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Effect of environmental temperature on damping capacity of Cu-Al-Mn alloy

JIAO Yu-qin(焦玉琴)[1, 2], WEN Yu-hua(文玉华)[1], LI Ning(李 宁)[1],
HE Jia-qiang(何加强)[1], TENG Jin(滕 劲)[1]

1. School of Manufacturing Science and Engineering, Sichuan University, Chengdu 610065, China;
2. School of Mechanical and Electrical Engineering, Qingdao University, Qingdao 266071, China

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Abstract: The effect of environmental temperature on the damping capacity of Cu-7.66Al-9.52Mn (mass fraction, %) alloy was studied. The result shows that with increasing the environmental temperature, the logarithmic decrement increases firstly and reaches the maximal value of 0.118. The reason is that more phase interfaces and twinning boundaries can move at a higher temperature, leading to higher consumption of energy, in despite of the decreasing of the amount of martensite. When the environmental temperature is above M_s, with further increase in the environmental temperature, the logarithmic decrement decreases sharply mainly because there is little martensite remaining in the alloy.

Key words: shape memory alloy; CuAlMn; damping capacity; environmental temperature

1 Introduction

With the development of modern industry, the hazard of noise and vibration becomes more and more serious. To reduce this kind of hazard is an imperative problem, which in some degree urges the study and development of high damping alloys. Among the traditional damping alloys, only MnCu alloys and NiTi alloys have both high damping capacity and high strength[1−2]. However, they are either difficult in processing or high in cost. Therefore, Cu-based shape memory alloys as damping alloys have been considered a possible alternative because of their excellent damping capacity and low cost[3−6]. However, polycrystalline Cu-based alloys, such as CuZnAl and CuAlNi, suffer from bad ductility because of their large grain size and high degree of ordering[7−9].

It has been found from recent studies that CuAlMn alloys with low aluminum contents show good ductility and shape memory effect because their parent phase with an $L2_1$ structure possesses a low degree of ordering [10−12]. However, the number of publication on the damping capacity of these alloys is rather limited. Recently, MALLIK and SAMPATH[13] have investigated the effect of composition and ageing on damping characteristics of CuAlMn.

Damping capacity of Cu-based alloys comes from unelastic strain of phase interfaces and martensite twin boundaries. These interfaces can move successively under external alternating stress, thus relaxing stress and consuming mechanical energy. The amount of interfaces is the most important factor to the damping capacity. Whereas in the course of application, the amount of interfaces might change with the environmental temperature, which would inevitably influence the damping capacity of the alloy. To date less reports are available about the effect of environmental temperature on the damping capacity of CuAlMn alloys with low aluminum contents. Therefore, the main purpose of this work is to study the damping capacities of Cu-7.66Al-9.52Mn (mass fraction, %) alloy at different environmental temperatures.

2 Experimental

The alloy was prepared by vacuum induction melting, using 99.9% Cu, 99.3% Al, 99.9% Mn (mass fraction). After being homogenized at 820 ℃ for 23 h, the ingot was squeezed into bars with 13 mm in diameter

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Corresponding author: LI Ning; Tel: +86-28-85405320; Fax: +86-28-85403827; E-mail: lining@scu.edu.cn
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at 800 ℃, then swaged into bars with 3.5 mm in diameter, and finally cold drawn into wires with 1.2 mm in diameter. All samples for measurement were cut from as-cold drawn wires with 1.2 mm in diameter. The samples were straightened, and then solution treated under constraints at 825 ℃ for 15 min, followed by a water quenching. After being quenched, the samples were immediately aged at 150 ℃ in an electrical oven for 15 min. The chemical compositions of the alloy are (mass fraction) 7.66% Al, 9.52% Mg and balance Cu.

