Effects of Alloying Elements on Martensitic Transformation Behavior and Damping Capacity in Fe-17Mn Alloy

S.H. Baik, J.C. Kim, K.K. Jee*, W.Y. Jang** and M.C. Shin*

Woojin Inc., Research Institute of Measuring Technology, C.P.O. Box 6666, Seoul, Korea
* Korea Institute of Science of Technology, Division of Metals, Seoul 136-791, Korea
** Chosun University, Department of Metallurgical Engineering, Kwangju 501-759, Korea

Abstract. Effect of carbon and Ti on $\gamma \leftrightarrow \varepsilon$ martensitic transformation behavior and damping capacity has been investigated in an Fe-17Mn alloy.
The suppressive force of carbon against $\gamma \rightarrow \varepsilon$ transformation increases linearly with an increase in carbon content, lowering M_s temperature and volume fraction of ε martensite. Carbon deteriorates damping capacity by reducing the area of γ / ε interfaces and by decreasing the mobility of the interfaces operated as damping source. The reduction in the mobility of the interfaces is accelerated when carbon-containing alloy is aged at high temperatures.
The effect of Ti on the damping capacity is found to be beneficial in carbon-containing alloy, because the Ti contributes to depletion of carbon solute by the formation of TiC.

1. INTRODUCTION

Thermoelastic martensitic alloys which experience phase boundary movement by deformation have been found to exhibit shape memory effect as well as internal friction[1,2]. Discovery of shape memory effect in Fe-Mn based alloys[3,4] undergoing non-thermoelastic $\gamma \leftrightarrow \varepsilon$ martensitic transformation raise a possibility that the alloys can absorb mechanical energy by internal friction.
Recently, some authors have reported damping property in Fe-Mn-Si-Cr[5], Fe-Ni-Mn[6] and Fe-Mn-Si[7] alloys deformed to stress-induced ε martensite. Though the proposed mechanism of damping capacity is a little different by authors, stress-induced ε martensite is responsible in common. In previous work, we have reported that Fe-Mn alloys show a good damping capacity which is caused by ε martensite formed on cooling[8,9]. The alloys have advantages of good mechanical properties and a low cost over non-ferrous damping alloys such as Mn-Cu[10] and Ni-Ti[11]. In commercial fabrication process, however, introduction of carbon is unavoidable because a large part of scrap which bears carbon is used. But the effect of carbon on the characteristics has not been clarified yet in the alloys.

In this study, the influence of carbon on the $\gamma \rightarrow \varepsilon$ martensitic transformation and damping capacity is investigated by adding carbon to an Fe-17Mn alloy reported to exhibit the highest damping capacity in the Fe-Mn alloy system[8,9]. Moreover, the addition of Ti is made in an attempt to reduce the detrimental effect of carbon to damping capacity.

2. EXPERIMENTAL

The analyzed compositions of the alloys used in this study are listed in Table 1, carbon is varied 0.02 to 0.28wt% in the Fe-17Mn alloy and up to 1.3wt% Ti is added to the Fe-17Mn-0.2C alloy.

Table 1. Chemical composition of the alloys used.(wt.%)

Alloy No.	1	2	3	4	5	6	7
Mn	17.68	17.84	17.86	17.32	17.88	17.81	17.56
C	0.02	0.10	0.20	0.28	0.20	0.21	0.21
Ti	-	-	-	-	0.43	0.82	1.31
Fe	bal.	bal.	bal.	bal.	bal.	bal.	bal.

The alloys were prepared by melting in an induction furnace with the addition of recarburizer. The resulting ingots were homogenized at 1150℃ for 24hrs before being hot rolled to bars and plates which

were then machined into specimens. After solution treatment at 1050℃ for 1hr, the specimens were quenched into water.

The damping specimen had a total length of 186mm with a reduced portion 7mm in diameter and 152mm in length. Damping capacity was measured using the Föpple-Pertz torsional pendulum with a resonance frequency of 12Hz, and evaluated as the specific damping capacity (SDC)[12]. Transformation temperatures such as M_s, A_s and A_f were determined using a thermo-mechanical analyzer, based on the volume contraction accompanying $\gamma \rightarrow \varepsilon$ transformation. The volume fraction of ε martensite was measured by comparing the intergrated intensities of $(002)\gamma$ and $(1011)\varepsilon$ peaks in X-ray diffraction. The TEM specimens were prepared by electropolishing with twin-jet in a 10% HClO₄/methanol solution. The electron microscope used was Philips CM-30 with an accelerating voltage of 300kV.

