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TWO WAY SHAPE MEMORY EFFECT OBTAINED BY STABILISED STRESS INDUCED MARTENSITE IN Cu-Zn-Al-Co AND Cu-Al-Mn ALLOYS

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Abstract. Two way shape memory has been achieved in Cu-Zn-Al-Co and Co-Al-Mn alloys by a training process based on the stabilisation of stress induced martensite. The effect of training temperature on the amount of two way shape memory obtained has been studied by training at various temperatures of between 50 °C and 170 °C above the A_f. After training the samples were thermally cycled various times (up to 100) through their martensitic transformation temperatures in the absence of applied stress to evaluate the degree of recovery of both the hot and cold shape and hence assess the two way shape memory effect. The results obtained showed that there existed an optimum training temperature at which maximum two way shape memory was observed.

INTRODUCTION

Most of the current applications of shape memory alloys are based upon one way shape memory, the material only remembering its "hot shape". However shape memory alloys can be suitably trained to obtain two way shape memory (TWSM), the material now remembering its "hot" and "cold shape". This results from the formation of suitable dislocation structures (1), internal stresses (2), retained martensite (3) or stress induced martensite (4, 5) during the training procedure which bias the formation of one particular martensite variant on subsequent cooling cycles, the formation of one martensite variant, instead of the normal 24 self accommodating martensite variants, being accompanied by a macroscopic shape change. As devices relying on the two way shape memory effect can find uses in control applications, there exists interest in developing simple but effective TWSM training methods. Various training methods have been proposed. These include shape memory effect training where the sample is repeatedly deformed in the martensitic state beyond its recoverable strain limit, the load removed, followed by heating into the high temperature (β) field, stress induced martensite training where the sample is repeatedly strained and unloaded at temperatures in the high temperature field (above the A_f temperature), and combined shape memory effect and stress induced martensite training techniques. However all of these techniques suffer from needing a repeated application of the training cycles, hence are quite complicated requiring considerable time. In addition the amount of two way shape memory achievable for certain shape memory alloys, e.g. Cu-Al-Mn, using these methods is very limited.

Training cycles based upon the formation of stabilised stress induced martensite have been shown recently to be particularly effective in developing two way shape memory in Cu-Zn-Al and Cu-Al-Mn shape memory alloys (6). The present paper details the effect of training temperature and time *on the two way shape memory developed in various Cu-Zn-Al-Co and Cu-Al-Mn shape memory alloys by the stabilised stress induced martensite method.*

EXPERIMENTAL

The composition and martensitic transformation temperatures of the alloys studied are given in Table I. The alloys were hot rolled to thicknesses of 0.5 - 1 mm and cut into strips of 70 mm long by 5 mm wide.

Training was carried out by :

1. *Heat treatment at 850 °C for 1 - 10 minutes followed by water quenching.*
2. *Samples were deformed at temperatures above A_f around cylinders of 40 - 75 mm diameter. This corresponds to a maximum surface strain of 0.7 - 2.5 %.*
3. *With the sample restrained around the cylinder, a heat treatment was carried out for times of 5 - 60 minutes in either an oil bath or oven at different temperatures ranging from 50 °C - 300 °C.*
4. *The sample was released from the cylinder while still at the training temperature and allowed to cool to room temperature.*

The amount of two way shape memory effect (TWSME) exhibited by the sample was measured by cycling the samples at zero stress between temperatures above the A_f and below the M_f. The residence time at the high and low temperatures of the thermal cycle was 5 to 10 s.. Measurements were carried out in the manner indicated in Figure 1. OO represents the shape of the sample during training while BB was the original shape before training. FF represents the cold shape and CC the hot shape.

The two way shape memory effect was assessed as :

$$TWSME\ \% = \frac{\delta_F - \delta_C}{\delta_O} \times 100$$

where

$\delta_F = X_F + Y_F$ = *deflection of cold shape.*

$\delta_C = X_C + Y_C$ = *deflection of hot shape.*

$\delta_O = X_O + Y_O$ = *deflection imposed during training.*

RESULTS

1. Effect of Training Temperature.

Figure 2 shows the deflection of the sample in its cold and hot shapes, δ_F and δ_C respectively, as a function of the training temperature for a Cu-Zn-Al-Co alloy (alloy 1 in Table I). Data are given for δ_F immediately after training prior to cycling (1 cycle), after 5 cycles and after 100 cycles. The deflection of the sample in its hot shape, δ_C, did not change appreciably with cycling so only data for the first cycle are given (7).

As can be seen, from Figure 2, the deflection of the hot and cold shape increases with training temperature and there is little change in cold shape on cycling. Similar results were reported in (7) and explained in terms of the amount of stabilised stress induced martensite formed at each *temperature. Figure 3 shows the TWSME as a function of temperature revealing a maximum TWSME of 65 % of the shape imposed during training for a training temperature of 110 °C (A_f + 120 °C).*

Similar results were obtained for a Cu-Al-Mn alloy (alloy 3), Figure 4, which shows a maximum TWSME of 53 % at a training temperature of 250 °C (A_f + 170 °C). The pronounced decrease in TWSME at temperatures above 250 °C should be noted. A similar effect was reported in (7) and postulated to be caused by precipitation (8).

