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Design and preparation of Zn-based materials possessing both high damping and good mechanical properties①

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[Abstract] A new idea of design and manufacture of metal-based materials possessing both high damping and good mechanical properties was proposed. The key of the idea is the combination of fining restriction-damping structures, using all mechanisms and taking advantages of different materials. Based upon this idea a foam ZA27 was prepared by the technology of prefabricated salt-mass centrifugal seeping foundry, its tensile strength and compressive strength are 83~ 119 MPa and 100~ 189 MPa, respectively. The damping properties of the foam ZA27 increase remarkably after the carpenter pastern or rosin (the damping-increased materials) was immerged into it, which approaches to the level of viscous-elastic polymer materials ($Q^{-1} \geqslant 20 \times 10^{-3}$).

[Key words] foam metals; damping; mechanical properties; Zn-based alloys
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1 INTRODUCTION

A mechanical structure will vibrate and make noisy when it is excited. This not only affects the precision and life of the machine, but also harms people's heath. It is a very efficient method to use materials possessing both high damping and good mechanical properties, which are commonly called as structural-functional materials (SFM), for decreasing vibration and noise. In this paper, SFM based on the metal for decreasing vibration and noise has been investigated.

2 MATERIAL DESIGN

2.1 Theoretical analysis

In recent years many attempts aimed to greatly increase damping properties have been made by traditional methods, but less progress was made[1~ 7]. The author think that there are many differences between metals and viscous-elastic materials in the structure, which results in great differences in damping properties. Furthermore, these differences in the structure cannot be eliminated by alloying and heat-treating of traditional metal materials. Therefore damping properties of metals or alloys could not be greatly improved to reach the level of viscous materials by means of the traditional idea and method. Multi-phase composites made from different kinds of materials usually cause different amount of strain when the materials bear the same stress because of their different elastic modulus. Thus this will result in relative distortion and interface viscous flow, which will expend and absorb vibration energy. Consequently it would be the ultimate approach to take advantage of the different materials and compound them together in order to greatly increase damping properties.

The essence of damping is expending and absorbing vibration energy. Damping capability depends on numbers of mechanism, such as energy expend and absorption of per unit of volume and total volume that will expend and absorb vibration energy. Most traditional damping alloys only possess one mechanism, so their damping capability cannot be very high. If a metal or an alloy is made as the porous state and another viscous-elastic material is immerged in the porous metal or alloy, not only the energy expending mechanism of two materials can be used, but also damping mechanism can be used to the greatest extent. In fact the damping in this case is the superposition of multi-damping mechanisms. Therefore the author suggest that in the design of SFM the damping structure should be ultimately fined at first, and then all mechanisms should be integrally used.

2.2 Material preparation

In order to fine restriction-damping structures and use all mechanism and exert the advantage of different materials sufficiently, the key is to prepare the porous metal and compound damping-increasing materials into the metal. There are many methods to get the porous metal. The author adopted the foam metal. By means of the method, the foam metal possesses a higher porosity ratio, good connectivity and controllable size, and the processing of foam metal is relative simple and practical. Damping-increasing materials should also be easy to compound and have good effect.

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The selection of matrix is also an important problem. In the past the foam aluminum alloy was widely investigated, and the preparing technology has been mature[6]; but the foam aluminum alloy possesses a much lower strength, and is not suitable as a structural material. The high aluminum zinc-based alloys (ZA alloys) have been a promising engineering material recently selected as the matrix materials in this work because it not only has higher strength and good damping properties in nonferrous metals, but also possesses a lower melts point and better processing properties.

3 EXPERIMENTAL

3.1 Preparation of foam metal matrix

There are many methods for preparing foam metal matrix. The centrifugal-seeping foundry, in which the molten metal is poured into a prefabricated salt-mass by centrifugal force, is more practical and has been adopted in this paper. A sketch of it is shown in Fig. 1.

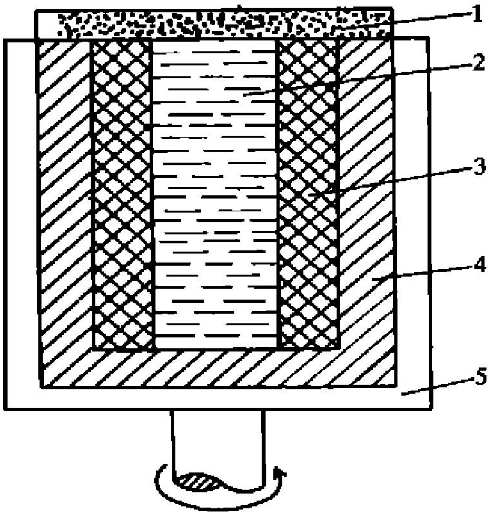

Fig. 1 Sketch of prefabricated salt-mass centrifugal-seeping foundry
1 —Coping; 2 —Molten metal; 3 —Salt-mass; 4 —Crucible; 5 —Centrifugal cylinder

