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EFFECT OF HOMOGENIZATION TREATMENT ON THE MECHANICAL AND MAGNETIC PROPERTIES OF THE 52Fe-28Cr-15Co-3Mo-2V ALLOY

This research investigates the effect of the homogenization process on the mechanical and magnetic properties of the 52Fe-28Cr-15Co-3Mo-2V alloy. The alloy was initially cast in a vacuum arc remelting (VAR) and then homogenized under vacuum at 1200°C for 10 h. X-ray diffraction (XRD) analysis confirmed that both the as-cast and homogenized samples consist of a single α phase. Nevertheless, variations in peak intensity indicated changes in grain orientation and texture. Vickers hardness measurements revealed a significant increase in hardness, from 279.14 to 494.24 Hv, resulting from the formation of a martensitic microstructure. Magnetic characterization demonstrated a decrease in saturation magnetization (M_s) from 1.28 T in the as-cast sample to 1.04 T in the homogenized sample, attributed to the change in texture of the sample post-homogenization. Furthermore, coercivity (H_c) of the homogenized sample increased by 2904.58 A/m due to the formation of the martensitic phase, which can pin the magnetic domains.

Keywords: Fe-Cr-Co-Mo-V alloy; Homogenizing; Mechanical properties; Magnetic properties; Martensitic structure

1. Introduction

Magnetic materials are critical components in a wide range of electronic and electrical devices [1-5]. The increasing demand for high-speed electric motors that can operate at extremely high rotational speeds has driven the need for materials with optimized magnetic and mechanical properties. However, modern permanent magnets often exhibit brittleness and limited ductility. A primary challenge in developing new technologies is finding materials that simultaneously possess strong magnetic properties and high mechanical strength [6-11].

Iron-chromium-cobalt (Fe-Cr-Co) alloys have attracted significant attention from researchers due to their widespread applications as well as favorable magnetic properties [12,13] These alloys are strong contenders against traditional materials like Alnico, offering advantages such as lower production costs and reduced cobalt consumption [14-18].

The hard magnetic characteristics of these alloys arise from the separation of the high-temperature homogeneous solid solution based on α-Fe into two distinct phases: a weakly magnetic α_2 phase (rich in Cr) and a strongly magnetic α_1 phase (rich in Co), which together form a modulated structure [2,19,20]. Given the critical role of magnetic properties, researchers have studied the effects of texture and alloying additions, such as aluminum, on the magnetic parameters of these alloys [21,22]. However, a significant challenge in utilizing these alloys lies in their brittleness and limited ductility. To enhance the performance of these motors, materials with improved mechanical strength are essential [14]. Recent research has shown that the the addition of alloying elements, such as vanadium (V), into CoCrFeMnNi alloys can significantly improve their mechanical properties. This improvement in strength is primarily attributed to the formation of a secondary sigma phase and enhanced solid solution strengthening effects [23-25].

Previous research [26] has shown that vanadium enhances the ductility and strength of Fe-Co alloys, while also improving coercivity (H_c) and remanent magnetization (M_r), making it suitable for industrial applications requiring semi-hard or hard magnetic alloys along with high mechanical properties. On the other hand, molybdenum, as a ferrite stabilizer, is expected to positively influence the microstructure and intrinsic magnetic properties, particularly the saturation magnetization (M_s), a critical magnetic parameter for magnetic alloys, ultimately contributing to improved performance. Therefore, in this study, the main aim is the improving the mechanical and magnetic properties of Fe-Cr-Co alloys by adding molybdenum (Mo) to the alloy composition alongside vanadium.

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2. Experimental

In this study, a high-purity alloy (purity >99.9%) with a nominal composition of 52Fe-28Cr-15Co-3Mo-2V (wt.%) was fabricated using the vacuum arc remelting (VAR) process. To achieve a homogeneous microstructure, multiple remelting cycles (at least four) were performed. Based on previous research [27], a temperature of 1200°C and a time of 10 hours were selected for the homogenization of the alloy. Therefore, the as-cast alloy was subsequently subjected to homogenization at 1200°C for 10 h in an argon atmosphere to enhance its structural uniformity.

