A STUDY OF SHAPE MEMORY EFFECT ABOVE $M_s$ TEMPERATURE IN A Cu-Zn ALLOY
USING THE TWISTING DEFORMATION AND ELECTRIC RESISTANCE METHODS

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INTRODUCTION

The shape memory effect (SME) is generally recognized to be caused by the reverse transformation of the deformed thermoelastic martensite (TEM); in a TiNi alloy, however, it has been reported that the SME is not related to the thermoelastic martensite but is caused by stress--induced martensite (SIM) [1]. The SME is mainly related to the R-phase transformation [2].

In a CuZn alloy, the SME is still thought to be caused by the reverse phase transformation of the deformed TEM [3]. K. Otsuka et.al reported that the SME in CuZn alloy essentially occurred between $A_s$ and $A_f$, thus the electric resistance did not change by deformation, and that the heating curves of electric resistance were indistinguishable for both the deformed and the undeformed specimen [4]. Because the TiNi alloy has a complicated phase transformation and the study of SME is very difficult, we chose to study a CuZn alloy which has a relatively simple phase transformation in this experiment. The study of SME has used a bending method; in this work we used the twisting method and the electric resistance $R$ was measured simultaneously [5].

EXPERIMENTS

Two wire specimens (Sample #1 Cu-40.5wt% Zn; Sample #2 Cu-40.2Wt% Zn) with a length of 10 cm and a cross diameter of about 1 mm were held at a temperature of 1073 K for 15 min. and then quenched into ice water. The phase transformation temperature was measured by electric resistance method. The results are $M_s = 128{^\circ}K$ for sample #1, and $M_f = 135{^\circ}K$, $A_f = 226{^\circ}K$ for sample #2. Sample #1 was cooled from room temperature to $135{^\circ}K$ which is $7{^\circ}K$ above $M_s$ (= 128$^\circ$K), the temperature was then kept constant while the twisting angle ($\Delta\phi$) plastically developed and, at the same time the electric resistance $R$ was measured. Then the sample was heated, and the shape recovery ($\Delta\phi$) and the relative resistance $R$ were measured. Sample #2 was cooled from room temperature to $120{^\circ}K$ which is below the $M_f$ (= 135$^\circ$K), then kept the temperature constant, and was made twisting angle ($\Delta\phi$) plastically, at same time measured the relative resistance $R$. Then the sample #2 was heated, and the shape recovery ($\Delta\phi$) and relative resistance $R$ was measured.
RESULTS AND DISCUSSION

The SME in Cu-Zn alloy above the $M_s$

The results for sample #1 are shown in Fig. 1. On cooling, the curve 1 is a straight line, so that the TEM transformation has not occurred. At a constant temperature of 135 K ($= M_s + 7K$) it was twisted plastically and this result is shown in Fig. 1 as line 4. It is also shown in Fig. 2 that the curve $R$ vs. twisting angle $\Delta \phi$ has a shape like a step. The increase of $R$ can only be explained by a phase transformation that is induced by the twisting deformation. Since the sample was twisted at 7 K above $M_s$ (below $M_d$), and since under stress only SIM transformation (P-M) has been found, Fig. 2 shows that the curve shape like a step means that the martensite induced by stress is not uniform. In Fig. 1 curve 2 the small protruding part corresponds to the fast shape recovery. The reason for this phenomenon is not clear. From curve 3, sample #1 shows that the total recovering SME ratio is 94%; we are thus sure that the SME is caused by the reverse transformation of SIM and not by the TEM.

The SME in Cu-Zn alloy below $M_s$

The measurement result of SME and resistance $R$ of sample #2 (Cu-40.2wt% Zn) is shown in Fig. 3. It was twisted at 120 K which is below the $M_f$; its $R$-$\Delta \phi$ curve has the shape of a step, as shown in Fig. 4. Figure 3 in which the resistance $R$ peaks appear, shows that the TEM

![Image](image.png)

Fig. 1. The electric resistance change in Cu-Zn sample #1 (Cu-40.5wt% Zn) during SME above $M_s$. Curve 1: The resistance $R$ vs. temperature $T$ on cooling; Curve 2: The $R$-$T$ curve on heating; Curve 3: The shape recovery on heating, the total recovering ratio is 94%; Curve 4: The sample was twisted plastically at constant temperature 135 K ($= M_s + 7K$).
Fig. 2. The resistance $R$ vs. twisting angle $\Delta \phi$ of sample #1 which was plastically twisted at 135K ($= M_s + 7K$). This curve is line 4 in Fig. 1.

Fig. 3. The shape recovery and resistance change during SME in Cu-Zn sample #2 (Cu-40.2wt% Zn). Curve 1: The electric resistance $R$ vs. temperature $T$ on cooling; Curve 2: The R-T curve on heating; Curve 3: The shape recovery on heating, the total recovering ratio is 92%; Curve 4: The sample was twisted plastically at constant temperature 120K which is below the $M_f$. 

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The resistance $R$ vs. twisting angle $\Delta \phi$ of sample #2 which was plastically twisted at 120K. This curve is line 4 in Fig. 3.

transformation was occurred. From Fig. 4, the curve like a step shows that this transformation is not uniform. This increase of $R$ can be explained by the SIM, and is not due to the reorientation of TEM or twinning. Because the change of $R$ is proportional to the amount of TEM [6], and the reorientation of TEM or twin cannot be increased, the SIM should be transformed from the TEM. This means the increase of $R$ induced per degree in Fig. 4 is much smaller than that is in Fig. 2. The strong internal stress existing in the sample below $M_f$ makes the SIM induced by external stress more difficult.

In Fig. 3 curve 2, there are two protruding parts at the temperature 230° and 240°K that have the character of a reverse SIM transformation. The two protruding parts correspond to two temperatures at which the shape recovery is fast. This result is the same as in Fig. 1 curve 2 and 3 at temperature 145K. In Fig. 3, from 230K to 251 K, the shape recovery is 65%. Thus, the SME is mainly caused by SIM. This point of view must be studied by other methods.

CONCLUSION

The TEM is not the necessary condition of the SME. In a Cu-Zn alloy, when the temperature is above $M_S$, the SME is caused entirely by the SIM.

REFERENCES

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