Damping capacity of samples was measured with JN-1 reversal torsion pendulum. Logarithmic decrement δ was used to characterize the damping capacity. δ is calculated by the following formulae:

$$\delta = \ln\frac{A_n}{A_{n+1}} \quad (1)$$

$$\gamma_{\max} = \frac{r}{l}\times\phi \quad (2)$$

where A_n is the nth vibration amplitude; A_{n+1} is the (n+1)th vibration amplitude; $\gamma_{\max}$ is the maximal torsion strain on the surface of the sample; r is the radius of the sample (0.6 mm); l is the length of the sample held (100 mm); and ϕ is the torsion angle (radian).

Transformation temperatures were measured by resistance—temperature method. Microstructure of the sample was examined with OLYMPUS-CK40M optical microscope. The phases of the sample present at room temperature were analyzed by X-ray diffraction techniques using Cu K_α radiation with Philips X Pert PMD.

3 Results

Fig.1 shows the martensite transformation curve of the sample. The arrow stands for the heating direction. The sample at room temperature underwent martensite inverse transformation when heating and at 150 ℃ the transformation finished. When cooling, at about 60 ℃, martensite transformation started.

Fig.2 shows the influence of environmental temperatures on the logarithmic decrement of the sample. The logarithmic decrement increased slowly from room temperature and reached the maximal value at about 60 ℃. And then it decreased sharply with further increase in environmental temperature. At 120 ℃, the logarithmic decrement was nearly half that at room temperature.

Fig.3 shows the microstructure of the sample. At room temperature, the sample consisted of martensite and parent phase. Fig.4 shows XRD pattern of the sample. There were much thermoelastic martensite of 18R, and some parent phases with $L2_1$ structure still remained.

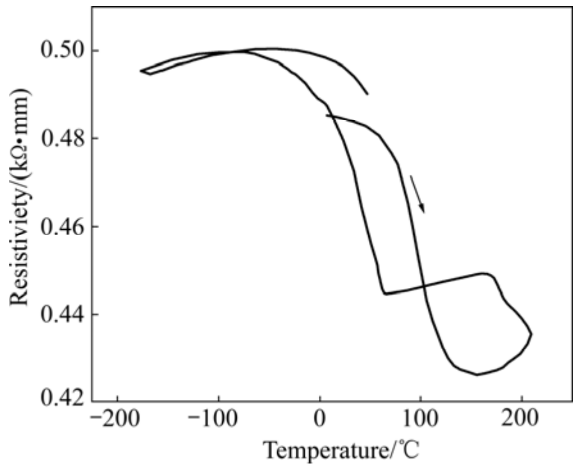

Fig.1 Martensite transformation curve of sample

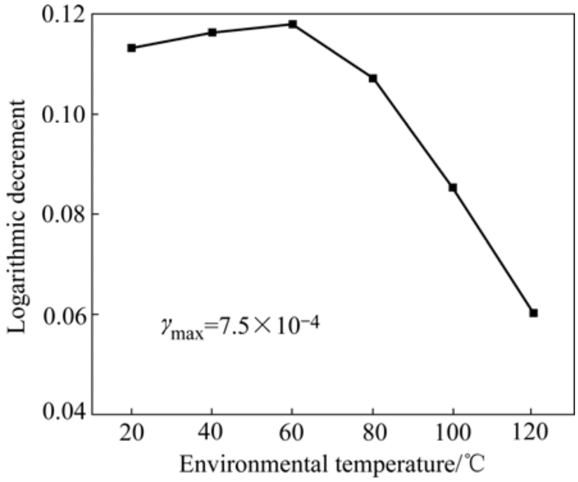

Fig.2 Influence of environmental temperature on logarithmic decrement of samples

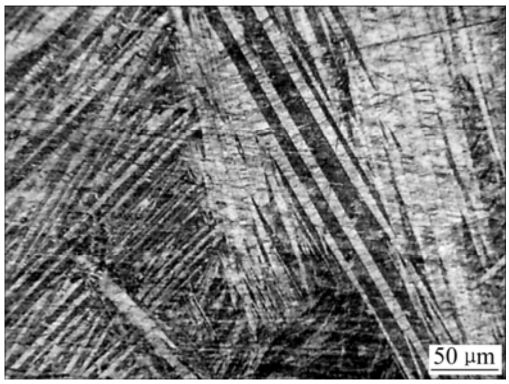

Fig.3 Microstructure of sample after solution and up-quenching treatment

4 Discussion

The damping origins of Cu-Al-Mn shape memory alloy are kinds of phase interfaces and twin boundaries in martensite variants. The amount of interfaces and

