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Transformation Behavior and its Effect on Damping Capacity in Fe-Mn Based Alloys

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Abstract. $\gamma \rightarrow \varepsilon$ transformation behavior in a Fe-21Mn alloy with different grain size and a Fe-32Mn-6Si alloy with various degrees of cold rolling is investigated and correlated with damping capacity. Effect of microstructure on damping capacity is discussed on the assumption that the capacity is proportional to volume swept by γ/ε boundaries.

1. INTRODUCTION

Fe-Mn based alloys have been well known for shape memory effect which is based on the formation of ε martensite when the alloys are deformed [1,2]. Thermoelastic martensitic alloys which experience phase boundary movement by deformation have been found to generate damping capacity [3,4]. Recently, there have been some reports that Fe-Mn based alloys undergoing non-thermoelastic martensitic transformation exhibit damping capacity [5].

This work is aimed at correlating $\gamma \rightarrow \varepsilon$ transformation behavior with damping capacity in Fe-Mn based alloys. The transformation takes place during cooling or by deformation according to alloy composition. Two Fe-Mn based alloys, Fe-21Mn (wt%) and Fe-32Mn-6Si (wt%) which undergo the transformation during cooling and by deformation respectively, are used in the study. The variation in the transformation behavior is made by changing grain size for the Fe-21Mn alloy and degree of cold rolling for the Fe-32Mn-6Si alloy.

2. EXPERIMENTAL PROCEDURE

The alloys were prepared by melting in a magnesia crucible in a vacuum induction furnace. The ingots were homogenized at 1000°C for 2hrs and hot-rolled at 900°C. After hot rolling, the Fe-21Mn alloy was subjected to 30% cold rolling, followed by heat treatment at various temperatures (700-1200°C) for 1hr to vary grain size. The Fe-32Mn-6Si alloy was cold rolled with various thickness reduction (1, 3, 5, 10, 15%) at a rate of 0.1% a pass to minimize the microstructural inhomogeneity across the thickness.

The free vibration method was applied to measure damping capacity with a strain gauge attached on the specimen [6]. Damping capacity was evaluated as the logarithmic decrement.

Measurement of volume fraction of ε martensite was made by comparing the volume change during reverse transformation with the specific volume difference which was

determined by X-ray diffraction. Since ϵ martensite in the Fe-21Mn alloy exhibits no anisotropy, its volume change is obtained as three times the length change due to the reverse transformation by 3. In the Fe-32Mn-6Si alloy, however, the sum of the length changes in the rolling (RD), transverse (TD) and normal (ND) directions was taken as volume change because of direction-dependent dilatometric behavior [7].

The specimens for TEM were prepared by eletropolishing in 10% HClO_4 /methanol solution at 223K. The microscope used is Phillips CM-30 with an accelerating voltage of 300kV.

3.RESULTS AND DISCUSSION

Fig. 1 shows optical microstructure of the Fe-21Mn alloy heat treated at various temperatures. As the temperature increases, grain size and ϵ martensite amount increases. No α' martensite is observed in the alloy.

Variation in grain size, from $3.5\mu\text{m}$ to $101\mu\text{m}$, with heat treatment temperature is shown in Fig. 2.

Fig. 3 represents dilatometric behavior of the alloy subjected to heat treatment at various temperatures. As and A_f temperatures as well as volume fraction of ϵ martensite formed during cooling from the heat treatment temperatures are determined from the heating curves. Ms temperatures are measured from the cooling curves. As, A_f and Ms temperatures are, irrespective of grain size, measured to be 185, 200 and 133 $^{\circ}\text{C}$, respectively. This result is inconsistent with the previous study on an Fe-15Mn alloy that Ms increases with the increase in grain size [8]. With the result of X-ray diffraction that 1.98% volume expansion accompanies $\epsilon \rightarrow \gamma$ transformation in the Fe-21Mn alloy, ϵ martensite amount, calculated from Fig. 3, is shown in Fig. 4.

Fig. 5 shows the effect of heat treatment temperature on damping behavior of the Fe-21Mn alloy. Damping capacity of all the specimens increases with increasing strain amplitude. Some thermoelastic martensitic alloys like Cu-based alloys [3,4] and Mn-Cu

Fig. 1. Optical microstructure of the Fe-21Mn alloy heat treated at 700 $^{\circ}\text{C}$ (a), 800 $^{\circ}\text{C}$ (b), 900 $^{\circ}\text{C}$ (c), 1000 $^{\circ}\text{C}$ (d), 1100 $^{\circ}\text{C}$ (e) and 1200 $^{\circ}\text{C}$ (f)

[9] are reported to exhibit the same behavior. But Fe-Mn alloys shows stronger strain amplitude dependence. As heat treatment temperature increases, damping capacity improves, reaching its maximum around 1000°C. Further increase in the temperature, however, aggravates damping capacity.

