THE BULLETIN OF OKAYAMA UNIVERSITY OF SCIENCE No. 41 A pp. 149-156 (2005)

Development of Zinc-Based Composites Having Good Damping and Mechanical Properties

Teruto Kanadani, Liu-Shuan Yang*, Keiyu Nakagawa and Goroh Itoh**

Department of Mechanical Systems Engineering, Okayama University of Science, 1-1 Ridai-cho, Okayama 700-0005, Japan

* *Department of Materials Engineering, Luoyang Institute of Technology, Luoyang 471039, P.R. China*

** *Department of Mechanical Engineering, Ibaraki University, Hitachi, 316-8511 Japan*

(Received September 30, 2005; accepted November 7, 2005)

Key words: composite material, foamed ZA27 alloy, carpenter plaster, resin, damping property, mechanical property

Abstract

A new idea on designing and producing metal-based composite materials having both high damping and good mechanical properties has been carried out. The key issue of the idea is (i) to select two high damping materials for the matrix phase that contributes to the mechanical properties and for the second phase that further raises the damping property, (ii) to utilize the microstructural effect by a fine dispersion of the second phase, and thus (iii) to harmonize the advantage of each phase material sufficiently. A zinc-based ZA27 alloy was melted and permeated into compressed salt-grain preform by means of centrifugal squeeze casting technique. The salt was rinsed out by water to obtain a foamed material.

The tensile and compressive strengths were 83-119 and 100-189 MPa, respectively. The damping property of the foamed material increased markedly, nearly to the level of visco-elastic polymer materials (damping, Q^{-1}, not less than 20×10^{-3}) after a carpenter plaster or rosin, the dispersing component, was infiltrated into the pore of the foamed material.

1. Introduction

A machine will vibrate and make noise during its use, which not only deteriorates its precision and lifetime but also harms human health. In order to minimize these detrimental effects, a very efficient method is to apply materials having both high damping and good mechanical properties to the structural components of the machine. Such materials can be referred to as structural damping materials (SDM), for designing and producing a machine structure.

Metals or alloys have usually good mechanical properties but poor damping properties compared to polymers. Although high damping alloys have better damping properties than those of common metals or alloys[1,2], their damping properties are still lower by 1 to 2 magnitudes than those of the visco-elastic materials. Thus they can be considered neither to be SDM's nor to be used when a great decrease in vibration is required. On the other hand, since polymers, especially visco-elastic materials, have good damping properties but poor mechanical properties, they cannot usually be used as structural materials. This paper describes the development of a new metal-based SDM for structural components where a reduction in both vibration and noise is required, in which composite materials consisting of a metallic matrix phase and of a visco-elastic polymer second phase have been prepared.

This paper was presented at the spring meeting of the Japan Institute of Metals, held in Yokohama, on March 29, 2005.

2. Material Design

2.1. Theoretical analysis

In recent years many attempts aiming at a great increase in damping properties have been made using traditional methods, but little progress has been made[1-3]. There are many inherent differences between metals and visco-elastic materials in the structure of atomic or molecular bonding, which results in great differences in damping properties. It is natural that these differences in structure cannot be eliminated by alloying and heat-treatment of traditional metallic materials. Therefore the damping properties of metals or alloys have not been improved greatly to reach the level of viscous materials by means of the traditional ideas or methods. It is widely known that resin concrete is a typical composite material that consists of two phases, namely., fine rock particles and a resin matrix, and has excellent damping properties. This is presumably ascribed to the microstructural damping mechanism besides the good damping properties of rock and resin themselves. Stress and strain are not uniform in a multi-phase composite consisting of different kinds of materials when a constant macroscopic stress is applied to the composite because of the different elastic moduli of the components. Thus this will result in distortion and interface viscous flow, which will absorb vibration energy. Consequently it would be the ultimate approach to produce a composite material consisting of two high damping phases in order to obtain a great increase in damping properties from the viewpoint of taking advantage of the component materials themselves and also of the dispersion effect of the second phase.

The essence of damping is absorbing vibration energy. Total damping capability of a material is the sum of the capability of each damping mechanism, such as dislocation damping, grain-boundary damping, damping caused by point defect diffusion, visco-elastic damping, etc. Since most traditional damping alloys have only one mechanism, their damping capability is limited. If a composite material consisting of a high-damping alloy and a visco-elastic polymer can be successfully produced, not only the damping mechanisms of the two separate materials but also the dispersion damping mechanism described above can be utilized to a great extent. The total damping in this case will be the superimposition of each damping mechanism. In this paper, the damping property will be characterized for such composite materials originally produced as a function of a microstructural parameter.