3. RESULTS

Fig.1 represents the variation in transformation temperatures with carbon content. As carbon content increases, M_s temperature decreases, indicating that carbon suppresses significantly $\gamma \rightarrow \varepsilon$ transformation. The suppressive effect of carbon against $\gamma \rightarrow \varepsilon$ transformation is also confirmed by Fig.2 which shows the change in amount of ε martensite with carbon content measured by X-ray diffraction.
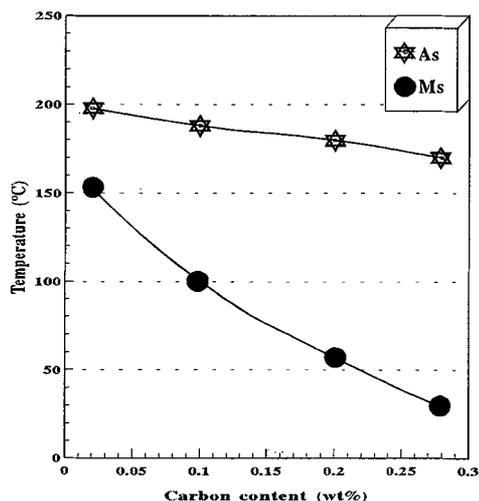

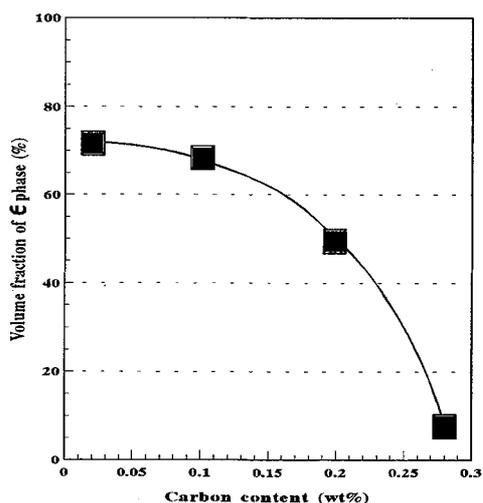Fig.1 Variation of transformation temperatures with carbon content in water-quenched Fe-17%Mn-X%C alloy.

Fig.2 Variation of amount of epsilon phase with carbon content in water-quenched Fe-17%Mn-X%C alloy.

Transmission electron micrographs of three alloys with a different carbon content in Fig.3 reveals that the number of ε plates decreases with increasing carbon content. The Fe-17Mn-0.02C and Fe-17Mn-0.1C alloys consist of stacking faults and ε plates with several variants in γ matrix. With futher increase in carbon content, as shown in Fig.3(c), tiny stacking faults and ε plates with only a little amount are observed. However, as previously reported in a Fe-17Mn-6Si-0.3C alloy[13], no formation of carbides occurs.

The effect of Ti addition to the Fe-17Mn-0.2C alloy on the transformation temperatures is shown in Fig.4. M_s temperature increases with increasing Ti content, indicating that Ti alleviates the suppressive force of carbon against $\gamma \rightarrow \varepsilon$ transformation. The addition of Ti to a carbon-free Fe-17Mn alloy, in our preliminary work, hardly creates any change in transformation behavior such as M_s temperature or volume fraction of ε martensite. The role of Ti appears significantly when it is added to carbon-bearing alloys.

Fig.5 represents the variation of damping capacity with carbon content in the Fe-17Mn-X%C alloys. Damping capacity of the alloys is kept almost constant up to 0.1%C, however, followed by a steep decrease on further increase in carbon content. The addition of Ti, as shown in Fig.6, is found to improve damping capacity in the Fe-17Mn-0.2C alloy, suggesting that Ti lessens the the detrimental effect of carbon to damping capacity.

