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**ORIGINAL ARTICLE**

# Magnetic Transitions and The Magnetic Characteristics of The Martensitic Transformations in A Fe-Mn-Co Alloy

Mustafa YUKSEL[1,♠], Sedat AGAN[2]

[1]*Fatih University, Vocational School of Health Sciences, 06370, Ostim Ankara TURKEY*
[2]*Kırıkkale University, Department of Physics, 71450, Kırıkkale TURKEY*

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**ABSTRACT**

In this study, the magnetic transitions and the magnetic characteristics of the thermally induced martensitic transformations in Fe-13.2%Mn-5.3%Co alloy have been investigated. The microstructure analysis of difusionless phase transformations forming in the alloy were performed by scanning electron microscopy (SEM), and the magnetic properties were revealed by Mössbauer spectroscopy and AC susceptibility. SEM observations reveal that two types of thermal-induced martensites, Ů(h.c.p.) and ŮNj(b.c.c.) martensites, form in the austenite grains of the alloy. Mössbauer spectra at room temperature reveal a paramagnetic character with a singlet for the ɔ (f.c.c.) austenite and Ůmartensite phases and a ferromagnetic character with a broad sextet for ŮNjmartensite phase. In addition, measurement of the AC susceptibility of the alloy shows that the magnetic transition from the paramagnetic order to magnetic disordered occurs below room temperature at 258 K.

**Key Words**: *Magnetic transitions, Martensitic transformations, Fe-Mn-Co alloy, Mössbauer spectroscopy, AC susceptibility, Scanning electron mycroscop.*

## 1. INTRODUCTION

It is well known that the martensitic transformation, which forms in many Fe, Cu, and Ti-based alloys and ceramics, is one of the most typical first-order structural diffusionless phase transition, and it has widely studied because of their technologic usages [1,2]. Among the Fe-based alloys, the Fe-Mn and Fe-Mn based alloys have been the subject of considerable interest in recent years due to their typical shape memory characteristic, good mechanical properties, and commercial importance [3-5]. Marinelli et al. investigated the martensitic transformation in a Fe-Mn-Co alloy [6]. In Fe-Mn-Si alloys, the martensitic transformation and shape memory effect were studied in detail [7,8]. Durlu [2,9] studied in detail the forming of the Ů martensite in a Fe-Mn-Mo alloy.

In the Fe-Mn alloys, two distinct types of martensite structures, namely Ů and ŮNjmartensites, might form

♠Corresponding author, e-mail: yukselphysics@gmail.com

depending on the Mn content in the austenite ɔ phase. Martensite formed on cooling is ŭNjbelow 10wt%Mn and is Ůabove 15wt%Mn. These martensites can also coexist in the alloys with Mn content between 10 and 15 wt% [10,11]. On the other hand, martensitic transformation in Fe-Mn alloys causes significant changes of their magnetic behaviors. In these alloys, the martensitic product phase can exhibit ferromagnetic, antiferromagnetic, and paramagnetic behaviours depending on its type despite the paramagnetic nature of the austenite parent phase. A paramagnetic Ÿ antiferromagnetic ordering reaction can also occur upon cooling in both the austenite (ɔ) and the Ů martensite phases of the Fe-Mn alloys, and such a magnetic transition in austenite phase stabilizes ɔ phase relatively to the competing Ůphase [10,12].

In this study, the magnetic transitions and the magnetic characteristics of the thermally induced martensitic transformations in Fe-13.2%Mn-5.3%Co alloy have been investigated by means of SEM, Mössbauer spectroscopy, and AC susceptibility.

