The magnetic properties of martensitic phase in Fe-Ni-Mn alloys: AC magnetic susceptibility observations

S. AKTURK*
Department of Physics, Science and Arts Faculty of Kırıkkale University, Yahsihan, 71450, Kırıkkale, Turkiye
E-mail: akturk_selcuk@yahoo.com

T. N. DURLU
Department of Physics, Science Faculty of Ankara University, Tandoğan, 06100, Ankara, Turkiye

Martensitic transformations can be classified into two groups with respect to their formation temperature and time dependencies, namely isothermal and athermal. The isothermal martensitic transformation involves both time and temperature whereas the athermal martensitic transformation is only dependent on temperature [1, 2]. In addition, a strong correlation between austenite—martensite phase transformation and its magnetic behaviour in Fe based alloys can be established. Despite the paramagnetic behaviour of austenite, martensite phase can show either ferromagnetic or antiferromagnetic behaviour [3, 4]. In Fe-Mn-Si and Fe-Cr-C alloys, the presence of a particular magnetic transition during martensitic phase transformation was investigated based on the temperature change with respect to magnetic susceptibility [4, 5]. Tamarat *et al.* determined the M_s temperature which is the transition temperature from the paramagnetic state to antiferromagnetic, and T_N–Neel, which is the transition temperature of the antiferromagnetic state to paramagnetic [4].

Magnetic susceptibility measurements in Fe-Ni-Mn alloys, particularly $(Fe_{0.65}\text{-}Ni_{0.35})_{1-x}Mn_x$, were extensively studied by Hesse [6] for their spin-glass property at low temperatures. The re-entrant system exhibits two consecutive temperature dependent magnetic phase transitions. Although these alloys show dominantly paramagnetic behaviour above Tc, the Curie temperature, they transform to ferromagnetic phase below Tc. In the same system, a freezing temperature, T_f, is observed when a magnetic phase transition occurs at a specific temperature; the system is believed to possess a spin-glass property [6, 7].

This paper reports applications of the AC magnetic susceptibilty to the study of athermal and isothermal martensitic phase transformations in Fe-Ni-Mn alloys.

Fe-Ni-Mn alloys were prepared by vacuum induction melting. Samples were austenized at 1100 °C in vacuum for 12 h and furnace cooled to room temperature. The specimens for magnetic susceptibility measurements were prepared from the bulk material in the form of discs of 1.5 mm radius and 1.5 mm thickness, and the experiments were performed on a computerized A.C. Susceptometer (Lake Shore model 7130) with a closed cycle refrigerator running between 25 and −263 °C. The sample was kept in helium exchange gas for speedy thermal equilibrium with a controllable temperature resolution better than 10 mK and moved between the centres of the secondary coils in order to minimize the unwanted signals and hence maximize the signal coming from the sample itself. The magnetic susceptibility measurements were taken by employing a lock-in amplifier with an input low pass filter. Thin foils for transmission electron microscope (TEM) observations were prepared from 3 mm discs electropolished by using a double-jet polishing technique with a solution of 150 ml 2-Butoxy Ethanol, 50 ml Percloric Acid and 300 ml Ethanol, at 35–40 Volt (DC) at room temperature. Then the specimens were examined in a Philips CM20/STEM operating at 200 kV and JEOL 3010 TEM operating at 300 kV.

In Fig.1, the magnetic susceptibility of the Fe-31.5% Ni-10%Mn alloy is shown for a temperature range of 25 to −263 °C. Paramagnetic to ferromagnetic and ferromagnetic to antiferromagnetic or a spin-glass phase transitions are observed when the magnitute of the applied AC field is 100 A/m and the frequency is 125 Hz for the continuously cooling mode. A paramagnetic specimen at room temperature transformed to ferromagnetic phase at approximately −25 °C. This continued until −218 °C at which point antiferromagnetic or a spin glass transition was observed. The specimen was gradually cooled down to −263 °C and later reheated to 25 °C; a curve similar to that of the one obtained for cooling was obtained. In the end, antiferromagnetic to ferromagnetic transition temperature, and, the Curie temperature, Tc, which is the ferromagnetic to paramagnetic transition phase, for Fe-31.5%Ni-10%Mn alloy were found to be −218 °C and −25 °C, respectively. In the ferromagnetic region, a large number of ferromagnetic domains formed and they were oriented in the direction of applied AC field. The magnetisation is basically the rearrangement of these domains. In the paramagnetic phase, however, above Tc, non-directional atomic moments are present and it exhibits short range behaviour. In the ferromagnetic state, AC fields are opposed by the motion of a Bloch wall. Below −218 °C

* Author to whom all correspondence should be addressed.