2.2. Material selection

In order to obtain a composite material as described above, a porous metal was prepared first and then a visco-elastic material that increases the damping was included into the pores of the metal. There are many methods to prepare a porous metal. The metal foaming method was adopted in this study. The foamed metal has high porosity, good connectivity and controllable pore size, and also the processing of foamed metal is relatively simple and practically feasible. Furthermore, the visco-elastic material can be included into the pores without difficulty and will have a good effect in increasing damping property.

The selection of the matrix is an important issue. In the past, the foamed aluminum alloys were widely investigated, and the preparation technology seems to have been mature. However, a foamed aluminum alloy has low strength, and hence is not suitable as a structural material in many cases. The zinc-based alloys (ZA alloys) with high aluminum content have become promising engineering materials in recent years because they have not only a higher strength and better damping properties, but also a lower melting point and hence better processing performances than aluminum alloys. Therefore, they are well suited to be the matrix metal, and thus ZA27, one of ZA series alloys, was selected as the matrix metal in this paper.

3. Experimental Procedures

3.1. Preparation of foamed metal matrix

There are several methods for preparing foamed metal matrix. The centrifugal squeeze casting, in which the molten metal is poured into a prefabricated sintered salt compact by centrifugal force, is practical and has been adopted in this study. A sketch of this is shown in Fig.1. The starting material was sodium chloride particles from which absorbed water was removed, and then the particles were sieved. The binder was potassium chloride. The salt compact was sintered at 660-670°C for 0.5 hr and then placed into a centrifugal machine. Next, the molten metal at 660-670°C was poured and rotated at a speed of 10 s^{-1} for 4-5 min in the centrifugal machine, by which the molten metal was included in the pores of the salt compact. Afterward, the metal/salt compound was transferred into water and cooled to room temperature to rinse out the salt, and then dried. In this way, the foamed metal was successfully obtained.

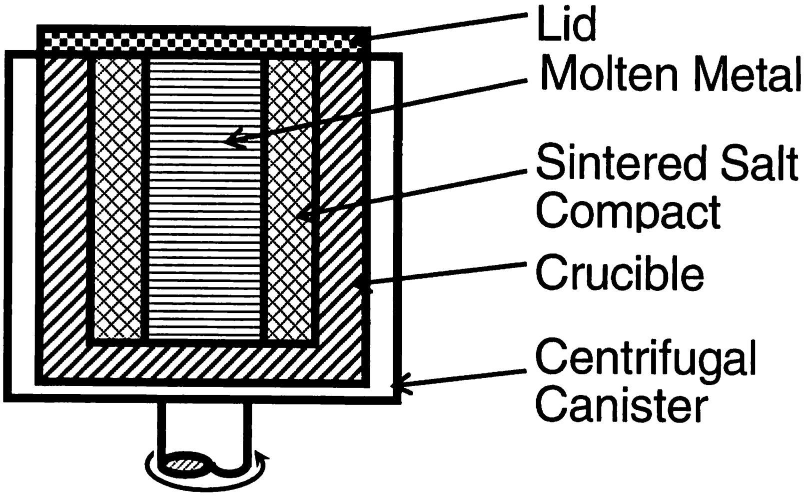

Fig. 1 Schematic drawing showing centrifugal squeeze casting system.

3.2. Compounding the foamed metal and visco-elastic material

Many kinds of polymer (visco-elastic) materials were preliminarily tested as the damping-increasing component of the composite material in this study. The results showed that a special carpenter plaster and rosin had good effect. The plaster or rosin was melted, poured into the centrifugal squeeze casting machine and then kept in a molten state for 13-15 min, which allowed the visco-elastic material to be compounded with the foamed metal. After that, the whole composite was removed from the crucible, water-cooled, kept in the water at room temperature for 10-12 min, taken out from the water and then dried.

3.3. Mechanical and damping tests

The tensile strength and compressive strengths of the matrix foamed metal in as-cast and annealed states were determined in order to correlate its mechanical properties with those of the composite. The annealing was made at 250°C for 3h followed by furnace cooling in order to eliminate the residual stress caused by machining.

