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POWDER INVESTIGATION OF THE PRODUCIBILITY OF CO BASED COMPOSITE MATERIALS PRODUCED BY POWDER METALLURGY METHOD

ABSTRACT

Cobalt-based composites have become increasingly important in advanced engineering applications due to their high temperature strength, wear resistance, and chemical stability. Nevertheless, the manufacturing behavior of these systems—particularly when produced through powder metallurgy—requires detailed investigation to understand how compositional adjustments influence microstructural and electrochemical performance. In this study, the producibility of Co-based composite materials fabricated by powder metallurgy was systematically evaluated with emphasis on powder mixing homogeneity, densification behavior, and post-sintering structural integrity. Elemental powders with high purity were blended in controlled proportions, compacted under a constant pressure, and sintered in an inert atmosphere to prevent oxidation and ensure stable metallurgical bonding. Microstructural characterization was carried out using scanning electron microscopy, which revealed the evolution of pore morphology, reinforcement distribution, and matrix–particle interactions. Variations in Co content were found to significantly influence the extent of densification and the formation of microstructural defects, indicating that cobalt plays a critical role in shaping the internal architecture of the composites. Overall, the study confirms that powder metallurgy provides a reliable route for producing Co-based composite materials with tunable microstructure and corrosion characteristics. The findings underscore the potential of these materials for demanding industrial environments where mechanical reliability, thermal stability, and corrosion resistance must coexist.

Keywords: Co-based Composites, Powder Metallurgy, Manufacturability, Microstructure, Characterization

1. INTRODUCTION

Powder metallurgy has become a strategic production route for advanced metal-based composite materials, particularly when precise control of chemical composition and microstructural architecture is required. Compared with conventional manufacturing techniques such as casting, machining, or hot–cold forming, powder metallurgy offers significant advantages in terms of material utilization, microstructural homogenization, compositional tailoring, and near-net-shape fabrication

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[1]. This makes the method highly attractive for the development of high-performance composites used in engineering applications where weight-to-strength ratio, wear resistance, and corrosion behavior are critical[2].

Cobalt and cobalt-containing alloys have long been recognized for their exceptional thermal stability, toughness, and resistance to chemical degradation. These properties enable their use in demanding industries, including aerospace, automotive, biomedical systems, precision mechanical parts, robotic components, and energy technologies. However, the industrial usability of Co-based systems highly depends on the optimization of microstructural integrity, pore morphology, and reinforcement distribution—parameters strongly influenced by the powder metallurgy process[3, 4, and 5].

In recent years, interest has increased in developing Co-based composite structures where cobalt acts either as a matrix former or as a functional reinforcement element. Properly engineered Co-based composites have the potential to overcome limitations associated with monolithic alloys, such as insufficient wear resistance or limited mechanical durability under corrosive environments [6]. Therefore, examining how cobalt interacts with the matrix, how it affects densification behavior, and how its presence modifies mechanical and electrochemical properties is of great significance for materials engineering [7 and 8].

This study focuses on the manufacturability of Co-based composite structures produced through powder metallurgy, aiming to clarify the influence of cobalt content on microstructure, pore formation, and the overall performance of the produced materials.

2. RESEARCH SIGNIFICANCE

The primary objective of this research is to evaluate how varying amounts of cobalt influence the manufacturability, microstructural evolution, and corrosion-related mechanical performance of powder-metallurgically produced composite materials. The study systematically investigates:

- The homogeneity of powder mixing and particle interactions,
- The effect of Co co-ratio on densification and pore distribution after sintering,
- Microstructural modifications as revealed by sem and SEM-mapping,
- The correlation between cobalt content and electrochemical behavior.

Highlights:

- Co-based composite samples were successfully fabricated using powder metallurgy.
- SEM analysis demonstrated that pore morphology and overall density change significantly depending on cobalt content.
- Samples with lower cobalt concentration exhibited higher polarization resistance (Rp), indicating delayed surface degradation and improved corrosion performance.

These results reveal that optimizing cobalt content can significantly enhance the functional behavior of composite systems, offering valuable insight for industrial applications requiring durable and corrosion-resistant materials.

3. EXPERIMENTAL METHOD-PROCESS; ANALYTICAL STUDY VEYA SUBJECT

To examine the manufacturability of Co-based composite structures, four different powder mixtures were prepared using elemental powders with 99.9% purity and a particle size of 325 mesh. The base alloy composition was selected to form a stable matrix, and cobalt was introduced in different proportions to analyze its impact on microstructural and electrochemical behavior.