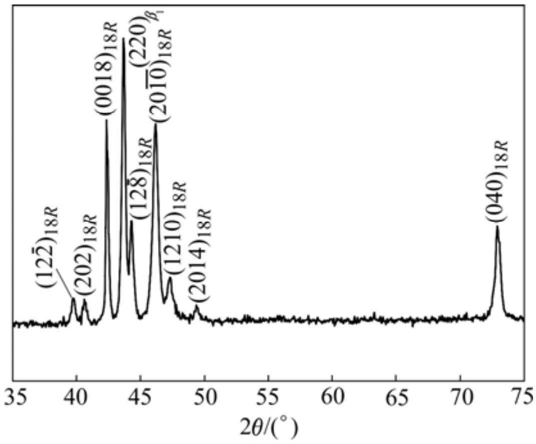

Fig.4 XRD pattern of sample after solution and up-quenching treatment

boundaries affects the damping capacity because damping capacity comes from the hysteretic mobility of them[1−2]. As it is known, the amount of thermoelastic martensite is a function of temperature[14]. Therefore, the temperature influences the amount of the martensite, and then affecting the damping capacity of the alloy as a result.

As for Cu-7.66Al-9.52Mn alloys, after solution and up-quenching treatment, the samples at room temperature contain 18*R* martensite and β_1 parent phase (with $L2_1$ structure), as shown in Fig.3 and Fig.4. Fig.2 shows that the logarithmic decrement(δ) increases slowly with the environmental temperature increasing and reaches the maximal value when the environmental temperature is about 60 ℃. In this period, damping capacity comes from two different aspects. On one side, martensite inverse-transformation makes the amount of martensite decrease while the amount of parent phase increases, which might lead to the reduction in damping capacity. On the other side, higher temperature can promote the movement of these kinds of interfaces. As it is known, both twin boundaries and phase interfaces have viscidity[15]. With the environmental temperature increasing, their viscidity decreases. Therefore, more boundaries and interfaces can slip at the same shearing stress when they are at higher temperatures. Because the slip movement is unelastic, it leads to consumption of energy, as shown in Fig.5. Moreover, more interfaces are involved in the transformation to parent phase at higher temperatures. Under the influence of the two above-mentioned sides, the logarithmic decrement thus increases slowly. Studies in this experiment indicate that below M_s the damping capacity of Cu-based shape memory alloys increases with the environmental temperatures increasing.

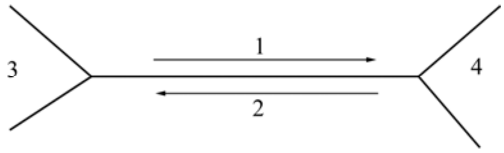

Fig.5 Slip model of interfaces[14] (1,2,3 and 4 stand for grains)

With further increase in the environmental temperature, although higher temperature can still decrease the coefficient of viscidity of these interfaces, the logarithmic decrement decreases due to the decrease in the amount of martensite. Because of martensite inverse-transformation, there are more and more parent phases and less and less martensites. The reduction in the amount of the interfaces plays the principle role. So, the logarithmic decrement decreases sharply. When the temperature increases to 120 ℃, martensite inverse-transformation almost finishes completely. The logarithmic decrement is nearly half that at room temperature.

5 Conclusions

1) With the environmental temperature increasing, the logarithmic decrement of the sample increases because at higher temperature more interfaces take part in movement under the same stress, which can make for the reduction in the logarithmic decrement due to martensite inverse transformation.

2) When the environmental temperature is above M_s, with further increase in the environmental temperature, the logarithmic decrement decreases because there is little martensites remained in the sample.

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