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# INVESTIGATING THE MICROSTRUCTURAL CHARACTERIZATION AND MAGNETIC PROPERTIES OF THE AS-CAST Fe-Co-14V ALLOY

This study investigates the microstructural characteristics and magnetic properties of the as-cast Fe-Co-14V alloy. Ingots of the Fe-Co-14V alloy were produced using vacuum arc remelting (VAR), and their microstructure was examined through optical microscopy (OM), field-emission scanning electron microscopy (FE-SEM) equipped with energy dispersive X-ray spectroscopy (EDS), and X-ray diffraction (XRD). The magnetic properties were assessed using vibrating sample magnetometry (VSM). The OM and FE-SEM micrographs and XRD patterns revealed that the room temperature microstructure of the as-cast Fe-Co-14V alloy is predominantly comprised of a vanadium-supersaturated austenite phase. Magnetic studies indicated that an increase in vanadium content leads to a decrease in saturation magnetization ($M_s$), accompanied by an increase in coercivity ($H_c$). The decrement in $M_s$ is attributed to the presence of the paramagnetic austenite phase, while $H_c$ is significantly influenced by the ability to rotate the wall of the magnetic domains.

*Keywords:* Hard magnetic materials; Fe-Co-V alloys; Microstructural characterization; Magnetic properties; VSM

## 1. Introduction

Iron-cobalt-based alloys represent a significant category of soft ferromagnetic materials, particularly suitable for applications in synchronous hysteresis motors (SHMs) [1-5]. These alloys have attracted considerable attention due to their unique magnetic properties, including high Curie temperature, elevated saturation magnetization ($M_s$), superior magnetic permeability, low energy loss, and extremely low magnetic anisotropy [5-12]. Moreover, they exhibit impressive mechanical properties characterized by high yield strength and tensile strength, alongside good flexibility in a disorder state. However, the flexibility of these alloys diminishes significantly due to ordering transformation [8,13].

Considering that these alloys are used to the production of specialized equipment, such as rotors and stators in aircraft internal generators and magnetic converters, telephone diaphragms, input and output nozzles of electromagnetic controllers, and active components in the SHMs rotor, they must possess not only high magnetic properties but also adequate flexibility and workability [1-3,6,8,13-18].

Research on iron-cobalt binary alloys has demonstrated that adding a third alloying element as a third component can greatly improve the mechanical properties of these materials. Among the various alloying elements studied, vanadium has emerged as a favored choice owing to its unique effects on the properties of iron-cobalt binary alloys [7-9,12,13,19-27]. The addition of vanadium to iron-cobalt alloys not only strengthens the material and enhances its flexibility but also significantly influences its magnetic attributes [4,6-9,15]. The increase in vanadium content promotes the stabilization of γ-phase and leads to the formation of paramagnetic precipitates, specifically $(Co, Fe)_3V$, within Fe-Co-V alloys. The presence of these paramagnetic phases within the ferromagnetic matrix modifies the magnetic behavior of the alloys, shifting their properties from soft to semi-hard and even hard magnetic states [4,7,15,24].

Hence, the main aim of this research is to conduct a comprehensive study of microstructural characteristics and magnetic properties of the as-cast Fe-Co-14 wt.% V alloy. To achieve this, the magnetic properties and microstructural features were thoroughly analyzed. Magnetic properties were measured using a vibrating sample magnetometer (VSM). At the same time, microstructural and structural characteristics were studied using a field emission scanning electron microscope (FE-SEM), optical microscopy (OM), and X-ray diffraction (XRD), respectively.

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## 2. Experimental

To produce the alloy used in this study, high purity materials (>%99.9), including iron, cobalt, and vanadium, were charged into a vacuum arc furnace (VAR) under argon atmosphere. To ensure homogeneity, the melting process was repeated five times. Finally, the alloy was cast into a closed-bottom, water-cooled copper mold with internal dimensions of 10×10×60 mm$^3$. The chemical composition, determined by inductively coupled plasma mass spectrometry (ICP-MS), is presented in TABLE 1.

TABLE 1

Chemical composition of the studied alloy

| Element | Co | Fe | V |
|---|---|---|---|
| (wt.%) | Balance | 33.90 | 13.85 |

Microstructural characterization was investigated using a FE-SEM (QUANTA FEG-450 model, FEI USA Co.) equipped with EDS, and an OM (CK40M-F200 model, OLYMPUS Co., Japan). The phase evolutions was studied using XRD (Philips Xpert model) with a Cu anode operated at 40 kV and 40 mA, and a step size of 0.05°. Also, the magnetic properties of the produced sample were investigated using VSM (MDKB model, Magnetic Daneshpajoh Co., Kashan, Iran) with a maximum field intensity of up to 1.5 T at room temperature.