2. Effect of training time.

Figure 5 displays the effect of training time on the amount of TWSME for a Cu-Al-Zn-Co (alloy 2) developed for various training temperatures. Maximum TWSME is achieved at shorter times the higher the training temperature which suggests the influence of diffusion controlled processes.

3. Stress developed during training.

In order to study the stresses developed during the training of a Cu-Al-Mn alloy (alloy 4), the whole training cycle was performed in an Instron tensile testing machine. The tensile test piece sample was strain gauged using a foil gauge on a polyimide base and a cyanoacrylate adhesive. This allowed a maximum strain of 3 % to be recorded and a normal operating range of -30 °C to 250 °C. Temperature compensation was provided by a dummy gauge on a similar alloy but one with no shape memory properties in the working range.

The sample was heated from room temperature to 50 °C (A_f + 70 °C) under zero load. The sample was then strained to 2 % strain, which was the maximum surface strain developed in the training of the sample around the cylinder. The temperature was then raised to 100 °C while the 2 % strain was carefully held constant by adjusting the applied load. The sample was then held at 100 °C for 30 minutes then unloaded while still at 100 °C. Figure 6 shows the stress-strain record during the test. When the temperature is raised to 100 °C the stress in the sample rises immediately as the SIM reverts to the parent phase and a reversion stress of some 80 N/mm^2 builds up.

Following training in the Instron tensile testing machine, the sample was thermally cycled and found to have a TWSME of 40 %.

DISCUSSION AND CONCLUSIONS

Appreciable TWSME has been obtained in Cu-Zn-Al-Co and Cu-Al-Mn alloys by using the stabilised stress induced martensite method. An optimum training temperature and time have been found for each alloy.

Measurements of the stresses developed during the heating under restraint (in the tensile testing machine) of a sample in which stress induced martensite has been formed during prior deformation has shown that an appreciable reversion stress develops as the stress induced martensite reverts to the parent phase. However when a certain stress has built up no further reverse transformation of the martensite will be thermodynamically possible as for that new condition of stress martensite will be the stable phase at that temperature rather than the parent phase. Hence although the martensite plates will shrink during the training heat treatment they will not disappear completely and a stress field will exist around the remaining martensite plates leading to dislocation movements. However although this reversion stress is developed instantaneously on increasing the temperature to the training temperature, it has been found that a certain time at that temperature is *necessary to obtain TWSME, suggesting that some diffusion controlled process is also involved. Transmission electron microscopy is being carried out to investigate this and will be reported in a subsequent paper.*

REFERENCES

(1) A. NAGASAWA, K. ENAMI, Y. ISHINO, et al., Scripta Metall., 8, 1055, (1974).
(2) K. ENANI, A. NAGASAWA, S. NENNO, Scripta Metall., 9, 941, (1975).
(3) J. PERKINS, R.O. SPONHOLZ, Met. Trans. 15A, 313, (1984).
(4) M.M. REYHANI, P.G. McCORMICK, Proceeds. Int. Conf. on Mar. Trans., Nara (Japan), 896, (1986).
(5) K. OISHI, L.C. BROWN, Met. Trans. 2, 1971, (1971).
(6) R. RAPACIOLI, V. TORRA, et al., Scripta Metall., 22, 261, (1988).
(7) J.M. GUILEMANY, J. FERNANDEZ, B.G. MELLOR, Scripta Metall., 24, 1941, (1990).
(8) J.M. GUILEMANY, J. FERNANDEZ, et al., Spanish Electron Microscopy Meeting, Cadiz, 49, Dec. (1990).

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TABLE I. Alloy compositions and martensitic transformation temperatures.

Alloy Nº	%Cu	%Al	%Zn	%Mn	%Co	M_f	M_s	A_s	A_f
1	73.7	6.7	18.9	-	0.7	-47	-19	-35	-7
2	72.5	6.6	20.2	-	0.7	-2	30	22	42
3	82.8	10.83	-	6.37	-	-30	40	10	80
4	82.3	11.42	-	6.28	-	-55	-15	-35	-18

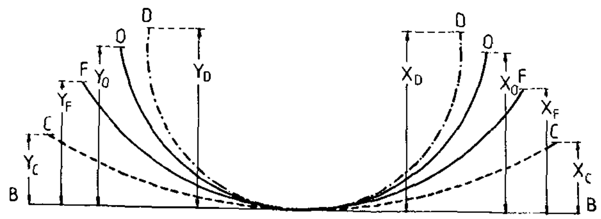

Figure 1. Schematic representation of the shape of the sample

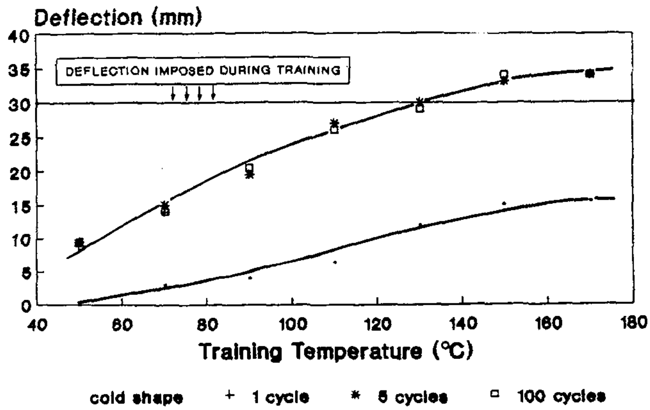

Figure 2. Deflection of the Cu-Al-Zn-Co (alloy 1) sample as a function of training temperature. Maximum surface strain imposed during training = 0.7%.