Tensile test was carried out at room temperature using Instron-type tester at initial strain rate of $2\times10^{-4}s^{-1}$. The gauge dimensions of the specimen for tensile test were $8\times30\times3^{t}mm^{3}$.

A non-contact resonance method has been adopted to evaluate the damping properties of the composite. A schematic drawing of the measuring apparatus is illustrated in Fig. 2. The size of the specimen is $3\times8\times120$mm. A sine wave was sent by the signal generator and transferred to sensor (1) by instrument (1). The sensor (1) transformed the wave to alternate mechanical energy, which was used to cause the simple vibration. Then sensor (2) transformed the alternate mechanical energy back to an electric signal, which is transferred to instrument (2) after being magnified by the amplifier. The oscillograph can show the original and damped vibrations.

The changing frequency of the signal generator can bring about a resonance curve of the specimen. Then the specimen damping, Q^{-1}, can be derived from the equation,

$$Q^{-1} = \Delta f / (\sqrt{3} f_r) \quad (1)$$

where Δf and f_r are the half width and the resonance frequency of the resonance peak, respectively[1]. Although the Q^{-1} values measured by this method are not the intrinsic damping of the material, being affected by the specimen size and resonance frequencies, they are convenient and sufficient for assessing the difference in the damping property of different specimens within the present study.

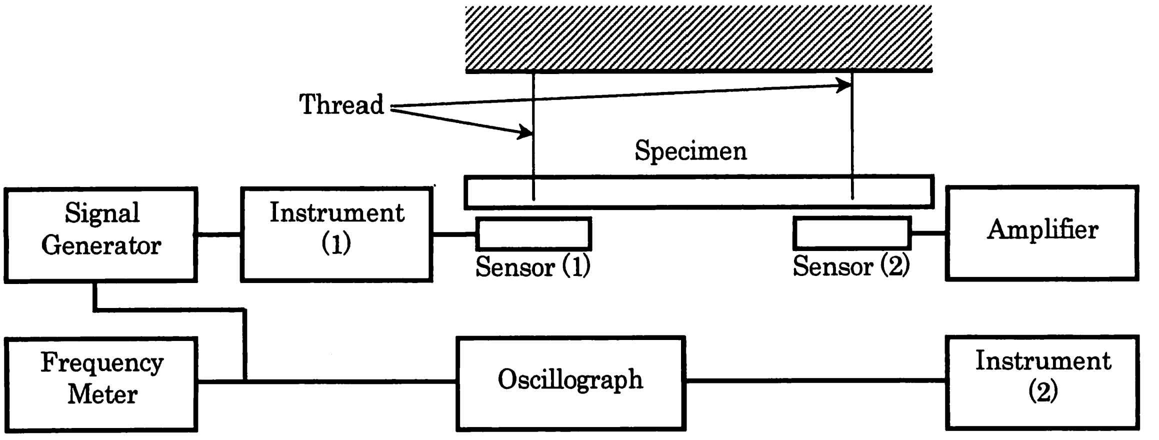

Fig. 2 Schematic drawing of the damping measurement apparatus (system).

4. Results and discussion

Porosity (volume fraction of pores) and apparent density of the foamed ZA27 alloy depended on the grain size of the starting salt particles, which are listed in Table 1. The finer the salt grain size, the lower the porosity and the greater the apparent density. Here, it is to be noted that the apparent density of the foamed alloy is only 1/2-1/3 of that of the traditionally cast ZA27 alloy, 5 $g \cdot cm^{-3}$, and is equal to or less than that of the traditional casting aluminum alloys.

The strength of the foamed alloy is shown in Table 2. For comparison, the tensile strength of some typical alloys is shown in Table 3.

It is obvious that the tensile and compressive strengths of the foamed ZA27 alloy increase with a decrease in the pore size or the porosity. Although the tensile strength of the foamed ZA27 alloy is only 1/4 to 1/3 of that of the traditionally cast ZA27 alloy, it is markedly higher than that of the foamed aluminum alloy, and is close to the level of ZL102 alloy. Thus the foamed ZA27 alloy can be used as a structural material like aluminum alloys.

Table 1 Main characteristic parameters of foamed ZA27 alloy.

ASTM grain number of the starting salt particles	6	12	28	45
Pore size (mm)	0.61	0.52	0.42	0.31
Porosity (%)	62	57	49	44
Apparent density ($g \cdot cm^{-3}$)	1.835	2.047	2.404	2.918

Table 2 Strength of foamed ZA27 alloy as a function of the grain size of the starting salt particles.