## 3. Results and discussions

The OM micrograph and XRD pattern of the as-cast alloy are presented in Fig. 1. As seen, the microstructure of the as-cast alloy is consist of martensite, austenite, and ferrite phases,

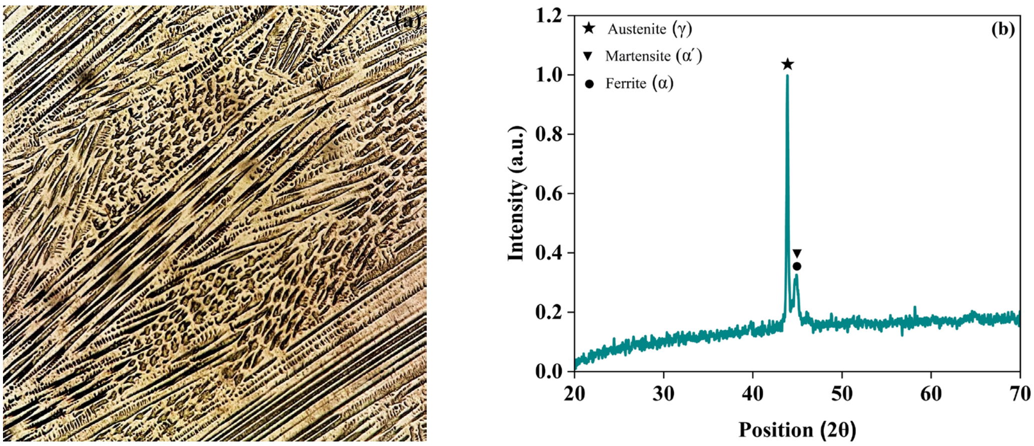


Fig. 1. (a) OM micrograph and (b) the XRD pattern related to the as-cast sample

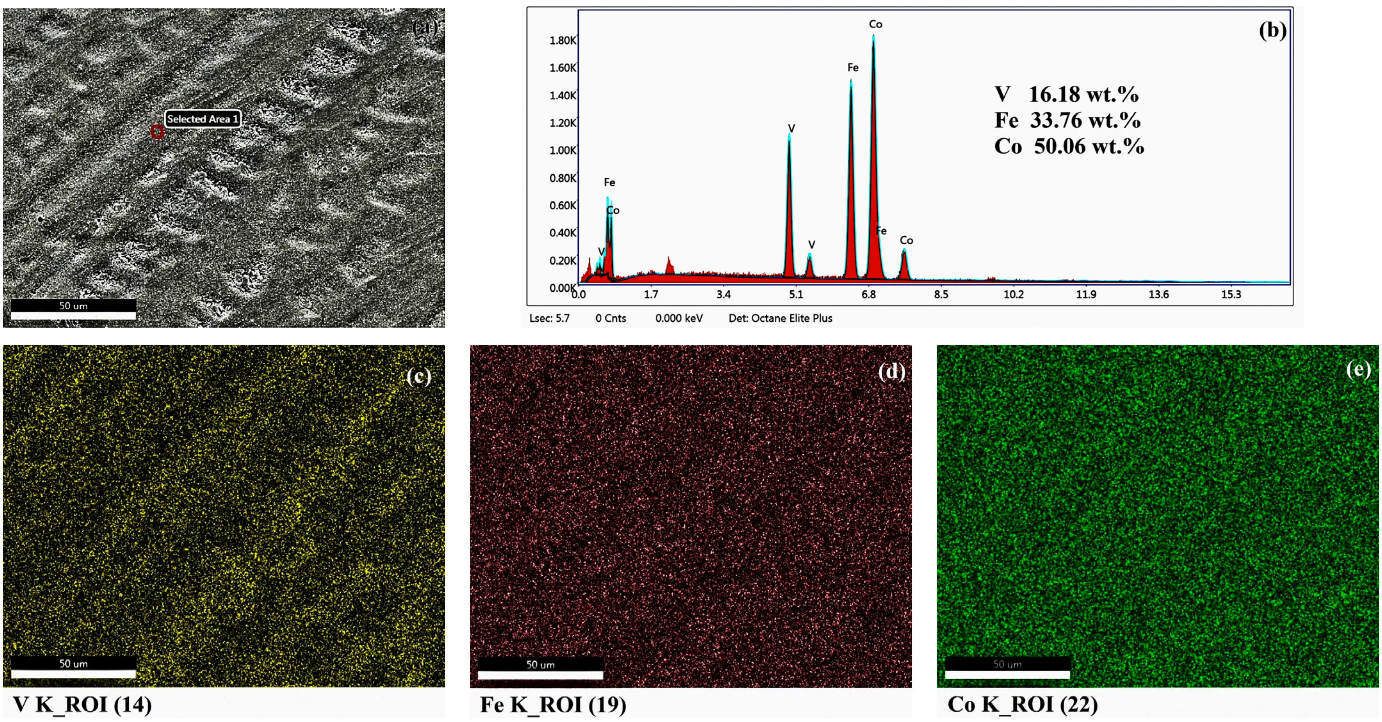


Fig. 2. EDS images of the sample of as-cast Fe-Co-14V alloy: (a) FE-SEM micrograph along with (b) the EDS spectrum, and (c-e) overlay elemental mapping images

which along well with the findings from previous publications [25,26].