Initially, matrix powders were weighed using a precision balance and mixed in a three-dimensional turbula mixer for 5 hours to ensure homogeneity. Following the mixing stage, all compositions were compacted under a constant pressure of 250 MPa, forming green compacts with consistent geometry.

The sintering process was conducted in a controlled Argon atmosphere at 975°C for 45 minutes to prevent oxidation and to promote metallurgical bonding between the powder particles. After sintering, samples were subjected to standard metallographic preparation steps—including grinding, polishing, and etching—to reveal their internal microstructure.

4. FINDINGS AND DISCUSSIONS

4.1. Scanning Electron Microscopy (SEM) Analyzes

SEM examinations revealed significant microstructural changes based on cobalt reinforcement level. Cobalt exhibited a uniform distribution throughout the matrix, indicating effective powder mixing and a successful sintering process. The homogeneous dispersion of Co contributed to improved particle bonding and enhanced matrix-reinforcement interaction (Figures 1, 2, and 3).

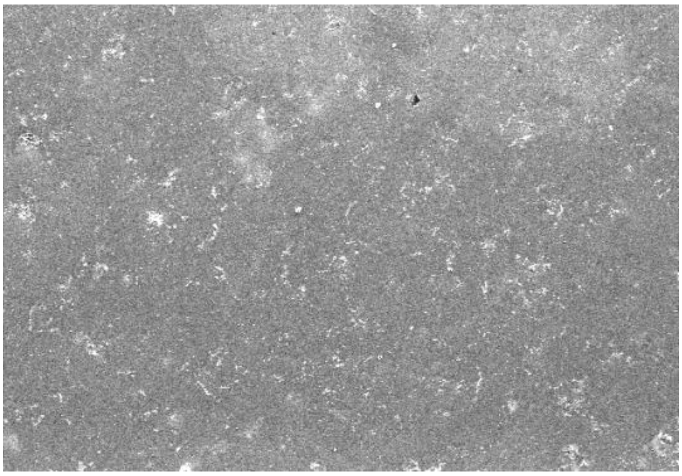

Figure 1. SEM Analysis image of sample number 1

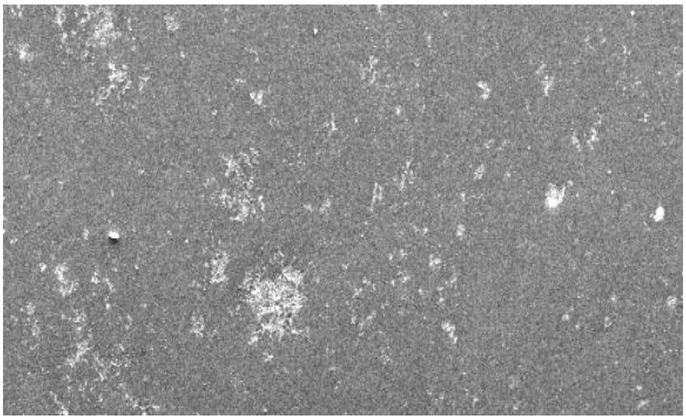

Figure 2. SEM Analysis image of sample number 2

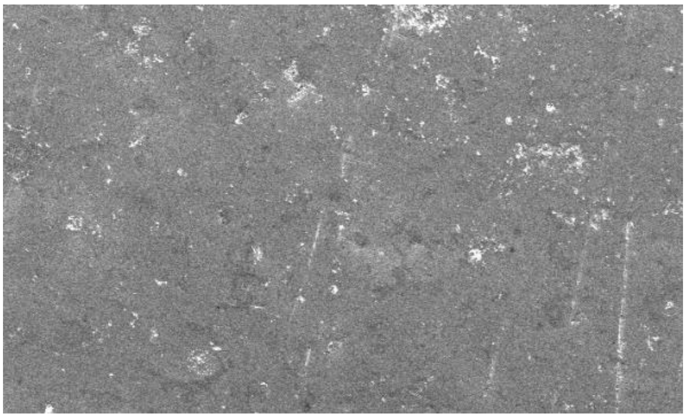

Figure 3. SEM Analysis image of sample number 3

Micrographs demonstrated that increasing Co content modified pore morphology, leading to noticeable variations in density. Samples with optimized cobalt ratios showed reduced porosity and more compact grain boundaries, suggesting improved diffusion and sintering kinetics [9, 10, and 11]. Localized cracks and voids observed in some samples indicated regions where densification was incomplete, emphasizing the influence of cobalt on sintering dynamics. Literature comparisons confirm that cobalt acts as a diffusion-active element, promoting densification when properly proportioned. Overall, the SEM results confirmed that cobalt content strongly influences the manufacturability and structural integrity of powder-metallurgically produced composites [12].