## 2. EXPERIMENTAL

The alloy employed in the present study was prepared by vacuum induction melting under an argon atmosphere from pure (99.9%) alloying elements and quenching as cylindrical rods with 1 cm diameter and 10 cm length. The chemical composition of the alloy was obtained as Fe-13.2%Mn-5.3%Co (wt. %) by using electron dispersion spectroscopy technique. Sample cut from ingot alloy was sealed into a quartz tube and then heat treated in the austenite ɔ-phase equilibrium region. It was homogenized at 1200 °C for 12h followed by quenching into water at room temperature. For SEM observations, the surface of the sample was first mechanically polished and afterwards the damaged surface layer was eliminated by etching in a solution composed of 5%Nitric acid and %95 methanol for 30 seconds. SEM observations were made in a JEOL 5600 scanning microscope operated at 20 kV. Mössbauer spectroscopy was applied to study the magnetism and volume fractions of both the austenite and martensite phases. Specimens examined by SEM were used for Mössbauer spectroscopy measurements at room temperature. A spectrometer with a 50 mCi 57 Co radioactive source (diffused in Rh) was used during study. A Normos-90 computer program was used to find out the Mössbauer parameters and relative volume fractions of the austenite and martensite phases. The Mössbauer spectra of examined sample were calibrated with respect to Ŭ-Fe and isomer shifts were given relative to the centre of the Ŭ-Fe. Specimen for magnetic susceptibility measurements was prepared from the bulk material in the form of disc with 1.5 mm radius and 1.5 mm thickness. The measurement was performed on a computerized AC susceptometer (LakeShore model 7130) with a closed cycle refrigerator between 25 and 275 K.

## 3. RESULTS AND DISCUSSION

Micro- structural characteristics of Fe-13.2%Mn-5.3%Co alloy was investigated by SEM. Figure 1 shows SEM micrograph of the microstructure forming in the as-quenched condition. The martensite crystals formed in the grains and austenite grains appear clearly. It indicates that the martensitic transformation starting temperature Ms is higher than the room temperature. The martensite plates have the different morphologies in austenite grains. The figure shows obviously that two types of thermal-induced martensites, Ůand ŭNjmartensites, coexist in the alloy. While the Ů martensite plates appear generally as parallel stacks of fine bands, the ŭNjmartensites form as little particles in thin plates tangle. Most of the bands of Ů martensite pass through the whole grain, i.e., from one end of grain boundary to the other.

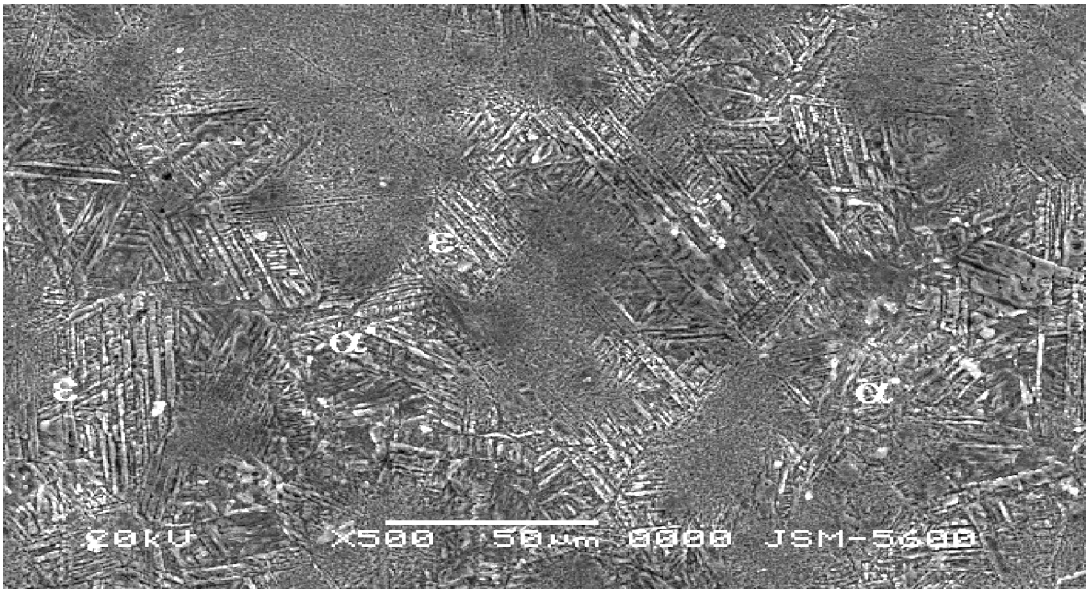


Figure 1. SEM micrographs showing the microstructure of quenched Fe-Mn-Co alloy.