The prefabricated salt-mass was prepared by sintering. The born material was the original salt that the crystal water has been removed and graded by sieves. The binder was KCl. The sintered salt-mass was put into centrifugal machine after it was heated into the molten salt-mass melt at 660~ 670 ℃ for 0.5 h, and then the molten metal was poured into the molten salt-mass melt at 660~ 670 ℃. After that, the machine rotates at the speed of 600 r/min for 4~ 5 min. Afterward the metal-salt mass was put into water and cooled to room temperature to remove salt, and then dried.

3.2 Damping-increasing materials

Many kinds of polymer materials have been tested as damping-increasing materials. The results show that an especial carpenter pastern and rosin have good effect. The pastern or rosin was melted and then the foam metal was immerged into it for 13~ 15 min. After that the foam metal was taken out and immediately immerged into water and held for 10~ 12 min. Then the foam metal was taken out and dried. It will be called mixture thereinafter.

3.3 Properties testing

The tensile strength and compressive strength of the foam metal matrix in cast and heat treatment state have been determined in order to evaluate mechanical properties of the mixture. The purpose of the heat treatment was to eliminate machining stress.

The non-contacted resonance method has been adopted in order to evaluate the damping properties of the mixture[8]. The size of specimen is 3 mm × 8 mm × 120 mm.

4 RESULTS

4.1 Main characteristic parameters

Aperture, hole ratio (see Table 1) and apparent density (see Table 2) are main parameters of the foam metal. The finer the salt granularity (mesh) is, the finer the aperture and the lower the hole ratio is. The apparent density here indicates the average density of the mixture. Its density is only 1/2~ 1/3 of the traditional casting ZA27, and is near to the traditional casting aluminum alloys.

Table 1 Main characteristic parameters of foam ZA27

Granularity (mesh)	6	12	28	45
Aperture/mm	0.61	0.52	0.42	0.31
Porosity ratio/%	62	57	49	44

Note: The granularity means the size of salt (the same below).

Table 2 Apparent density of foam ZA27

Granularity (mesh)	6	12	28	45
Aperture/mm	0.61	0.52	0.42	0.31
Apparent density/($g \cdot cm^{-3}$)	1.835	2.047	2.404	2.918

Note: The density of traditional casting ZA27 is about 5 g/cm^3.

4.2 Mechanical properties

The mechanical properties of the foam ZA27 are shown in Table 3. In order to compare them, the mechanical properties of some usual metals are shown in Table 4.

It is obvious that the tensile strength and compressive strength of the foam ZA27 is increasing with decreasing size of pores. The strengths of the foam ZA27 alloy are only 1/4~ 1/3 of the traditional casting ZA27, however its strengths are much higher than those of the foam aluminum alloy, and were close to the level of ZL102 alloy (T2 state). It may be used as a structural material like aluminum alloys.

Table 3 Mechanical properties of foam ZA27

Granularity (mesh)	As-cast		As-heat treatment*	
	Tensile strength /MPa	Compressive strength /MPa	Tensile strength /MPa	Compressive strength /MPa
6	83.4	100	81.0	89
12	96.2	124	91.3	106
28	105	168	104	154
45	119	189	109	187

* Heated at 250 ℃ for 3 h, and then cooled slowly in furnace.

Table 4 Mechanical properties of some usual metals[9, 10]

Materials	ZL102[1]	ZL104[2]	ZL108[3]	ZA27[4]	Foam aluminum alloy
Tensile strength/MPa	145	190	190	324	9.9

Superscript: 1—Permanent model, T_2 state; 2—Permanent model, T_1 state; 3—Al-12% Si, porosity ratio about 65%; 4—Sand model, heated at 320 ℃ for 3 h and then cooled slowly in furnace.

4.3 Damping properties

The determining results of the vibration attenuation and resonance frequency are shown in Fig. 2 and Fig. 3, respectively. The damping properties appreciably decline after heat treatment (in order to eliminate machining stress), however they remarkably increase after the damping materials have been immerged. The effect of carpenter pastern is better than that of rosin.