Phase identification of the alloy was carried out using X-ray diffraction (XRD, AW-XDM300) analysis with a Cu target, allowing for the characterization of the crystalline phases present. The hardness was measured through Vickers micro hardness tests, performed with an MH3 KOOPA hardness device. To ensure the precision of the hardness measurements, the hardness test was repeated 10 times for each sample, and the average value was calculated. Additionally, the magnetic properties of the alloy were investigated using vibrating sample magnetometry (VSM) to assess its magnetic performance.

3. Results and discussions

Fig. 1 displays the XRD patterns for both the as-cast and homogenized samples. The results indicate that the microstructure of the alloy consists exclusively of the *α* phase in all conditions, with no secondary phases detected. A comparison between the XRD pattern of the 52Fe-28Cr-15Co-3Mo-2V alloy and 68Fe-23Cr-9Co alloy [2] homogenized for various times shows complete agreement between the two sets of patterns. This suggests that the addition of V and Mo into the alloy did not lead to the formation of secondary phases or induce significant changes in the diffraction pattern.

Although there were no changes in chemical composition or the stability of the identified phases, slight variation in the intensity of the diffraction peaks between the as-cast and homogenized states are observed. This discrepancy can be attributed to differences in grain distribution and orientation resulting from the different processing conditions [28].

The Vickers hardness testing demonstrated a significant increase in hardness following the homogenization process, with values rising from 279.14 Hv in the as-cast condition to 494.24 Hv in the homogenized state. This marked enhancement in hardness can be linked to the formation of a martensitic microstructure, confirming that the homogenization treatment effectively improves the mechanical properties of the alloy [29].

To investigate the magnetic properties of the studied alloy, hysteresis loops for both the as-cast and homogenized samples are presented in Fig. 2. Key magnetic parameters, including M_s, H_c, and M_r are extracted from these curves and are summarized in TABLE 1. The results show that after homogenization, M_s decreased, while M_r and H_c increased.

M_s, an intrinsic property of the material, is primarily influenced by chemical composition and the volume fraction of non-magnetic phases. Also, the interaction between magnetic domain walls and crystal defects significantly affects the magnetic properties of materials, particularly H_c. According to the domain wall pinning model, H_c arises from obstacles that hinder the motion of domain walls due to microstructural inhomogeneities [29,30]. Hilzinger and Kronmüller [31] suggested that intrinsic H_c originates from randomly distributed crystal defects