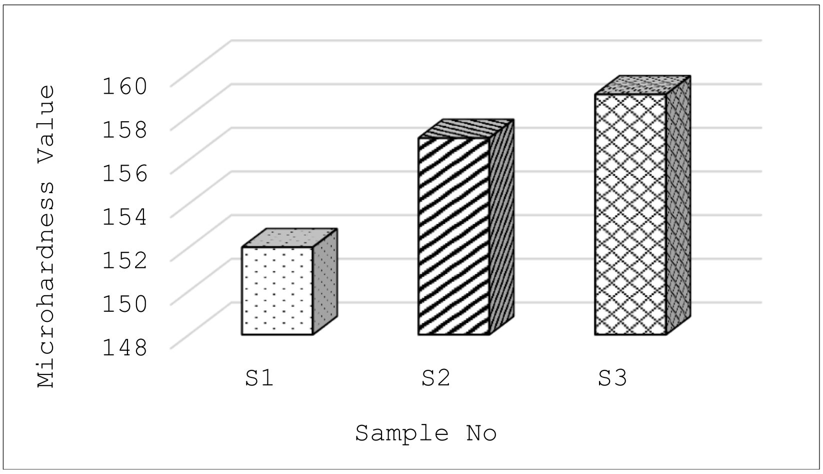

Figure 4. Microhardness value of composite samples

Figure 4 presents the microhardness results of all composite samples produced within the scope of the study graphically. To more accurately assess the hardness distribution of the samples, microhardness measurements were performed at 100 µm intervals along a defined line on the sample surface, allowing for detailed analysis of both local and overall hardness changes. This method is particularly important for evaluating the heterogeneous structures observed in composite materials produced using powder metallurgy.

According to the results, the average hardness value of the first sample, which is a matrix alloy, was determined to be approximately 152 HV. This value represents the basic hardness level of the unreinforced Co-based sample. With the addition of a small amount of Cu to the second sample, the hardness value increased to 157 HV [13]. This initial increase, achieved with the initiation of Cu addition, indicates the initial effect of the hard phases forming within the sample. In the third sample, where the reinforcement ratio was increased, the hardness value was determined to increase further, reaching 159 HV. This increase is attributed to the increased resistance to deformation under load due to the particles being more densely distributed within the matrix. Thanks to their high elastic modulus and hardness, Cu particles limit the local deformation behavior of the matrix phase, resulting in significant improvements in the measured microhardness values [14, 15, 16, and 17]. This value corresponds to the highest microhardness performance of all samples. These phase transformations occurring during sintering create high-strength regions at the matrix/reinforcement interfaces, significantly increasing the overall hardness of the material. Literature indicates that reinforcements provide significant hardness increases, particularly in copper and nickel alloy matrices [18].

When the microhardness results are evaluated, it is clear that the Cu addition consistently and significantly improves the sample's mechanical properties. The lowest hardness value in the unreinforced sample is a natural consequence of the ductile structure of the matrix alloy. Conversely, the increased Cu content directly affects both the amount of phases and the hardness distribution within the matrix, leading to increases in performance parameters. In particular, the 10% Cu-reinforced sample yielded the highest hardness value, suggesting that this composite ratio may be the optimum reinforcement level. Thus, it was concluded that systematically increasing Cu reinforcement significantly improves the hardness properties of Co-based composites and could expand the material's application areas [19, 20, and 21].

5. CONCLUSION AND RECOMMENDATIONS

This study demonstrates that cobalt plays a crucial role in shaping the microstructure of powder metallurgically produced composite materials. Under constant pressing and sintering conditions, varying cobalt content led to observable changes in pore distribution and reinforcement homogeneity. Co-based composites were successfully fabricated and displayed controllable microstructural evolution. SEM analyses revealed that cobalt content significantly alters pore size, distribution, and overall densification.

CONFLICT OF INTEREST

The author(s) declare that they have no potential conflict of interest.

FINANCIAL DISCLOSURE

This research received no financial support.

DECLARATION OF ETHICAL STANDARDS

The authors of the article declare that the materials and methods used did not require ethics committee approval and/or regulatory approval.

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