Effects of Deformation and Thermal Cycling on Damping Capacity of Co-21 mass% Mn alloy

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Effects of deformation and thermal cycling on damping capacity of Co-21 mass% Mn alloy have been studied. The thermal ε martensite produced during cooling improves the damping capacity of the alloy. However, the ε martensite formed by deformation or thermal cycling treatment deteriorates the damping capacity. The reason is that the dislocations introduced during the deformation or thermal cycling treatment disrupt the movement of damping sources such as stacking fault boundaries in ε martensite.

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1. Introduction

Most recently, we have reported¹ that Co-Mn system undergoing α(fcc) → ε(hcp) non-thermoelastic martensite transformation exhibits a high damping capacity which is strongly dependent on the amount of ε martensite like an Fe-17%Mn alloy.²-⁵) The cooling treatment used in the previous work¹ had a limit in increase of ε martensite content. For example, a maximum 78 vol% of thermal ε martensite was obtained by subzero cooling treatment at liquid nitrogen (77 K) in Co-21%Mn alloy. In the present paper, therefore, the two different treatments, such as deformation and thermal cycling were carried out to increase ε martensite content above the 78 vol%, and the damping capacity of Co-21%Mn alloy was measured at room temperature as a function of ε martensite content and was compared with the results for the cooling treatment of the previous work.¹

2. Experimental Procedures

A Co-21 mass%Mn alloy was melted in vacuum by means of a high frequency induction furnace, and was cast into a metallic mould. The chemical composition of the alloy is listed in Table 1. The ingot of about 4 kg was homogenized in a protective atmosphere at 1273 K for 24 h and was hot-rolled to bars with a diameter of about 13 mm. From the bars, the specimens for microstructural observation, X-ray diffraction test, and damping capacity measurement were prepared by rolling and machining. All the specimens were solution treated at 1273 K for 1 h and were subsequently quenched into water of room temperature, followed by subzero treatment at liquid nitrogen (77 K).

Thermal cycling treatment of the subzero-treated specimens was conducted by heating and cooling between 543 K just above the austenite finish temperature (Ar) and room temperature, in order to increase the ε martensite content more than the subzero-treated state, 78 vol% ε. On the other hand, the cold-rolling of the subzero-treated specimens was carried out at 133 K to increase the amount of ε martensite by stress-induced martensite transformation.

The damping capacity in a logarithmic decrement(δ) defined as eq. (1) was measured at room temperature at a strain amplitude of 6 × 10⁻⁴ using a rectangular-type cantilever specimen (120 mm × 12 mm × 1.3 mm) freely vibrating in a flexural mode:

\[ \delta = \ln \left( \frac{a_n}{a_{n+1}} \right) \]  

(1)

where \( a_n \) and \( a_{n+1} \) represent nth and n+1th strain amplitude, respectively.

The specimens for optical microstructural observation were electro-polished in a solution of 10% HClO₄ + 90% CH₃COOH, and etched with a solution of 60 mL HCl + 15 mL HNO₃ + 15 mL CH₃COOH + 15 mL H₂O. Foils for transmission electron microscopy (TEM) were jet-polished in a solution of 10% HClO₄ + 90% CH₃COOH and then observed in a JEOL JEM-200CX operating at 200 kV.

The volume fraction of ε martensite was determined by measuring the integrated intensities of ε (10-1) and α (200) X-ray diffraction peaks.⁶-⁸) Owing to cross-rolling, texture structure was scarcely developed in the specimens subjected to various deformation degrees below 30%, and the error due to the texture was ignored in the measurement of ε volume fractions.