0022-2461

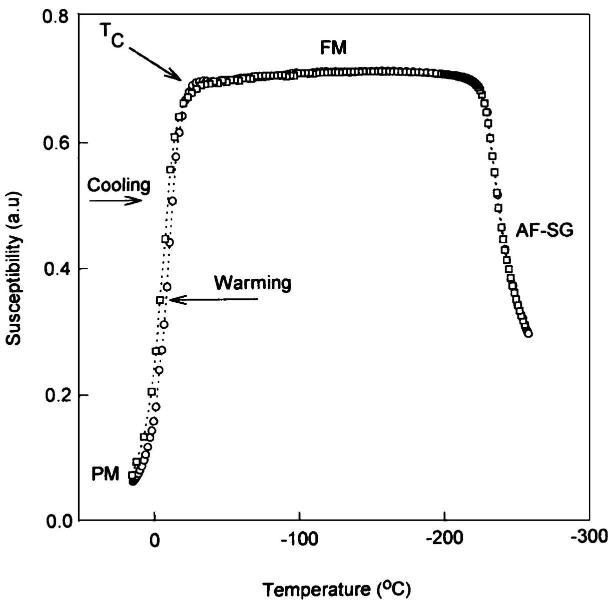

Figure 1 Magnetic susceptibility against temperature curves of Fe-%31.5Ni-%10Mn alloy.

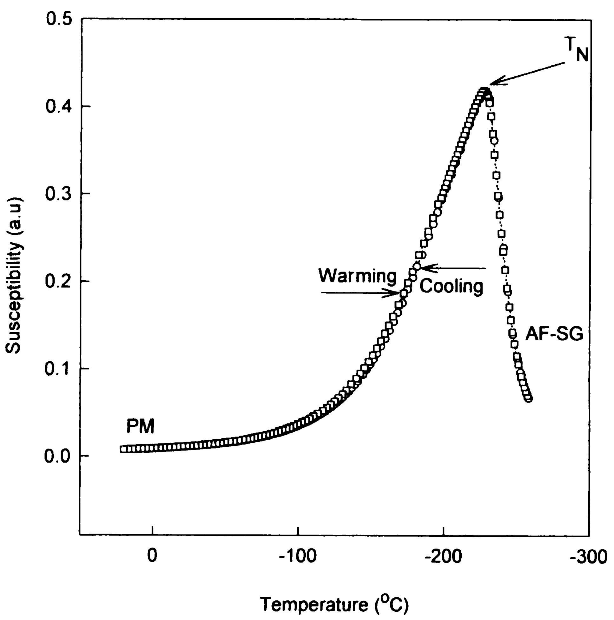

Figure 2 Magnetic susceptibility against temperature curves of Fe-%25Ni-%5Mn alloy.

the magnitude of magnetic susceptibility is lower due to the obstruction of the spin affecting the domain wall motion. In this case, antiferromagnetic groups are formed and spins begin to freeze by gaining viscosity due to the strong interaction between ferromagnetic and antiferromagnetic groups and by the obstruction of domain wall motion. Hence the sharp transition in magnetic susceptibility is usually observed at low temperatures [8]. The specimen showed these magnetic phase transitions but preserved its austenitic structure. From this, it can be concluded that no crystallographic phase transformation occurs during a magnetic transition, which was also confirmed by Hesse [9]. In contrast to this result, magnetic phase transition detected during magnetic susceptibility studies, in Fe-Cr-C alloy was found to be accompanied by a crystallographic change from austenite to athermal martensite. Phase changes occuring were from paramagnetic austenite to ferromagnetic martensite and this was of great importance to determine the M_s temperature in Fe-Cr-C alloy [5].