In Fe-Mn alloys, so far studies on the austenite Ÿ martensite phase transformations have revealed that austenite ɔ phase can be transformed to Ů and ŭNj martensites, and ŮŸ Ŭ' transformation is also possible

under some physical conditions. This transformation behaviour is quite sensitive to the Mn content of alloy, and there mainly coexist Ů and ŭNj phases between 10-15wt%Mn [3,9]. Our results show that the Co addition to the Fe-Mn alloy does not change coexisting of Ů and ŭNj martensites between 10-15%wtMn. In addition, SEM observations reveal that the transformations in the alloy have athermal characteristic. As well known, martensitic transformations can display two separate kinetics named as athermal kinetics and isothermal kinetics. The key difference between athermal and isothermal kinetics essentially originates from the time dependency during transformations [13,1] .

There is a strong relationship between the magnetic behaviour and austenite-martensite phase transformation in Fe-Mn alloys. The martensitic product phase can exhibit ferromagnetic, antiferromagnetic, and paramagnetic behaviours depending on its type despite the paramagnetic nature of the austenite parent phase. Consequently, a magnetic transition reaction occur along with austenite-martensite transformation [10,12]. In the present study, the magnetic characters of the austenite and martensite phases were examined with Mössbauer.

Figure 2 shows the Mössbauer spectra obtained at room temperature on the quenched alloy. The spectra are characterized by a broad sextet and a central singlet. In Mössbauer spectroscopy, ferromagnetic (or antiferromagnetic) character of materials displays a typical sextet whereas paramagnetic structure exhibits only a singlet. Besides, it is known that ŭNj (h.c.c.) phase is a ferromagnetic while ɔ (f.c.c.) and Ů (h.c.p.) phases display generally paramagnetic character in Fe-Mn alloys [15,16]. Therefore, in Figure 3, the sextet belongs to ferromagnetic ŭNj martensite phase as the paramagnetic singlet can be ascribed either to ɔ austenite phase or to Ů martensite phase. This result shows that paramagnetic Ÿ ferromagnetic transition occurs along with austenite Ÿ martensite transformation in the alloy. The Mössbauer parameters such as isomer shifts (ŭ), hyperfine magnetic fields (Bhf) with the calculated % volume fractions of phases are given Table 1. It is almost impossible to sort the paramagnetic ɔ and Ů phases out by Mössbauer spectrometry at room temperature. Therefore, the volume fractions of Ů and ɔ phases is evaluated together in Table 1. As is seen in the table, the amount of ŭNj martensite is rather higher than that the Ů martensite in the alloys. The internal magnetic field value of ŭNj martensite phase was found as 32.27 Tesla.

Besides, a paramagnetic Ÿ magnetically disordered state reaction is observed when the magnitude of the applied AC field is 80 A/m and the frequency is 111 Hz with continuously cooling mode. The magnetic susceptibility in the alloy for temperature range of 25 and 275 K is given Figure 3. As seen in the figure, there is distinct change at 258 K temperature which indicates the magnetic transition from paramagnetic order to magnetically disordered state.