Grain size number	As-cast		Annealed*	
	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

Note: * Annealed at 250°C, for 3h and then furnace-cooled.

Table 3 Tensile strength of several typical alloys.

Material	ZL102*1	ZL104*2	ZL108*2	ZA27*3	Foamed Al-12%Si alloy*4
Tensile strength (MPa)	145	190	190	324	9.9

Note: *1 Cast in a permanent mold, and T2-treated[6].

*2 Cast in a permanent mold, and T1-treated[6].

*3 Cast in a sand mold, annealed at 320°C for 3 h and then furnace-cooled[7].

*4 Porosity, about 65%[8].

The results of the examination on the specimen damping and resonance frequency of the foamed ZA27 alloy and composite materials are shown in Figs.3 and 4, respectively, as a function of the size of the starting salt particle, i.e., pore size of the foam. Although the specimen damping appreciably declined by annealing, it is markedly increased by including the visco-elastic materials into the pores. It is to be noted that the effect of carpenter plaster is better than that of rosin.

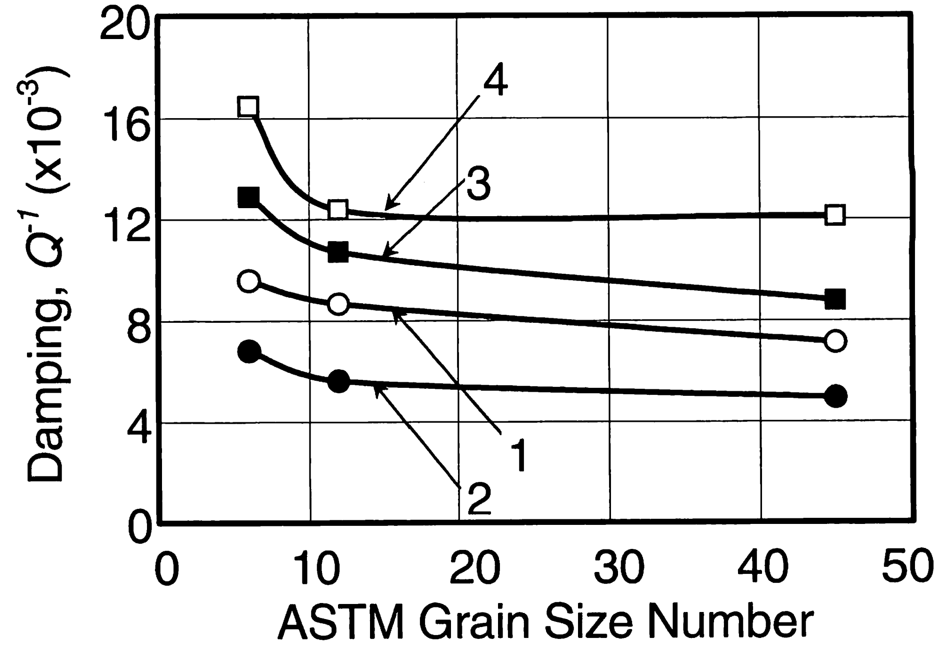

Fig. 3 Damping of the specimens correlated to the grain size of the starting salt particles.
1: As-cast; 2: Annealed; 3: Annealed and compounded with rosin; 4: Annealed and compounded with carpenter plaster.