For Fe - 25%Ni - 5%Mn alloy, magnetic susceptibility measurements were also carried out for 125 Hz frequency and 100 A/m applied magnetic field and temperature dependability of magnetic susceptibility was investigated for a temperature range from 25 to −263 °C. In Fig. 2, the specimen that is paramagnetic at room temperature transformed to antiferromagnetic or a spin glass phase at approximately −225 °C. Here the Neel temperature, which is the antiferromagnetic to paramagnetic transition temperature, $T_{N,}$ is −225 °C. Despite the absence of crystallographic change corresponding to magnetic phase transition as in Fe-31.5%Ni-10%Mn, Fe-25%Ni-5%Mn exhibited athermal and isothermal martensitic transformation. Here, athermal phase transformation took place around −140 °C and isothermal martensite was obtained at about −128 °C, which is the nose temperature [10], after holding for about 25 h. In Fe-%25 Ni-%5 Mn, there is known to be an isothermal phase transformation from austenite to martensite and the specimen was held at −128 °C for 55 h since it is a fact that isothermal martensitic transformation is both a time and temperature dependent transformation. TEM figures of

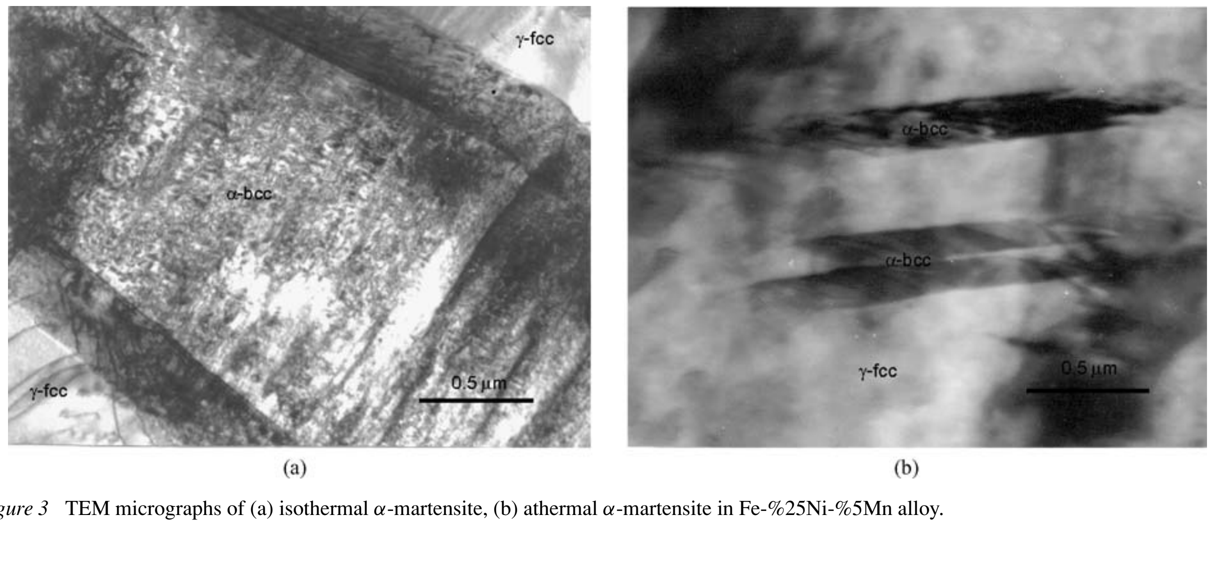

Figure 3 TEM micrographs of (a) isothermal α-martensite, (b) athermal α-martensite in Fe-%25Ni-%5Mn alloy.

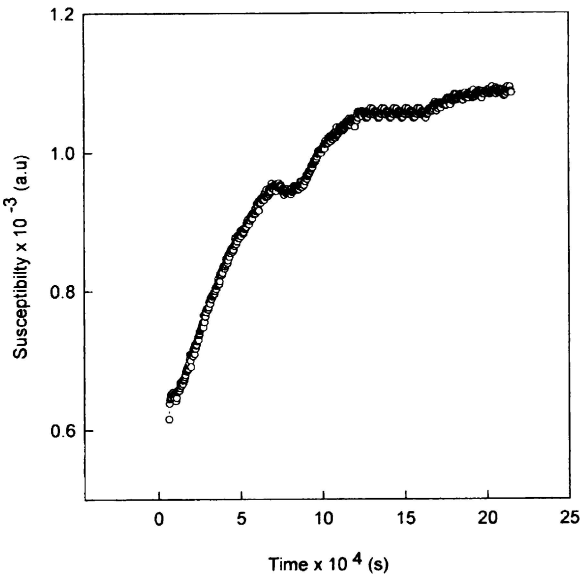

Figure 4 Magnetic susceptibility change of Fe-%25Ni-%5Mn alloy at −128 °C with respect to time.

