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Effect of heat treatment on shape memory properties of ductile CuAlMn alloys ①

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[Abstract] The effect of heat treatment on shape memory properties of the ductile CuAlMn alloys was studied. The results show that the heating temperature for the solution treatment should be around 100 ℃ above the transformation temperature in order to obtain good shape memory properties, heating for 10 min at this temperature doesn't have much influence on the shape memory properties, faster cooling rate helps to obtain good shape memory properties and the shape recovery rate(SRR) decreases with raising ageing temperatures. For Cu-16Al-10Mn alloy, the heat treatment process to acquire higher recovery rate is heating at 800 ℃ for 15 min, quenching into ice water and ageing below 150 ℃ for 15 min. For Cu-17Al-10Mn alloy, the process is the same except heating at 700 ℃.

[Key words] CuAlMn alloys; recovery rate; heat treatment; shape memory alloys

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1 INTRODUCTION

Cu-based shape memory alloys (SMAs) are commercially attractive systems for applications because of their lower cost. Up to now, Cu-Zn and Cu-Al based SMAs have been widely studied. However, these Cu-based alloys, especially the alloys of Cu-Al-Ni system and the ones with high Al content in the Cu-Zn-Al system are seriously limited in use because they are too brittle to be sufficiently cold worked and possess very low fatigue strengths[1~3]. There have been some studies on adding Mn to substitute Al[4~6]. Recently, a new type of CuAlMn SMA with good ductility was found by increasing Mn content to 10% (mole fraction) and decreasing Al content to 14% ~ 17% (mole fraction). These alloys exhibit 15% strain to failure, and can bear 60% ~ 90% deformation when rolled. At the same time, they have good shape memory (SM) effect in bending test with 80% ~ 90% recovery rate[7,8]. The purpose of the present work is to investigate the effect of heat treatment on the shape memory properties of these ductile CuAlMn alloys and to find the most suitable heat treatment technology for practical applications.

2 EXPERIMENTAL

The materials in use were Cu-16Al-10Mn and Cu-17Al-10Mn (composition in mole fraction, %).

The dimension of the specimen was 40 mm × 2 mm × 0.2 mm.

The heat treatment for the specimen were: β transformation at 650 ~ 900 ℃, heat preservation for 2 ~ 30 min, quenching into ice water, oil or air, ageing treatment at room temperature or 100 ~ 250 ℃.

The transformation temperatures were detected by electrical resistance measurement.

The recovery rate was obtained by bending test. The specimen was deformed into a round shape below M_f(about 0 ℃) with the radius R equal to 5 mm, which corresponds to 2% strain. Then the specimen was heated to a temperature above A_f(about 200 ℃) and the radius r were measured. The recovery rate was calculated as $(r - R)/r \times 100\%$.

3 RESULTS AND DISCUSSION

3.1 β transformation temperature

The relation between the β transformation temperature and the recovery rate is shown in Fig.1.

It can be observed that the recovery rate increases to a maximum and then decreases with increasing β temperatures. According to the phase diagram of CuAlMn alloy[7], the critical β temperature is 710 ℃ for Cu-16Al-10Mn and 610 ℃ for Cu-17Al-10Mn. Since SM effect is associated with thermo-elastic martensitic transformation, it is necessary to form single β phase before quenching in order to obtain good SM effect. At the same time, the heating temperature and time should be controlled to be as low

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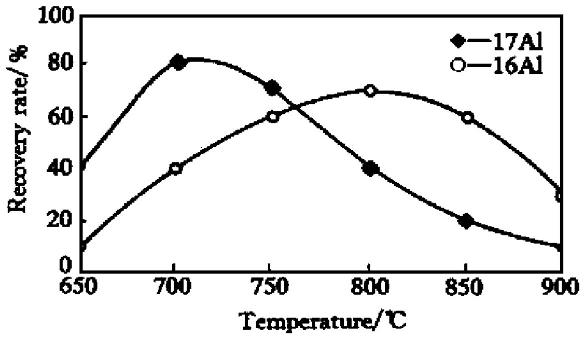

Fig.1 Relation between β temperature and recovery rate

and short as possible to avoid the decrease of strength with too large grain sizes[9]. Thus, the variation of the recovery rate with the β temperature as shown in Fig.1 might be explained as the following. When the heating temperatures are just above the critical β temperature, the sufficient solution and the refining grains by re-crystallization lead to good SM effect. When the heating temperatures are too high, the grains can grow easily because of rapid diffusion speed. So large grains are obtained and the mechanical properties of the specimen are degraded. Thus, the irreversible slip will occur at lower stresses because the yield stress decreases.

This leads to a decrease of the recovery rate. In conclusion, the suitable temperature for heat treatment should be about 100 ℃ above the critical β temperatures.

3.2 Preservation time for β transformation

The relation between the preservation time for β transformation at 700 ℃ and the recovery rate of 17Al alloy is shown in Fig.2. At the beginning, the shape recovery rate (SRR) increases with the increase of the preservation time. After 10 min, it reaches a maximum. Then, it decreases slightly with increasing time. This phenomena indicate that the solubility of the β phase increases with increasing time and

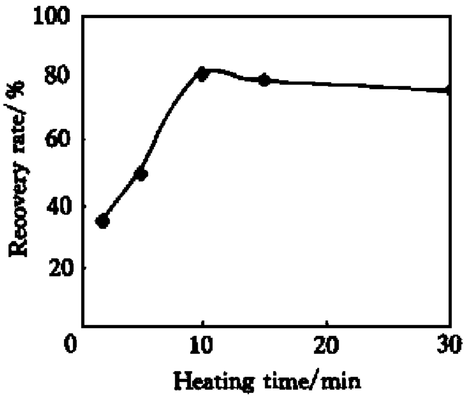

Fig.2 Relation between heating time at 700 ℃ and recovery rate of 17Al alloy

comes to a saturation point after 10 min. Therefore, the decrease of SRR after 10 min should be resulted from the increase of grain size. However, the grain size increases very slowly with the preservation time, so it has little influence on SM effect.