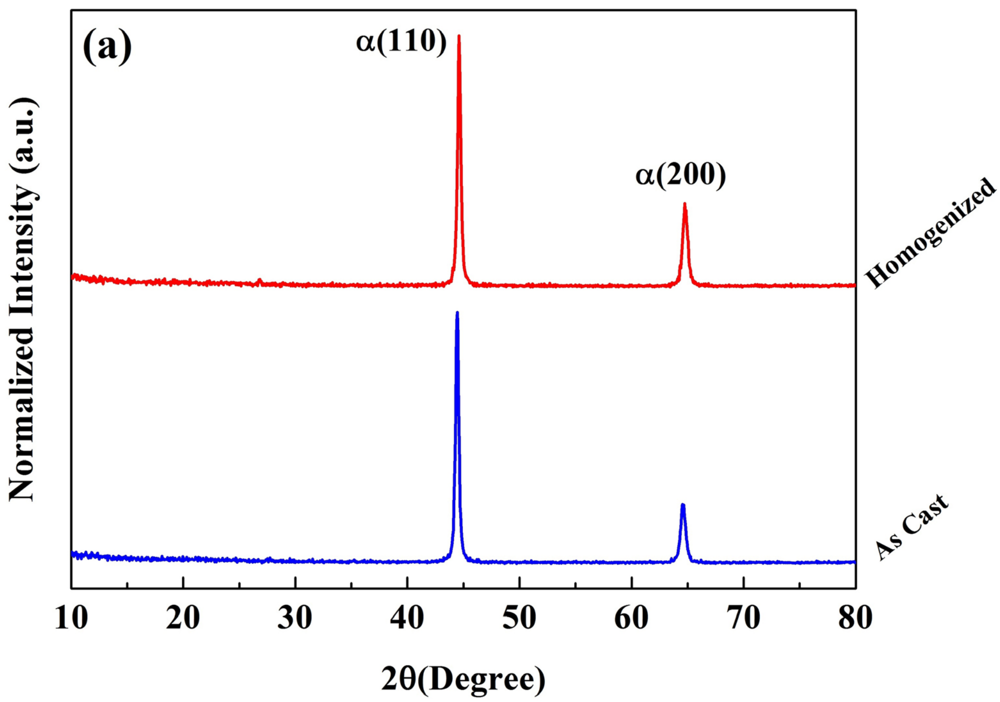

Fig. 1. X-ray diffraction pattern of as-cast and homogenized 52Fe-28Cr-15Co-3Mo-2V alloy at 1200°C for 10 h

as well as the energy of domain walls relative to the crystal lattice. In other words, examining the material's microstructure is key to understanding changes in magnetic parameters.

As-cast structure typically exhibits a dendritic morphology, which transforms into a uniform, coarse-grained structure through homogenization. Due to their more ordered crystalline structure and fewer crystal defects (such as dislocations and vacancies), the grains' interior magnetizes more easily and exhibits higher magnetization [32]. In contrast, grain boundaries, due to higher internal stresses, magnetic anisotropy arising from the orientation of magnetic moments, and the presence of impurities, magnetize more slowly. Therefore, it can be expected that M_s would be lower in the as-cast state. Additionally, in the as-cast condition, due to the dendritic structure, compositional in homogeneities, and internal stresses arising from asymmetric contraction during cooling, it was expected that H_c and M_r would be higher due to their influence on domain wall motion. However, the observed trend was contrary to this expectation. One of the primary reasons for these discrepancies is the change in the sample's texture. A comparison of the diffraction patterns in Fig. 1 shows changes in peak intensity, indicating changes in texture. With homogenization and changes in grain orientation, especially when the grain orientation is not aligned with the easy axis of magnetization, a decrease in M_s and an increase in H_c can be expected. Furthermore, the formation of martensitic structures due to homogenization also leads to an increase in H_c. It should be mentioned that other factors such as non-uniform cooling, residual stresses, the presence of dislocations, and formation of stable magnetic structures resistant to changes in magnetic moment direction due to homogenization can also affect magnetic properties [29,33].

To further investigate the magnetic properties, the magnetic parameters of the 68Fe-23Cr-9Co alloy are also presented in TABLE 1. It is noted that this alloy exhibits a higher M_s in both as-cast and homogenized states compared to the studied alloy, but its H_c is significantly lower. The simpler structure of the 68Fe-23Cr-9Co alloy, combined with fewer alloying elements, allows iron atoms to align more readily in parallel magnetic arrangement, resulting in a higher M_s. Additionally, this less complex structure makes the magnetic orientation of