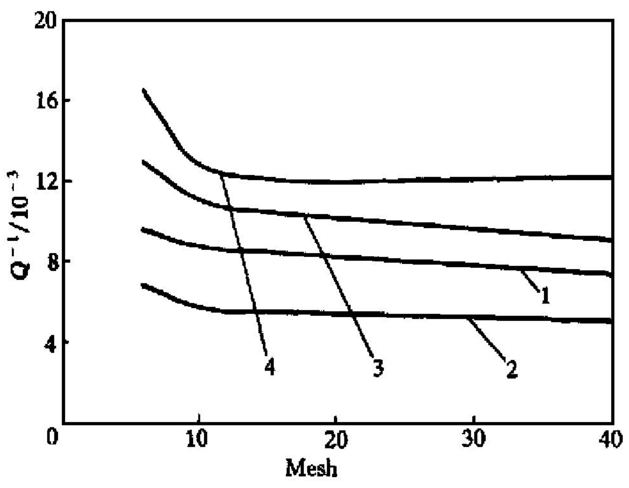

Fig. 2 Vibration attenuation of specimen
1—As cast; 2—Heat treatment; 3—Heat treatment+ rosin; 4—Heat treatment+ carpenter pastern

The investigation has shown that the value of vibration attenuation of the traditional casting ZA27 greatly decreases with the increasing of the resonance frequency. But the value of vibration attenuation of the mixture changes not so much when the resonance frequency increases markedly with decreasing of the size of pores. This indicates that the mixture possesses different mechanism of vibration attenuation compared with the traditional casting ZA27, and also indicates that the mixture is not sensitive to frequency change, but is fit for damping structural materials.

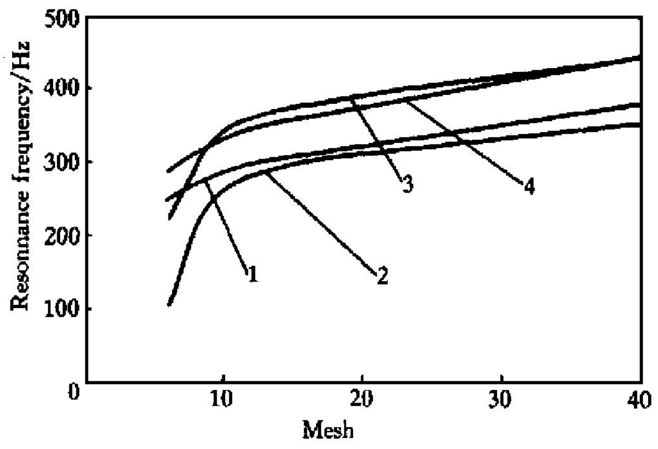

Fig. 3 Determined results of resonance frequency
1—As casting; 2—Heat treatment; 3—Heat treatment+ rosin; 4—Heat treatment+ carpenter pastern

The damping properties of different materials are shown in Table 5. It is obvious that the damping property of the foam ZA27 is one order higher than that of the traditional casting ZA27. The damping property of the foam ZA27 increases remarkably after the damping-increased materials were immerged into the foam ZA27 (namely the mixture), and the damping property is near to the level of viscous-elastic materials ($Q^{-1} \geqslant 20 \times 10^{-3}$).

Table 5 Damping properties of different materials

Materials	ZA27	Foam ZA27	Mixture	Viscous-elastic materials
$Q^{-1}/10^{-3}$	0.487	6.82	16.46	≥20

Note: Data of ZA27 according to Ref. [8], determining method and specimen size was basically the same as this paper; mixture was based on 0.61 mm and carpenter pastern (after heat treatment)

5 CONCLUSION

1) A new idea of design of metal-materials possessing both high damping and good mechanical properties was put forward. That is fining restriction-damping structure, using all mechanism and exerting the advantage of the different materials sufficiently.

2) The foam ZA27 has prepared by a prefabricated salt-mass centrifugal-seeping the foundry. Aperture and porosity ratio are 44%~62% and 0.31~0.61 mm respectively. The apparent density is about 1.8~2.9 g/cm³. The damping property of the foam ZA27 is one order higher than that of the traditional casting ZA27. The tensile strength and com-

pressive strength are 83~ 119 MPa and 100~ 189 MPa, respectively.

3) The damping properties of the foam ZA27 improved remarkably especial when the carpenter pastern or rosin has been immerged into, and here with whose damping properties were near to the level of viscous-elastic materials ($Q^{-1} \geqslant 20 \times 10^{-3}$).

4) The value of vibration attenuation of the mixture changes not so much when the resonance frequency increase markedly with decreasing of the size of pores. So it might be a perfect high damping structural materials.

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