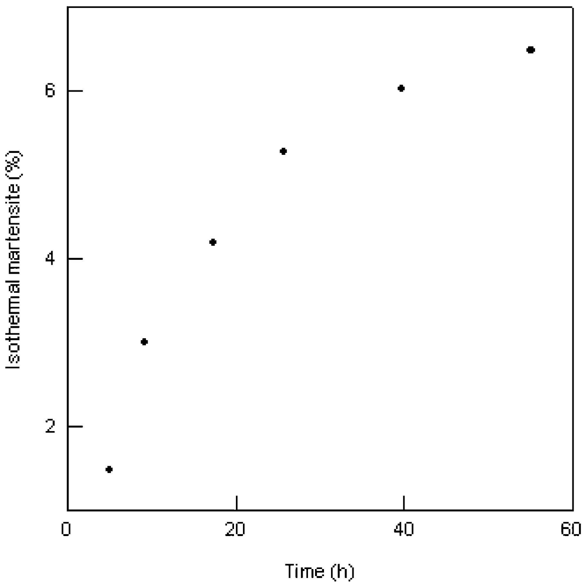

Figure 5 Isothermal martensite percentege plotted against time.

athermal and isothermal martensite structure are given in Fig. 3a and b.

In Fig. 4, a variation in magnetic susceptibility is shown as a function of time at −128 °C. Magnetic susceptibility is expected to increase with time since a transition of ferromagnetic or antiferromagnetic phase occurs. It is seen from the AC magnetic susceptibility measurement that magnetic susceptibility occurs over a longer period of time and for a limited amount. This result indicates that isothermal martensite grows slowly over a long period of time in Fe-25%Ni-5%Mn alloy. Moreover, the reason the magnetic susceptibility begins to increase after a constant period of time is probably because of the formation and growth of new martensite crystals. In Fig. 5, changes in volume fraction of isothermal martensite phase are plotted against time.

As a result, although athermal and isothermal martensitic phase transformations have been observed in an Fe-25%Ni-5%Mn alloy, they has not been observed in an Fe-31.5%Ni-10%Mn alloy. On the other hand, there is no crystallographic phase transformation occuring during a magnetic transition in these alloys. Paramagnetic to ferromagnetic and ferromagnetic to antiferromagnetic or a spin-glass phase transition were observed and T_C was determined to be −25 °C in an Fe-31.5%Ni-10%Mn alloy. Additionally a paramagnetic to antiferromagnetic or a spin-glass phase transition are observed and T_N is determined to be −225 °C in an Fe-25%Ni-5%Mn alloy.

Acknowledgments

One of authors (S. Aklurk) is grateful to Dr. A. Gencer and postgraduate students Mr. E. Aksu with experimental work. This work is supported by Turkish Scientific and Research Council, TÜBİTAK

References

1. S. KAJIWARA, *Phlos. Mag. A* **43** (1980) 1483.
2. D. Z. YANG, B. P. J. SANDVIK and C. M. WAYMAN, *Metall. Trans. A* **15A** (1984) 1555.
3. J. H. YANG, H. CHEN and C. M. WAYMAN, *Met. Trans.* **23A** (1992) 1439.
4. K. TAMARAT, G. ANDRE and B. DUBOIS, in Proceeding of International Conferance on Martensitic Transformations (ICOMAT 92), edited by C. M. Wayman and J. Perkıns (Institute for Advanced Studies, Monterey, CA 1993) p. 1181.
5. S. AKTURK, A. GENCER and T. N. DURLU, *J. Mater Sci Lett.* **16** (1997) 389.
6. T. ECKELT, C. BOTTGER and J. HESSE, *J. Magnet Magnetic Mater.* **104–107** (1992) 1665.
7. A. WULFES, C. BOTTGER and J. HESSE, J. SIEVERT and H. AHLERS, *J. Magnet Magnetic Mater* **104–107** (1992) 2069.
8. A. GENCER, I. ERCAN and B. OZCELIK, *J. Phys. Condens. Matter* **10** 191 (1998).
9. J. HESSE, Hyper. Interact **47** (1989) 378.
10. G. KURDJUMOV and P. O. MAKSIMOVA, *Dokl. Akad. Nauk SSSB* **61** (1948) 83.

Received 26 April
and accepted 10 February 2004