Carbon atoms worsen damping property with time as well. Shown in Fig.7 is the change in damping capacity measured at room temperature after the alloys being subjected at 80℃ for various time. The Fe-17Mn-0.2C alloy suffers significantly the drop in damping capacity while the Fe-17Mn-0.02C alloy is

immune to the aging effect. The addition of Ti keeps also damping capacity in the carbon-containing alloy from the aging effect, in the Fe-17Mn-0.2C-0.8Ti alloy, thus no aging effect take place.
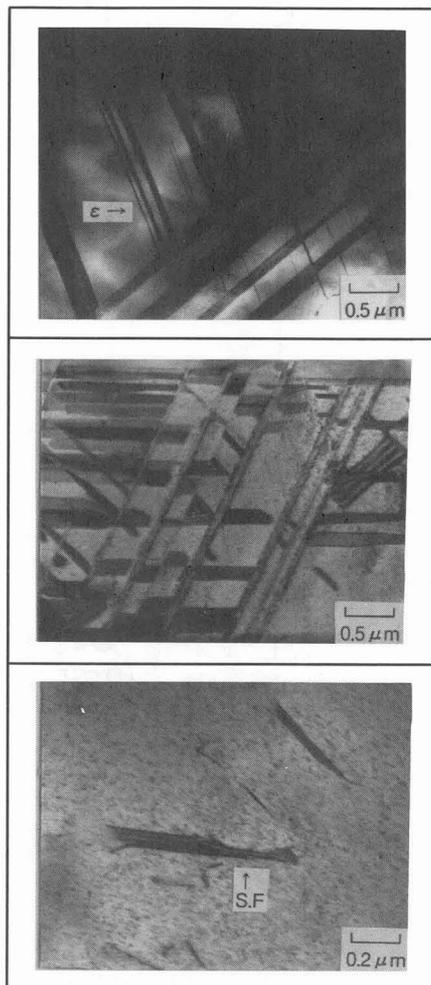

Fig.3 Transmission Electron Micrographs of the water-quenched alloys.
(a) alloy-1 (Fe-17%Mn-0.02%C) (b) alloy-2 (Fe-17%Mn-0.10%C)
(c) alloy-3 (Fe-17%Mn-0.28%C)

4. DISCUSSION

The suppressive force of carbon against $\gamma \rightarrow \varepsilon$ transformation in Fe-Mn alloy can be calculated by thermodynamical consideration as follows. In a Fe-Mn binary alloy system, the free energy difference between γ and ε martensite is expressed as the following equation using a regular solution model[14,15].

$$\Delta G^{\gamma \rightarrow \varepsilon} = X_{Fe} \, \Delta G_{Fe}^{\gamma \rightarrow \varepsilon} + X_{Mn} \, \Delta G_{Mn}^{\gamma \rightarrow \varepsilon} + X_{Fe} \, X_{Mn} \, \Delta \theta^{\gamma \rightarrow \varepsilon} \quad ----(1)$$

Shown in Fig.8 is the temperature dependence of $\Delta G^{\gamma \rightarrow \varepsilon}$ of the Fe-17Mn alloy obtained using the results of the $\Delta G_{Fe}^{\gamma \rightarrow \varepsilon}$, $\Delta G_{Mn}^{\gamma \rightarrow \varepsilon}$ and $\Delta \theta^{\gamma \rightarrow \varepsilon}$ by some authors[16-18]. From the Fig.1, the variation of the $\Delta G^{\gamma \rightarrow \varepsilon}$ necessary for $\gamma \rightarrow \varepsilon$ transformation with carbon content is obtained as shown in Fig.9. The $\Delta G^{\gamma \rightarrow \varepsilon}$ is to found to increase linearly with increasing carbon content. The $\Delta G^{\gamma \rightarrow \varepsilon}$ for a carbon-free Fe-17Mn alloy, estimated to be 90J/mole, agrees well with previous result anticipated from the difference between As and Ms[19]. It is noteworthy to compare quantitatively carbon and grain boundary in hindrance to $\gamma \rightarrow \varepsilon$ transformation. It is reported that an Fe-15Mn alloy with a grain size of $1\mu m$, besides 90J/mole, needs an additional driving force of 150J/mole[15], which is equivalent to 0.09%C.
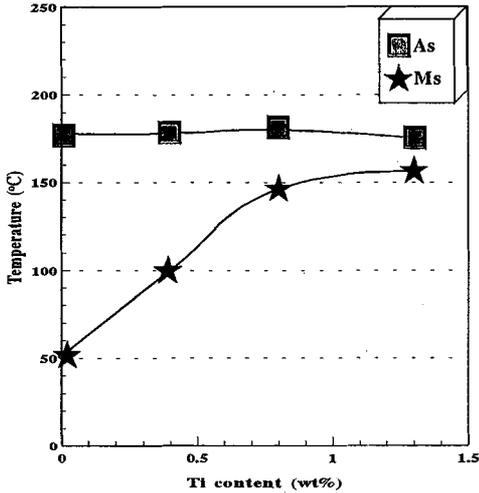
Fig.4 Variation of transformation temperatures with Ti content in water-quenched Fe-17%Mn-X%C alloy.
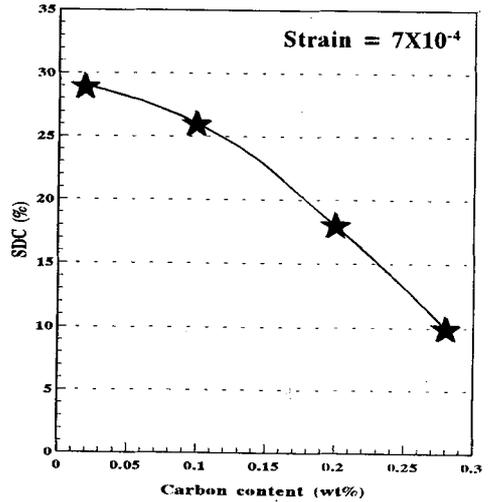

