TWSME in Cu-Al-Ni Alloys Obtained by Stabilised Stress Induced Martensite

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Abstract. The effect of deformation degree, temperature and time of ageing on the TWSME has been studied in polycrystalline and single-crystalline Cu-Al-Ni alloys. The results confirm that to obtain the best TWSME one needs to select the training parameters. The trained single crystals exhibit a lower TWSME than the polycrystalline alloys for the same training conditions. In the trained single crystals a single martensite variant has not been observed, but they showed a fewer variants than the untrained samples. The TEM studies of the trained samples exhibit a complex dislocation arrangements which interact with very thin induced plates of martensite. Ageing of the one of polycrystalline alloys caused precipitation of coherent γ_2 - phase particles. No precipitates were found in the second one and in the similarly trained single crystals although in these alloys a significant TWSME was observed. This means that the role of the γ_2 - phase particles presence to obtain the TWSME by ageing under stress is not that important as it has been suggested.

1. INTRODUCTION

The two-way shape memory (TWSM) effect is a well known phenomenon which can be introduced into shape memory alloys by several methods i.e. thermomechanical training [1], constraint ageing [2] or stabilisation of stress-induced martensite [3,4]. Different mechanisms of inducing the two-way shape memory effect have been suggested. Significant role is thought to be played by specific dislocation arrangements [5,6], stabilised martensite plates [4], precipitates of the γ_2 phase [4,7] and by internal stress fields [2,4]. Thus the problem is not solved.

The aim of this work was to study of the TWSM induced by ageing under stress in Cu-Al-Ni alloys.

2. EXPERIMENTAL PROCEDURE

Two polycrystalline Cu-Al-Ni-Ti-B alloys (P1 and P2 samples) and a Cu-Al-Ni single crystal (S sample) were studied in the work. The characteristics of the alloys are given in Table 1 (The characteristic temperatures were determined from TWSM hysteresis loops obtained by heating and cooling without external stress. TWSM effect was induced in the samples by classic thermomechanical training).

Table 1 The characteristic temperatures [$^{\circ}\text{C}$] and chemical compositions of samples [wt.%]

sample	M_s	M_f	A_s	A_f	Al	Ni	Ti	B
P1	25	-12	5	40	13.5	3.2	0.30	0.07
P2	73	40	54	84	13.4	3.1	0.25	0.06
S	128	87	115	153	13.3	3.0	-	-

The P1 and P2 alloys were prepared in an induction furnace in argon atmosphere, then they were homogenised at 800°C for 1 h followed by hot rolling to the thickness of 0.8 mm. The S specimen was grown by the Bridgman's method. Flat specimens were cut from all the three alloys, the dimensions for the P1 and P2 specimens were 25 x 5 x 0.8 mm and for the S sample - 15 x 4 x 0.6 mm. These specimens were quenched from 850°C to water. Then they were aged under tensile stress for different values of the deformation (1% or 2%), ageing times (from 10 to 120 minutes) and temperatures (from 120 to 220°C). The specimens were cooled down under the stress and then the stress was released and the specimens were 10 times cycled between M_f and A_f .

The two-way shape memory effect was measured and calculated from the relation:

$$\%TWSM = \frac{\Delta l_{TWSM}}{\Delta l_{IND}} \cdot 100\%$$

where: Δl_{IND} - change of the specimen length caused by the external stress during inducing the two-way shape memory effect,
 Δl_{TWSM} - change of the specimen length during a working cycle of the TWSM effect i.e. between the A_f and M_f temperatures.

The structural studies were carried out on thin foils using JEM 3010 transmission electron microscope. Also light microscopy observations were conducted.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Results of the two-way shape memory effect measurements are presented in the Table 2. It can be seen that the defined earlier %TWSM depends mainly on the deformation degree during the stress inducing process (Fig. 1). The average values of the TWSM effect for 2% deformation are in the range of 30 - 40% for both P1 and P2 specimens. For 1% deformation the TWSM effect values are in the range of 60 - 70% which is twice as much as for the larger deformation degree. In the applied range of ageing temperatures no significant dependence of the obtained effect values on the time and temperatures of ageing was observed. This is in good agreement with the results presented in [4] for the temperatures above 100°C.

