Damping performance of Cu-Zn-Al shape memory alloys in engineering structures

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Abstract: The stress strain curves of two CuZnAl shape memory alloys which have the martensitic transformation temperatures of 50 °C and −10 °C respectively, were measured by using electronic material tester after treated by different heat-treatment conditions. The results show that the area enclosed by hysteresis loop of the CuZnAl shape memory alloy in martensitic state is much larger than that of the alloy in austenitic state with super-elasticity at room temperature. Therefore, the former has better vibration attenuation effect. After being oil-quenched, water-quenched, and step-quenched, the CuZnAl alloy takes on more stable shape memory effect, better super-plasticity and superelasticity (pseudelasticity). A CuZnAl shape memory alloy damper was designed, produced and installed to a 2-layer frame structure. In addition, the vibration experiments were made by dynamic data collecting analysis meter. The velocity of vibration attenuation of frame structure with CuZnAl shape memory alloy damper is much faster than that without it. And with the help of CuZnAl shape memory alloy damper, the attenuation period reduces to 1/10 of the original.

Key words: CuZnAl shape memory alloy; heat treatment; hysteretic property; structure damping

1 INTRODUCTION

Shape memory alloy (SMA) has a high recoverable strain about 6%−8% which is much greater than that of steel. And during its deformation, the loading and unloading paths form a hysteresis loop because they do not overlap. Thus SMA can consume lots of mechanical energy to reduce vibration. Furthermore, the larger the area enclosed by hysteresis loop, the better the effect of damping. As SMA has shape memory effect (SME) and super-elasticity, the SMA in austenitic state at room temperature can be combined with shock isolation device. On one hand, seismic energy is dissipated by means of the super-elasticity hysteretic dissipation performance during earthquake. On the other hand, SMA can reset shock isolation device by the restoring force produced by the SMA super-elasticity when the residual deformation occurs during earthquake. SMA, which is in martensitic state at room temperature, can be connected to limited discrete points of structure due to its SME. The vibration energy will be dissipated and the reaction of structure will be reduced through the superplasticity hysteretic dissipation performance when the structure vibrates. After the vibration, SMA can reset the structure by the restoring force produced by SMA at high temperature. In recent years, the application of Ti-Ni SMA in structure control have been studied. But the study about the application of CuZnAl SMA in that field is rarely reported. The source of CuZnAl SMA is more available and inexpensive than that of Ti-Ni alloy. So it has a wider applicability in engineering. The problems of large grain size of CuZnAl SMA and the stabilizing of martensite were solved by SI et al. The results show that the grain size of CuZnAl can be refined and martensite can not be stabilized. The mechanical properties are improved considerably by rare earth (m(La) : m(Ce) = 1 : 1). And the excellent memorial properties are remained. The microstructure indicates that the rare earth segregates at grain boundary and impedes the grain growth leading to the improvement of mechanical properties of CuZnAl SMA. If the composition of rare earth is higher than 0.10%, the memorial properties will be worsened. Based on the reasearches, the damping performance of engineering structures of CuZnAl SMA was studied in this paper.

2 EXPERIMENTAL

The elemental compositions of alloy 1 and alloy 2 are shown in Table 1. The martensitic transformation temperatures of the two alloys are 50 °C and −10 °C, respectively. Electrolytic Cu, Zn and Al were melted in electric induce furnace.
When the temperature of the molten alloy reaches 1230 °C, the rare earth was added. The casting alloys (dimensions: 80 mm × 150 mm) were produced in mould. After they annealed at 850 °C for about 24 h to homogenize, the ingots were chipped to clear up oxidation scab. At last, they were forged and rolled into sheets with 0.25 mm thickness. The sheets were quenched in oil, 150 °C oil, water and air, respectively, after being annealed at 830–850 °C for 0.5 h. Then they were aged at 140–150 °C for 1, 3 and 5 h, respectively.

Table 1  Elemental composition of the alloy1 and alloy 2 (Mass fraction, %)

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Zn</th>
<th>Al</th>
<th>Ni</th>
<th>rare earth (La+Ce)</th>
<th>Cu</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25.25</td>
<td>3.74</td>
<td>0.98</td>
<td>0.08</td>
<td>Bal.</td>
</tr>
<tr>
<td>2</td>
<td>26.08</td>
<td>3.85</td>
<td>0.98</td>
<td>0.08</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

The stress-strain curves of the two alloys treated by different heat-treatment conditions were measured by WDW-200 material tester controlled by computer. The tensile samples with dimension of 200.00 mm × 8.00 mm × 0.25 mm, were analyzed by NIKON horizontal microscope and JXA-840A scanning electron microscope (SEM). A CuZnAl SMA damper was installed in a 2-layer frame structure. And then, the vibration experiments were made by YDS-1 dynamic data collecting analysis meter.

3 STRESS-STRAIN CURVES OF CuZnAl SMA

In order to eliminate the influence of the clamping chuck, the tensile samples were prestretched 3 times in which the maximum strain is 1.0%. In the stress-strain curves, the area enclosed by hysteresis loop shows the energy consumed by the alloys.

3.1 Stress-strain curves of alloy 1

The stress-strain curves of alloy 1 and the area enclosed by the stress-strain curves are shown in Fig. 1 and in Table 2, respectively. After the samples were quenched in oil, water and 150 °C oil, with the ageing time prolonging, the area enclosed by hysteresis loop increases a lot, the residual deformation becomes larger and the super-plasticity gets better. That is to say, their hysteresis energy dissipation becomes better. After the samples were quenched in air, the area enclosed by hysteresis loop is the smallest. The microstructure of alloy 1 treated by air-quenching is not martensite but α+β phase, so it does not have SME. Though it has the area enclosed by hysteresis loop, the alloy can not make the structure reset after being heated and can not be used repeatedly. So, in terms of the ability of energy dissipation, oil quenching, water quenching and 150 °C oil quenching are beneficial to promote the damping performance.

3.2 Stress-strain curves of alloy 2

Alloy 2 was stretched repeatedly with equal strain. The areas enclosed by the force-deformation curves are shown in Table 3. After the samples were quenched in oil, water and 150 °C oil, with increasing the hysteretic cyclic time, the areas enclosed by hysteresis loop reduce gradually. At the first 10 cycles, the areas change greatly. After 10 cycles, they turn to be stable. The alloy treated by long-time ageing has worse pseudoelasticity and damping effect. Alloy 2 treated by air-quenching