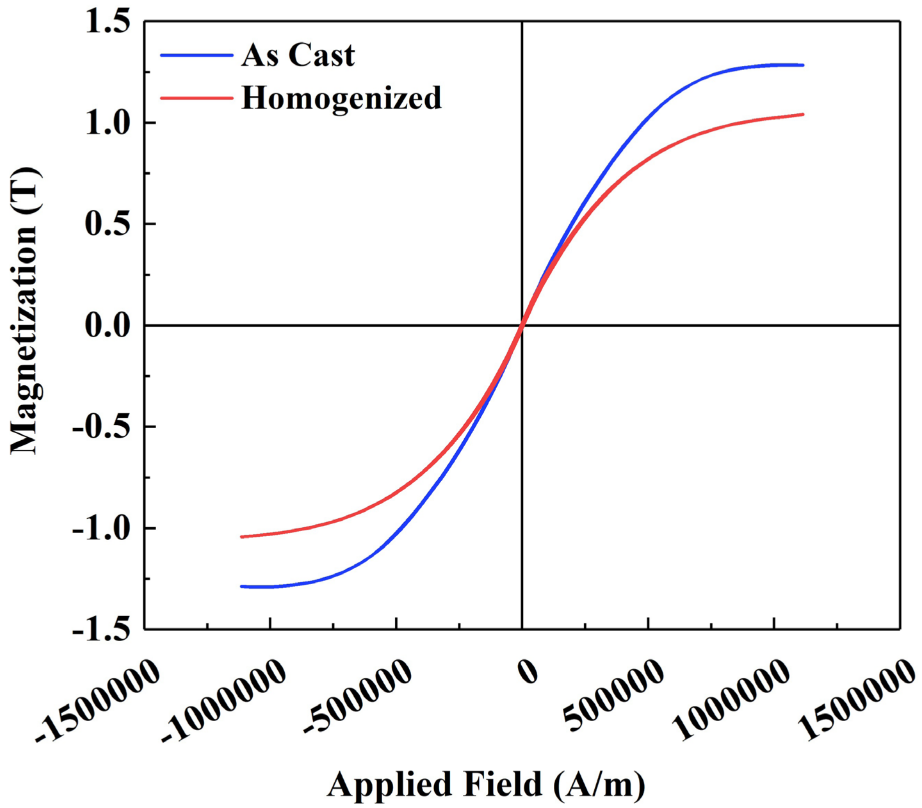

Fig. 2. Hysteresis curves of as-cast and homogenized samples

TABLE 1

Comparison of magnetic properties of 52Fe-28Cr-15Co-3Mo-2V alloy in as-cast sample and after homogenization at 1200°C for 10 h

Alloy composition	Condition	M_s (T)	M_r (T)	H_c (A/m)	Ref.
52Fe-28Cr-15Co-3Mo-2V	As-cast	1.28	0.004	1435.58	Present work
	Homogenized	1.04	0.012	4349.71	
Fe-23Cr-9Co	As-cast	1.49	—	795.77	[2]
	Homogenized	1.66	—	557.04	

grains less susceptible to external magnetic fields and mechanical stresses, leading to a reduced H_c.

In contrast, the presence of non-magnetic alloying elements in the 52Fe-28Cr-15Co-3Mo-2V alloy disrupts the magnetic ordering of iron atoms, resulting in a decrease in M_s. Moreover, these elements introduce internal stresses and crystallographic defects, which compromise the stability of the magnetic structure and contribute to the enhancement of H_c. Consequently, the addition of Mo and V into the studied alloy results in a magnetically harder material than the 68Fe-23Cr-9Co alloy, as evidenced by its higher coercivity.

4. Conclusion

This research focused on the development and characterization of a 52Fe-28Cr-15Co-3Mo-2V alloy, which was cast using a vacuum furnace and subsequently subjected to a homogenization treatment at 1200°C for 10 h. The findings from this study can be summarized as follows:

1. The homogenization treatment successfully preserved the alloys microstructure as a single-phase *α*, with no secondary phases detected. Comparisons with the Fe-23Cr-9Co indicated that adding Mo and V did not lead to the formation of secondary phases or significant changes in the XRD pattern.
2. A significant increase in hardness was achieved through homogenization, with values rising from 279.14 Hv in the as-cast state to 494.24 Hv in the homogenized state. This enhancement in hardness can be attributed to the development of a martensitic microstructure.
3. Although the M_s decreased from 1.28 to 1.04 T following homogenization, this reduction was due to changes in grain orientation. . In contrast, the H_c increased from 1435.58 A/m in the as-cast state to 4349.71 A/m post-homogenization, driven by the formation of the martensitic phase, the changes in internal stresses, and the formation of more stable magnetic structures.
4. The addition of Mo and V into the Fe-Co-Cr-based alloy resulted in a significant increase in coercivity, rendering this alloy magnetically harder than the Fe-23Cr-9Co alloy.

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