Table 2 Values of %TWSM obtained for different alloys and different treatment

(T_A - temperature of ageing, t_A - time of ageing, the notation e.g. 120/1 means that the specimen was aged at 120°C under 1% tensile strain)

Alloy	P2				P1			S	
Sample	120/1	120/2	160/1	160/2	120/2	160/2	200/2	185/1	220/1
$T_A - A_f$	36°C	36°C	76°C	76°C	80°C	120°C	160°C	32°C	67°C
$t_A=10$	44	28	60	40					
$t_A=20$	60	32	55	36	43	40	46		
$t_A=30$	64	30	61	40				47	50
$t_A=45$	58	30	70	41	32	32	30		
$t_A=60$	60	36	62	30					
$t_A=120$	64	28	70	22					

The single crystal specimen which was also deformed by 1% shows values of the induced TWSM effect significantly smaller than the P1 alloy with the same deformation degree.

Light microscopy observations show (Fig. 2) that the martensite plates which were initially randomly distributed in the sample, after the TWSM training (by SSIM method) becomes partially replaced by plates of a preferential orientation in relation to the external stress direction. Both, the coagulation and reorientation of the plates were observed. However, it was not possible to obtain a single variant of the martensite plate.

Figure 1: Values of the TWSM versus ageing time for different ageing temperatures and deformation degrees (sample P2)

Figure 2: Microstructure of the S sample in the as-quenched state (a) (b) and corresponding images after inducing TWSM by the SSIM method (220/1) (c) and (d)

At room temperature the P1 alloy after inducing TWSM consisted of two phases: β_1 matrix and 2H martensite plates as it was shown by transmission electron microscopy studies. In the parent phase a complex arrangements of dislocation were observed in the form of low angle boundaries or pile-ups lying along martensite plate traces (Fig. 3). In the case of the P1 alloy small precipitates of the γ_2 phase were also present.

Figure 3: Structure of the β_1 phase in the P1 alloy after inducing the TWSM effect ($200/2$, $t_A=20$)

In the P2 alloy after inducing TWSM the 2H martensite was observed. In this alloy the γ_2 precipitates were not observed. The internal structure of the martensite plates is very complex (Fig. 4). Areas were found where inside every second plate, small plates situated at 40° angle to the plate edge were visible. Inside the small plates one can see dislocations. Similar variants of the martensite plates induced inside the big original plates during the thermomechanical cycling were reported in [8].

Figure 4: Structure of the P2 alloy after inducing the TWSM effect ($160/2$, $t_A=30$): bright field image (a), dark field images for two variants of martensite plates (b) and (c)

Similar complex arrangements of tiny plates and dislocations were observed in the single crystal S sample (Fig. 5).

The specimen S was heated in the microscope to the temperature about 200°C and „in situ” observations of the foil were carried out. It was found that the small plates inside the bigger one disappeared and in these places pile-ups of dislocations occurred (Fig. 5b). Similarly as in the P2 alloy the γ_2 precipitates were not observed in the S sample. The difference of the internal structure of every second martensite plate observed in the P2 and S samples could be interpreted as the effect of different orientation of the plates in relation to the direction of the external stress. After „in situ” heating in the studied areas of the S sample the stabilised martensite plates were not observed, although the temperature of 200°C is lower than the temperature at which the TWSM effect was induced by stress. One can suggest that the applied training caused occurring

dislocation arrangements in the parent phase which favour creation of very small martensite plates between every two parallel dislocations (Fig. 4a). The stress field arising around such plates control nucleation of the neighbouring plates. An interesting effect visible on Fig. 5b is a strain-field contrast which differs from the one shown in [4]. In the samples of the P2 and S alloys the γ_2 phase precipitates were not observed, but yet the obtained two-way shape memory effect is large. This means that the precipitates do not play that important role in inducing the effect by ageing under stress as it was suggested in [4,7].

Figure 5: Structure of the 220/1 sample of the S alloy after inducing the TWSM effect (a) and after „in situ” heating (b)

4. CONCLUSIONS

- The value of a deformation degree applied during inducing the TWSM effect by the SSIM method has the biggest influence on the %TWSM value.
- No important influence of the γ_2 precipitates on the value of the TWSM effect induced by the SSIM method was observed in the studied alloys.
- A complex internal defect structure depending on the variant of the martensite plates was observed which could be due to different (more or less favourable) orientation of the plates in relation to the external stress during inducing.
- The observed dislocation arrangements and related fine plates of the martensite create stress fields which are responsible for the TWSM effect.

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