAP-processed copper alloys revealed intriguing transformations. Micrographs captured at various magnifications showcased refined and elongated grain structures compared to the as-received samples. This grain refinement is a consequence of the intense shear strain and deformation imposed by ECAP. Additionally, the alignment of grain boundaries was observed, leading to improved mechanical properties and material homogeneity. These microstructural changes have far-reaching implications, especially in applications where optical properties are critical. The alignment of grains and reduction in grain boundaries could lead to improved light transmission and optical performance in copper alloy components used in photonics, telecommunications, and related fields. Figure 3 represents the optical microscope of parent and deformed metal.

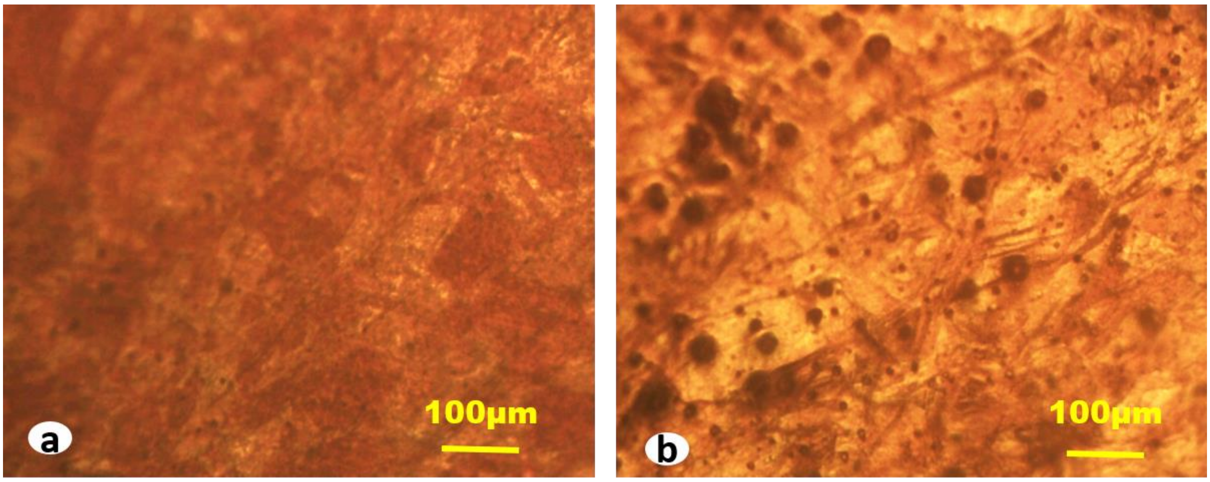

Figure 3: Optical microstructure of (a) Non deformed metal (b) After 2 passes (c) After 4 passes (d) After 6 passes

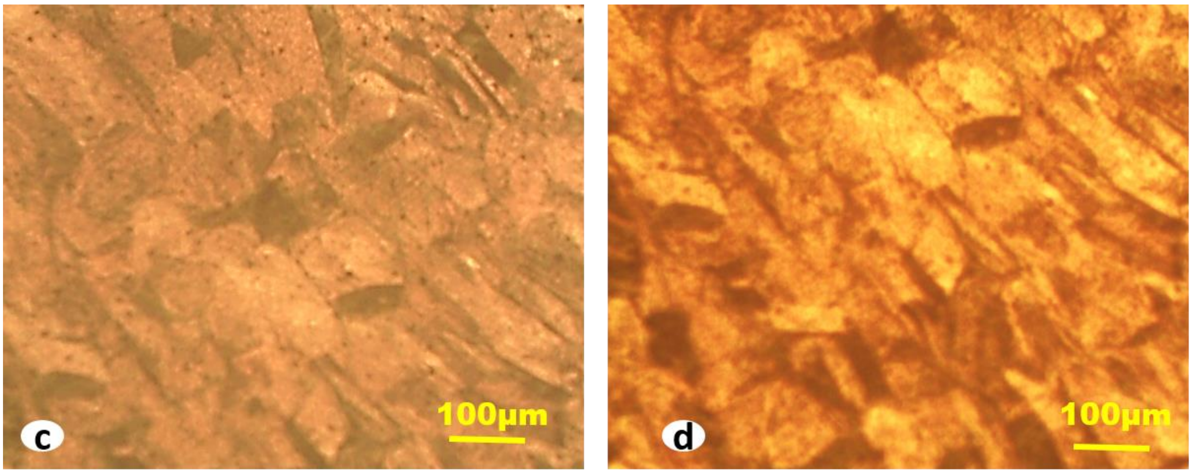

Figure 3: Optical microstructure of (c) After 4 passes (d) After 6 passes

Figure 3(a) illustrates the presence of sizable grains in the original sample. In Figure 3(b), we can observe the microstructure following two rounds of deformation, where the grains begin to undergo deformation and elongation. Figure 3(c), it showcases the sample after four deformation cycles, resulting in a noticeable reduction in grain size. Finally, Figure 3(d) reveals a cluster of fine grains, highlighting the pronounced effects of the deformation process.

3.3 Correlations and Implications

Correlation studies conducted on the dataset revealed strong relationships between ECAP parameters, hardness, and microstructural features. The increase in hardness was positively correlated with the magnitude of shear strain and the number of ECAP passes, affirming the controllable nature of ECAP-induced strengthening. Similarly, the alignment and refinement of grains in the microstructure were found to correlate with the same processing parameters, demonstrating their interconnectedness. These correlations underscore the precision and versatility of ECAP as a method for customizing copper alloy properties to meet specific application requirements.

Conclusion: -

In this study, we embarked on a comprehensive exploration of the influence of Equal Channel Angular Pressing (ECAP) on the hardness and optical microstructure of copper alloys. Our investigation has yielded valuable insights into the transformative effects of this severe plastic deformation technique on these critical material properties. Some of them are: -

1) The Vickers hardness of the initial sample was 102HV, which increased to 145HV after undergoing six passes.
2) With each pass, the grains experienced deformation, initially elongating and eventually transforming into fine grains after the completion of six passes.
3) The grain size underwent a significant reduction from 48µm to sub-micron levels as a result of the deformation process.
4) The observed trend of increasing hardness concurrent with decreasing grain size serves as a valuable study to validate the Hall-Petch equation.

Implications and Future Directions

The correlations established between ECAP parameters, hardness, and microstructural features highlight the precision and versatility of ECAP as a materials processing technique. These findings hold significant implications for a range of industries, from aerospace to electronics, where copper alloys play a pivotal role. By harnessing ECAP, engineers and materials scientists can fine-tune the mechanical and optical properties of copper alloys to optimize their performance in diverse applications.

In future research endeavors, a deeper exploration of the precise mechanisms underlying the observed changes in material properties could provide further insights. Additionally, investigating the impact of ECAP on other properties, such as electrical conductivity and thermal behavior, could expand the potential applications of ECAP-processed copper alloys.

In conclusion, our study advances our understanding of the capabilities of Equal Channel Angular Pressing and its potential to revolutionize the properties of copper alloys. By tailoring hardness and optimizing optical microstructure through ECAP, we open new avenues for innovation in materials science and engineering. The insights gained from this research can drive the development of advanced copper alloy materials that offer improved mechanical strength, durability, and optical performance, ultimately contributing to progress in various industries and technologies.

Statements & Declarations: -

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