3.3 Cooling rate

16Al specimens were quenched into different mediums after β treatment at 800 ℃ for 15 min. The results are listed in Table 1.

Table 1 Influence of cooling rate on shape memory properties of 16Al alloy

Property	Quenched into ice water	Quenched into oil	Quenched into air
M_s/ ℃	89	67	-
M_f/ ℃	10	7	-
A_s/ ℃	21	14	-
A_f/ ℃	93	71	-
SRR/ %	80	50	-

The specimens quenched into ice water exhibit the best SRR. Those quenched into oil still have a reasonable SRR. However, the specimen cooled in air has no SM effect. This maybe due to the precipitation of low-temperature equilibrium phase during the cooling process. Because of the very slow cooling rate in air, too many α phases are precipitated in the specimen and the martensitic phases could not form. Thus, the specimen did not show any SM effect. The specimen quenched into oil has a few α phases and some martensitic phases. Therefore, it exhibits SM effect, but SRR is not very big. It is known that M_s should increase with decreasing cooling rate[9]. Here, it is the opposite. This is possibly due to the fact that the Al content in the matrix increases as a result of the precipitation of low Al content α phases. The increase of Al content leads to a decrease of M_s[7]. Therefore, the specimen quenched into ice water has the highest M_s, since the very few precipitation of α phases appears at a very rapid cooling rate.

3.4 Ageing temperature

Fig.3 shows the relation between the ageing temperature and SM effect of 17Al alloy.

SRR drops as the ageing time rises. The reason is that the equilibrium α phase precipitated from the alloy during the ageing process will restrain subsequent phase transformation. With increasing ageing temperatures, the amount of α phase precipitation will increase and SRR will decrease. Ageing effect is one of the most important factors restricting the application of the Cu-based SMAs. It usually results in a change of the transformation temperature and a degradation of SM properties[10]. The alloys studied in this paper have the same ageing problem. Our results suggested that to ensure good enough SRR, the

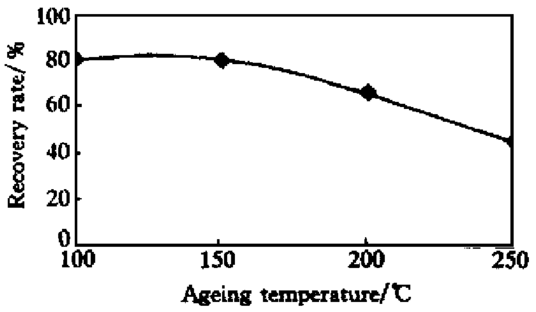

Fig.3 Influence of ageing temperature on SRR

ageing process to stabilize M_s point should be conducted below 150 ℃.

3.5 Transformation temperature

Table 2 shows the effect of heat treatment on the transformation temperature. The effect is complicated since it is related to both the precipitation of the equilibrium α phases and the order transformation from β phase to the martensite. More studies have to be carried out to clarify the results.

Table 2 Influence of heat treatment on transformation temperature

Heat treatment method	M_s/ ℃	M_f/ ℃	A_s/ ℃	A_f/ ℃
17Al: 700 ℃×15 min, 0 ℃ ice water, 150 ℃×15 min	73	23	42	84
17Al: 700 ℃×30 min, 0 ℃ ice water, 150 ℃×15 min	63	21	32	70
17Al: 700 ℃×30 min, 0 ℃ ice water, 150 ℃×30 min	62	27	42	106
17Al: 750 ℃×15 min, 0 ℃ ice water, 150 ℃×15 min	94	34	57	111
16Al: 750 ℃×15 min, 0 ℃ ice water, 150 ℃×15 min	95	36	56	116
16Al: 750 ℃×20 min, 0 ℃ ice water	69	7	35	97
16Al: 750 ℃×20 min, 100 ℃ oil	88	25	47	106
16Al: 750 ℃×20 min, 22 ℃ oil	103	42	48	108
16Al: 800 ℃×15 min, 20 ℃ oil, RT for 4 d	67	7	14	71
16Al: 800 ℃×15 min, 0 ℃ ice water	89	10	21	93

4 CONCLUSIONS

1) The solution treatment temperature for the β transformation should be about 100 ℃ over the phase boundary. Too high and too low temperatures will lead to a decrease of SRR.

2) After heating for 10 min at the β transformation temperature, the SM properties do not change significantly any more with a longer time.

3) The cooling rate of quenching has a strong influence on the SM properties. The faster the cooling rate, the better the SM properties.

4) The shape recovery rate decreases with increasing ageing temperatures.

5) For Cu-16Al-10Mn alloys, the heat treatment method to obtain a high shape recovery rate is heating at 800 ℃ for 15 min, quenching into ice water and ageing below 150 ℃ for 15 min. For Cu-17Al-10Mn alloys, it is the same except heating at 700 ℃.

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