Fig.5 Variation of specific damping capacity with carbon content in water-quenched Fe-17%Mn-X%C alloy.
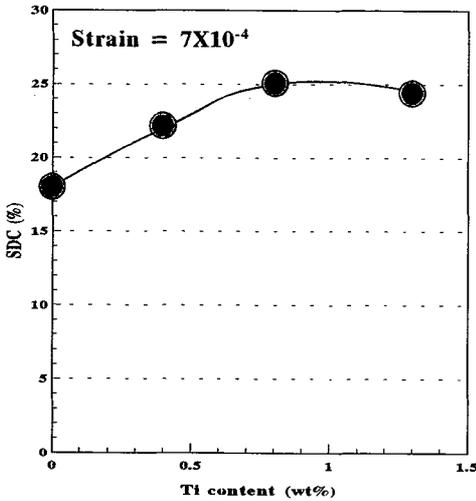

Fig.6 Variation of specific damping capacity with Ti content in water-quenched Fe-17%Mn-0.2%C alloy.
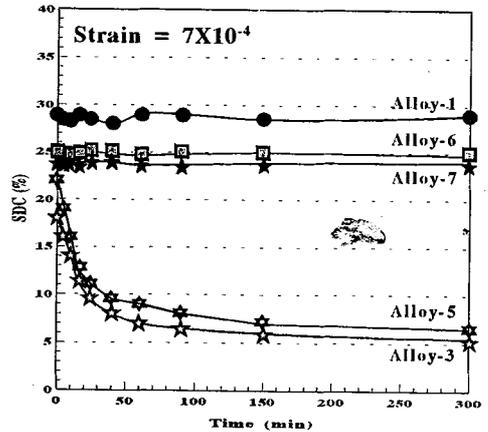

Fig.7 Variation of specific damping capacity with aging time at 80°C in Fe-17%Mn-X%C-Y%Ti alloy.
  (a) alloy-1 (Fe-17%Mn-0.02%C)
  (b) alloy-3 (Fe-17%Mn-0.2%C)
  (c) alloy-5 (Fe-17%Mn-0.2%C-0.43%Ti)
  (d) alloy-6 (Fe-17%Mn-0.2%C-0.82%Ti)
  (e) alloy-7 (Fe-17%Mn-0.2%C-1.31%Ti)

There are two factors contributing to elastic strain on vibration. One is atomic separation and the other is, responsible for damping capacity, irreversible phase boundary movement. Since the shear strain of $\gamma \rightarrow \varepsilon$ transformation in the alloy amounts to tan 19.4 degrees, the boundary movement can generate deformation. The damping mechanism of the alloy may be attributed to the anelastic movement of γ / ε boundaries on vibration. And damping capacity, if assumed to be an increasing function of volume swept by the boundaries, is proportional to the multiplication of the boundary area by travel distance.