Fig. 2 displays the FE-SEM micrograph along with the EDS results of the as-cast sample. A comparison of Figs. 1 and 2 suggests that the significant part of this microstructure consists of vanadium-supersaturated phases (γ-phase), which appear as bright areas in the OM image.

Previous studies indicate that in Fe-Co binary alloys, only the α ferromagnetic phase is stable at room temperature. Adding vanadium to iron-cobalt alloys increases the stability of the γ-phase, thereby reducing the polymorphic transformation temperature in these alloys. For instance, when the alloy contains 7.15 wt.% vanadium, the starting temperature of the polymorphic transformation is reduced to 490°C [5]. Based on the phase analysis results presented in Fig. 1, it is observed that with the presence of 14 wt.% vanadium, the stability of the γ phase is significantly enhanced, allowing it to remain stable at room temperature. This leads to forming a dual-phase alloy (α + γ).

To investigate the magnetic properties of the studied alloy, the hysteresis loop (M-H) of the as-cast sample is presented in Fig. 3. Important magnetic parameters, such as $M_s$ and $H_c$ were extracted from this curve and are summarized in TABLE 2.

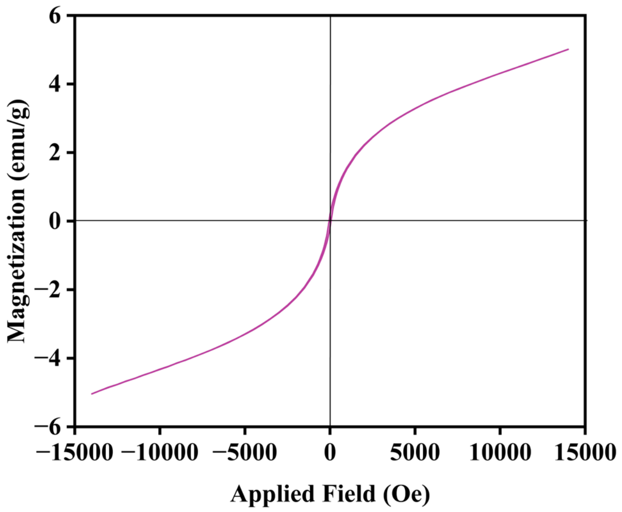


Fig. 3. Hysteresis loop of the as-cast Fe-Co-14V alloy

TABLE 2

Magnetic parameters of the as-cast Fe-Co-14V alloy

| Alloy composition | $M_s$ (emu/g) | $H_c$ (A/m) |
|---|---|---|
| Fe-Co-14V | 5.01 | 4,453.153 |

Upon the addition of 14 wt.% vanadium, the $M_s$ of the Fe-Co alloy was reduced by 65.01%. The significant decrease in $M_s$ can be attributed to the presence of the non-magnetic γ-phase, which is in good agreement with that reported by others [4,6,8].

In contrast to $M_s$, $H_c$ is strongly dependent on the material‘s microstructure and can be affected by various structural defects, such as dislocations, grain boundaries, and precipitates [9,23,28]. Notably, the addition of vanadium can lead to an increase in $H_c$. For instance, Kamali et al. [3] demonstrated that the $H_c$ in an alloy with the composition Fe-Co-10V is higher than in the alloy containing 7.15 wt.% vanadium, as investigated by Hasani et al. [4].

In this regard, it was found that this magnetic parameter can increase further with the addition of vanadium, reaching 14%, which significantly enhances the coercivity of the alloy.

## 4. Conclusion

In this study, the microstructural characterization and magnetic properties of the as-cast Fe-Co-14V alloy were investigated. The findings revealed that at room temperature, the microstructure contained a γ phase, which, due to its paramagnetic nature, contributed to a decrease in $M_s$. The addition of vanadium to iron-cobalt alloys increases the stability of the γ-phase, thereby reducing the polymorphic transformation temperature in these alloys. Furthermore, the effect of vanadium on the polymorphic transformation temperature is significant; with 14 wt.% vanadium, the stability of the γ-phase is sufficient for it to remain stable at room temperature, leading to the formation of a dual-phase alloy (α + γ). In contrast to $M_s$, $H_c$ increases with the increased stability of the γ-phase.

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