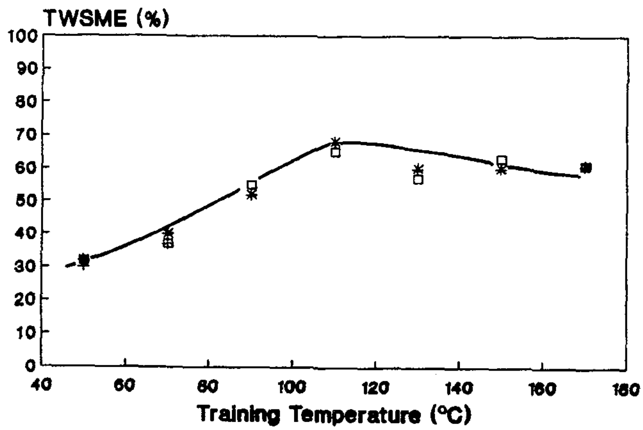

Figure 3. Two way shape memory effect (TWSME) as a function of training temperature for the Cu-Al-Zn-Co (alloy 1) sample.

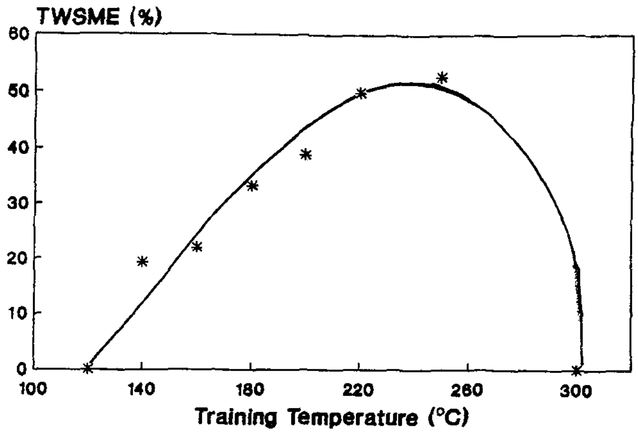

Figure 4. Two way shape memory effect (TWSME) as a function of training temperature for the Cu-Al-Mn (alloy 3) sample. Maximum surface strain imposed during training = 2.5%.

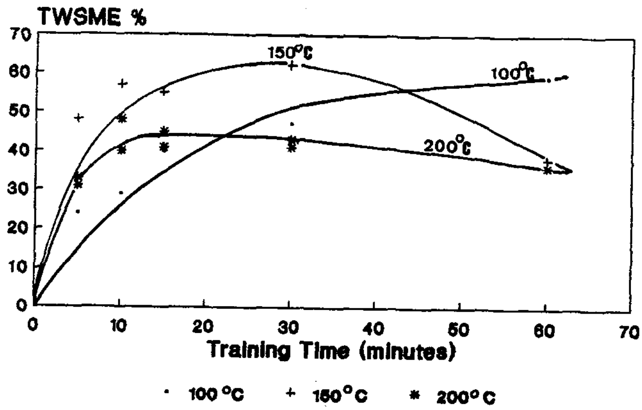

Figure 5. Two way shape memory effect (TWSME) as a function of training time for various training temperatures for the Cu-Al-Zn-Co (alloy 2) sample.

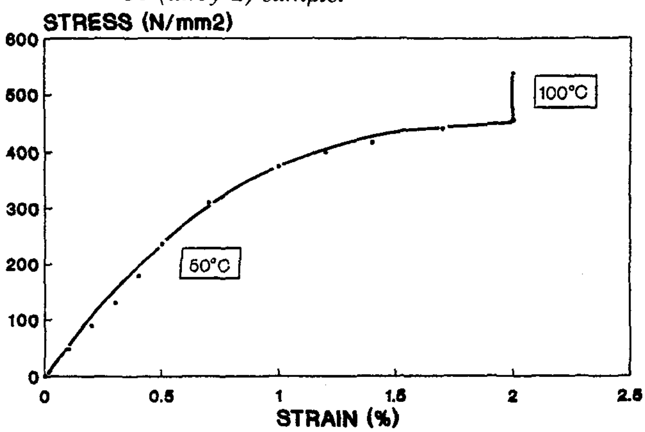

Figure 6. Stress-strain record of the Cu-Al-Mn (alloy 4) sample trained in an Instron tensile testing machine.