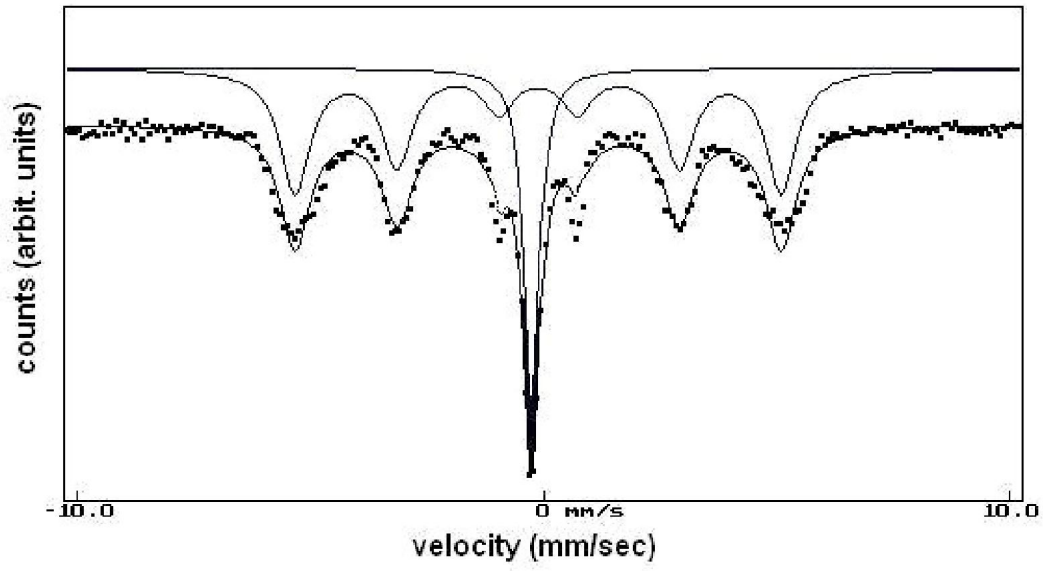


Figure 2. Room temperature Mössbauer spectra for quenched Fe-13.2%Mn-5.3%Co alloy. (Single pick: Austenite phase, Six pick: Martensite phase).

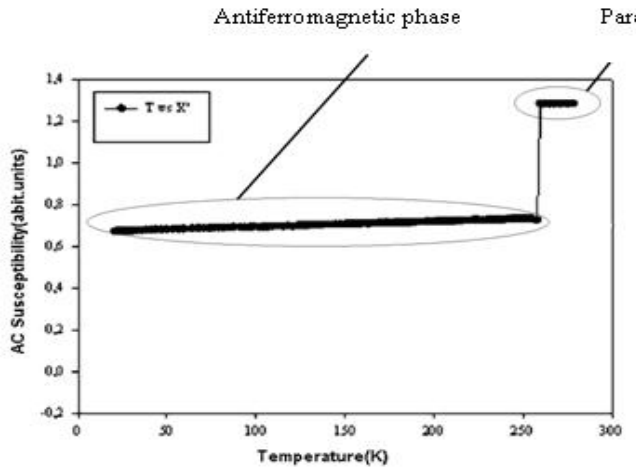


Figure 3. Magnetic susceptibility against temperature curves of Fe-13.2%Mn-5.3%Co alloy.

Table 1. Some Mössbauer parameters of studied Fe-13.2%Mn-5.3%Co alloy.

| ɔ+Ů phase (%) | ŮNjphase (%) | ŭɔ+Ů ± 0.002 (mm/s) | ŭŮNj 0.001 (mm/s) | Bhf (ŮNj (Tesla) |
|---|---|---|---|---|
| 24.021 | 75.979 | -0.1109 | -0.2386 | 32.27 |

Besides, a paramagnetic Ÿ magnetically disordered state reaction is observed when the magnitude of the applied AC field is 80 A/m and the frequency is 111 Hz with continuously cooling mode. The magnetic susceptibility in the alloy for temperature range of 25 and 275 K is given Figure 3. As seen in the figure, there is distinct change at 258 K temperature which indicates the magnetic transition from paramagnetic order to magnetically disordered state.

## 4. CONCLUSIONS

In conclusion, the magnetic behavior of Fe-13.2%Mn-5.3%Co alloy linked to the austenite-martensite phase transformation. The magnetic transition reaction from paramagnetic to ferromagnetic state occurs along with austenite-martensite transformation. Besides, the other magnetic transition forms also from paramagnetic order to magnetically disordered state at 258 K.

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