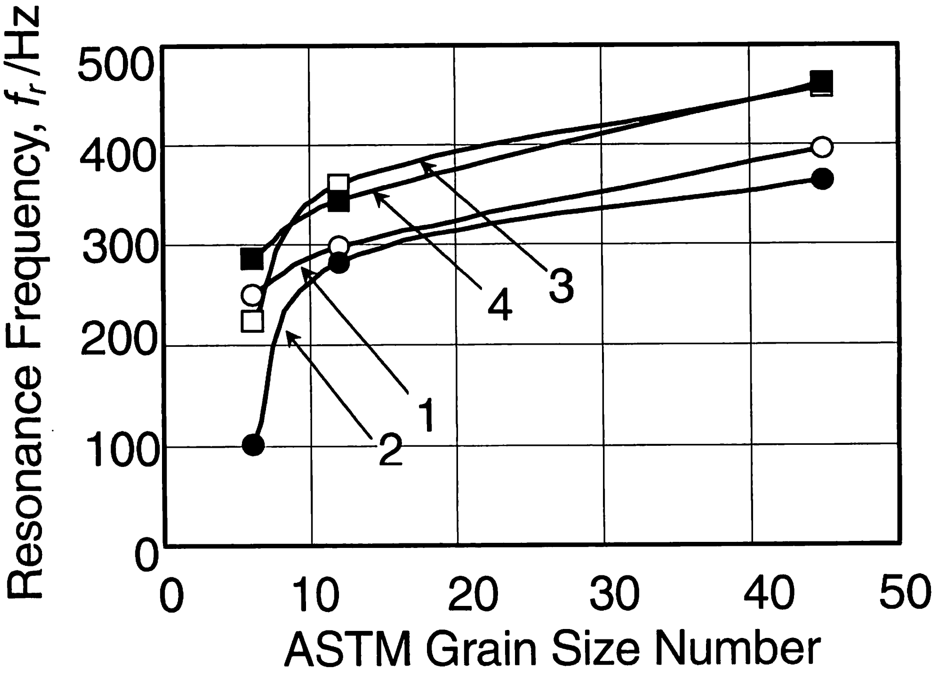

Fig. 4 Resonance frequency of the specimens correlated to the grain size of the starting salt particles. Specimen symbols are the same as in Fig. 3.

It is known that the damping of the traditionally cast ZA27 alloy sharply decreases with increasing resonance frequency[2]. However, the specimen damping of the composites as well as the foamed ZA27 alloy in the present study does not significantly change when the resonance frequency increases with decreasing pore size. This indicates that the composites as well as the foamed alloy have a different mechanism of damping from the traditionally cast ZA27 alloy, and also that the mechanism is not sensitive to frequency change.

The damping properties of different materials are shown in Table 4. It is obvious that the damping property of the foamed ZA27 is a magnitude higher than that of the traditional castings, and that it increases markedly by including the visco-elastic material to form the composite, as described above. The obtained damping property of the composite is close to the level of monolithic visco-elastic materials ($Q^{-1} \geq 20\times10^{-3}$). Considering the good damping property as well as the mechanical properties described earlier, the composite materials studied in the present paper are now regarded as excellent structural damping materials.

Table 4 Damping property of different materials.

Materials	ZA27[*1]	Foamed ZA27	Composite	Visco-elastic materials
Specimen damping Q^{-1} ($\times 10^{-3}$)	0.487	6.82	16.46	≥ 20

Note: [*1] Assessing method and specimen size is basically the same as in this paper[9].

[*2] The grain size number of the starting salt particles is 6 and carpenter plaster is contained after annealing.

5. Conclusion

A new idea of designing metal-based composites having both high damping and good mechanical properties was carried out in practice on a laboratory scale. The idea consists of refining damping microstructures, applying most of the damping mechanisms and sufficiently combining the advantage of each component material. Foamed ZA27 alloys prepared by a centrifugal casting technique using sintered preforms of salt particles were concluded to be more lightweight and a magnitude higher in damping than the traditional castings of the same alloy. A Further marked increase in damping was noted when the visco-elastic materials, namely. carpenter plaster or rosin, were contained into the pores of the foamed ZA27 alloys to convert them into composite materials. The resultantly obtained damping property was close to the level of visco-elastic materials ($Q^{-1} \geq 20\times10^{-3}$). Thus the obtained composite materials can be concluded to be excellent structural damping materials.

[REFERENCES]

1) I. G. Ritchie and Z-L. Pan: Metall. Trans., A, **22A**(1991) 607-616.

2) I. G. Ritchie, Z-L. Pan and F. E. Goodwin: Metall. Trans., A, **22A**(1991) 617-622.

3) Youyouke: Metals, (1990) (2) 13-16.

4) Da Jiuzheng: Metal Process, (1994) (6) 57-59.

5) Liu Yaowen: Light Metals, (1996) (9) 46-49.

6) "Casting Handbook—Casting Nonferrous Alloys—", Mechanical Industry Publisher, Beijing, China, (1993) 54-55.

7) "Casting Handbook—Casting Nonferrous Alloys—", Mechanical Industry Publisher, Beijing, China, (1993) 79.

8) Sha Quanyou: Thesis of Luoyang Institute of Technology, (1999) 76.

9) Liu Yaowen: Thesis of Luoyang Institute of Technology, (1996) 68.