3. Results and Discussion

3.1 Effect of deformation on the damping capacity of Co-21 mass%Mn alloy

The Co-21 mass%Mn alloy quenched into water of room temperature, followed by subzero-treatment at 77 K, was cold-rolled at 133 K. The optical microstructures of the cold-rolled alloy are shown in Fig. 1. It is seen that the amount of ε martensite (dark plate) increases with increasing deformation degree. It is noticeable that the ε martensite plates are clearly

Table 1 Chemical composition (mass%) and transformation temperatures (K) of experimental alloy.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Mn</th>
<th>C</th>
<th>S</th>
<th>Co</th>
<th>M₆</th>
<th>A₇</th>
<th>A₈</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-21 mass%Mn</td>
<td>21.1</td>
<td>0.01</td>
<td>0.0004</td>
<td>bal.</td>
<td>347</td>
<td>469</td>
<td>500</td>
</tr>
</tbody>
</table>
observed up to 10% deformation, but when the specimens are deformed above the 10%, the microstructures are heavily distorted and the distinction between α(fcc) and ε(hcp) phases becomes difficult.

Figure 2 shows a plot of ε martensite content versus the reduction in thickness for the alloy. It is observed that the amount of ε martensite increases linearly with increasing deformation. The damping capacity of the alloy measured at room temperature from 78 vol% ε martensite before the deformation to 92 vol% after 30% deformation is plotted as a function of ε martensite content in Fig. 3. In this figure, the damping data for the thermal ε martensite contents reported in the previous paper,1) was replotted together. As shown in Fig. 3, the damping capacity of the stress-induced ε martensite does not correspond to the extended line of the damping capacity for the thermal ε martensite, and decreases steeply with increasing stress-induced ε martensite content. In order to analyze the reason why the damping capacity is deteriorated with the increase in stress-induced ε martensite, the hardness and TEM microstructure were examined. Figure 4 shows the hardness of the alloy as a function of ε martensite content. It is noteworthy that the hardness associated with the stress-induced ε martensite is much lower than that of the thermal ε martensite.
higher than the extended line of the hardness for the thermal $\varepsilon$ martensite. This is presumably ascribed to the production of dislocations besides formation of stress-induced $\varepsilon$ martensite during the deformation. As shown in Fig. 5, it is actually observed in TEM micrographs that the larger the deformation degree, the higher the dislocation density in the alloy. Therefore, the cause for the deterioration of the damping capacity in spite of increased $\varepsilon$ martensite content after deformation is considered that such dislocations play a role to suppress the movement of stacking fault boundaries in $\varepsilon$ martensite, which were proved to be the damping sources of the alloy in the previous study.1)

3.2 Effect of thermal cycling on the damping capacity of Co-21 mass% Mn alloy

The volume fraction of $\varepsilon$ martensite and damping capacity of the alloy subjected to thermal cycling treatment are plotted against the number of thermal cycles in Fig. 6. The amount of $\varepsilon$ martensite rapidly increases up to five cycles, and then

![Graph of log decrement vs. $\varepsilon$ martensite content](image1)

![Graph of hardness vs. $\varepsilon$ martensite content](image2)

![Transmission electron micrographs](image3)

![Graph of amount of $\varepsilon$ martensite and damping capacity vs. thermal cycles](image4)
keeps almost constant above five cycles, while the damping capacity rapidly decreases up to five cycles and holds almost constant value above five cycles. The reason why the damping capacity of the thermal-cycled specimens decreases in spite of the increased \(\varepsilon\) martensite content is that a density of dislocations introduced during thermal cycling becomes larger with increasing the number of thermal cycles, as shown in Fig. 7, which act as barriers to movement of the damping sources as in the case of the deformation.

4. Conclusion

The effect of deformation and thermal cycling on the damping capacity of Co-21 mass\%Mn alloy was investigated and the results obtained in this study are summarized as follows.

(1) When the Co-21 mass\%Mn alloy is deformed at 133 K, the damping capacity decreases in spite of the increased \(\varepsilon\) martensite volume fraction. This is caused by the dislocations introduced during deformation, which play a role to suppress the movement of damping sources such as stacking fault boundaries in \(\varepsilon\) martensite.

(2) When the Co-21 mass\%Mn alloy is thermal-cycled, the damping capacity decreases in spite of the increased \(\varepsilon\) martensite content. The reason is also ascribed to the dislocations introduced during the thermal cycling as in the case of deformation.

REFERENCES


Fig. 7 Transmission electron micrographs of (a) water quenched specimen, (b) 3 thermal-cycled specimen and (c) 5 thermal-cycled specimen (298 K–543 K).