Fig. 6 shows transmission electron microstructure of the alloys heat treated at 700,

Fig. 2. Variation in grain size with heat treatment temperature

Fig. 3. Dilatometric behavior of the alloy subjected to heat treatment at various temperatures

Fig. 4. Effect of heat treatment temperature on ϵ martensite amount

Fig. 5. Effect of heat treatment temperature on damping behavior of the Fe-21Mn alloy

Fig. 6. Transmission electron microscopy of the Fe-21Mn alloy heat treated at 700 (a), 1000 (b) and 1200°C (c)

1000 and 1200°C. They consist of ε martensite plates with different size and amount and stacking faults in γ matrix. With higher heat treatment temperature, the volume fraction of ε martensite increases as is expected from Fig. 4, and its size becomes larger.

There are two factors contributing to elastic strain on vibration. One is atom displacement and the other is, responsible for damping capacity, 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 the anelastic movement of γ/ε boundaries during deformation. And damping capacity, if assumed to be an increasing function of volume swept by the γ/ε boundaries, is proportional to the multiplication of the boundary area by travel distance. The correlation between the damping capacity and the microstructure can be explained by comparing the area of γ/ε boundaries.

The number of ε martensite plates increases with the increase in heat treatment temperature up to 1000°C, as shown in Fig. 6. Further increase in the temperature, however, lessens the number of ε martensite plates despite the increase in ε martensite amount, leading to the area reduction of γ/ε boundaries. That is why damping capacity of the alloy heat treated at 1200°C decreases as shown in Fig. 5. With Fe-21Mn alloy, it is difficult to discuss the effect of travel distance which depends on mobility of the phase boundaries. Investigation into relationship between damping capacity and microstructure of an Fe-32Mn-6Si alloy undergoing $\gamma \rightarrow \varepsilon$ transformation by deformation helps us understand the role of mobility.

Fig. 7 shows the effect of cold rolling degree on damping behavior of Fe-32Mn-6Si alloy. Damping capacity of all the specimens increases proportionally to the strain amplitude and can be expressed by a simple power curve relation, $\delta \propto \varepsilon^n$. The exponent, n , which is higher than 1 for all the specimens, gradually decreases with increasing degree of cold rolling. Damping capacity, which is improved by cold rolling upto 3%, however, deteriorates with further cold rolling.

Fig. 8 represents variation in ε martensite amount with the degree of cold rolling, indicating that the amount increases linearly with increasing degree upto 3%. The rate of increase, however, becomes smaller as the degree of cold rolling increases.

Fig. 9 shows transmission electron microscopy of the specimens subjected to 3% and 5% cold rolling. In the 3% rolled specimen, dislocations or slip bands can hardly be found, indicating that the alloy has been deformed only by nucleation and growth of ε martensite in the early stage of cold rolling upto 3%. Thus the volume fraction of ε martensite increases almost linearly with the degree of cold rolling. With further

Fig. 7. Effect of cold rolling degree on damping behavior in the Fe-32Mn-6Si alloy

Fig. 8. Variation in ϵ martensite amount with the degree of cold rolling

Fig. 9. Transmission electron microscopy of the Fe-32Mn-6Si alloy subjected to 3% (a) and 5% (b) rolling

rolling, slip deformation by dislocations takes place, besides the formation of ϵ martensite, as shown in Fig. 5(b). Slip deformation decreases the rate of ϵ formation with higher degree of cold rolling, suggesting that the movement of γ/ϵ becomes more difficult.

As the degree of cold rolling increases, the number of ϵ martensite plates and the area of the phase boundaries increase. Over 5% rolling, however, the decrease in mobility bring up deterioration of damping capacity.

Comparison between Fig. 5 and Fig. 7 indicates that damping capacity of the Fe-21Mn alloy is superior to that of the Fe-32Mn-6Si alloy, though they have comparable size and volume fraction of ϵ martensite. It is suggested that the mobility depends on composition itself and whether ϵ martensite is formed by cooling or deformation.

4. CONCLUSION

In the Fe-21Mn alloy, as grain size increases, volume fraction of ε martensite increases while transformation temperatures, such as M_s , A_s and A_{s1} , remain unchanged. The alloy heat treated at 1000°C exhibits the highest damping capacity, which is attributed to the largest area of γ/ε boundaries.

The Fe-32Mn-6Si alloy is deformed by formation of ε martensite in early stage. If degree of cold rolling exceeds 5%, however, slip begins to occur due to decrease in mobility of the boundaries, deteriorating damping capacity though the boundary area increases.

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