The deterioration in damping capacity by the addition of carbon is attributed to the following two reasons. With an increase in carbon content, the volume fraction of ε martensite decreases as shown in Fig.2, leading to the area reduction of γ / ε boundaries. Secondly, the carbon atoms hinder the movement of γ / ε boundaries by pinning them.
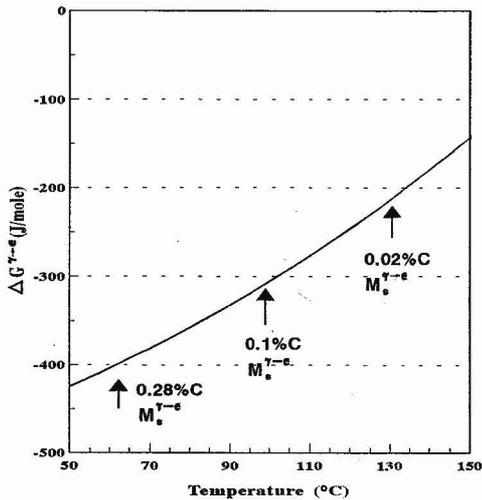
Fig.8 Relation between temperature and the chemical free
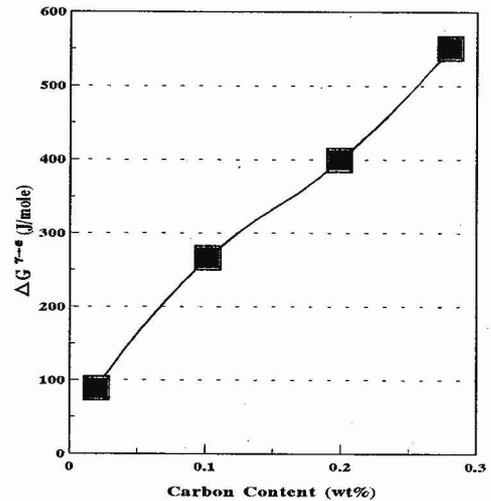energy change for austenite to epsilon martensitic
transformation.

Fig.9 Relation between carbon content and the chemical free
energy change as suppressive effect on epsilon
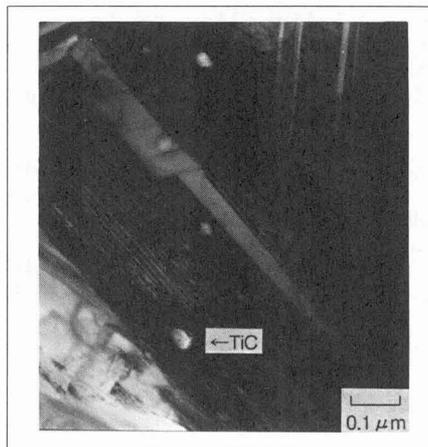martensitic transformation.

Fig.10 Transmission Electron Micrographs of the water-quenched
Fe-17%Mn-0.2%C-0.8%Ti alloy.

The adherence of carbon to the boundaries may be caused by the stress due to the difference in
d-spacing between $(111)\gamma$ and $(0002)\varepsilon$ parellel to each other. The d-spacing of $(0002)\varepsilon$, depending on
the content of Mn, is about 1.5% smaller than that of $(111)\gamma$ which is the habit plane. Thus γ matrix
region near γ/ε boundaries experience tensile stress, acting as the preferential sites for carbon atoms.
The carbon atoms collected near the boundaries prevent their movement, aggravating damping capacity. The
pinning effect becomes more obvious when the Fe-17Mn-0.2C alloy is aged as in Fig.7, for aging
treatment thermally activates carbon atoms to take the preferential sites.

The beneficial effect of Ti addition to the Fe-17Mn-0.2C alloy in damping capacity is related with the
formation of carbides. Fig.10 shows the transmission electron micrograph of the Fe-17Mn-0.2C-0.80Ti
alloys. Carbides, identified as TiC(cubic, a=4.33Å), are observed in addition to stacking faults and ε
plates. The carbides themselves, without coherency to γ, seem to block the growth of ε plates for no

carbides exist in the ε plates. The effect of depletion of carbon solute, however, overrides the negative effect of the carbides for the encouragement of $\gamma \rightarrow \varepsilon$ transformation.

5. CONCLUSION

1) Carbon is found to suppress significantly $\gamma \rightarrow \varepsilon$ transformation in Fe-Mn alloys, decreasing Ms temperature and volume fraction of ε martensite.
2) Aggravation in damping capacity by carbon is attributed to the decrease in area of γ / ε boundaries and hindrance to the movement of the boundaries by pinning. Carbon atoms also worsen rapidly damping capacity in the Fe-17Mn-0.2C alloy when the alloy is subjected to aging treatment.
3) The addition of Ti offsets the suppressive effect of carbon by depleting carbon solute due to the formation of TiC.

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