Short Note

Vibration Damping Analysis of Cu-Sn/Carbon Fiber Sintered Composite Materials by Frequency Response Function of FFT Analyzer

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ABSTRACT
In recent years, in fields of an eco-friendly automobile, an advanced industrial machine, and a precision electronic device, controlling of vibration damping behavior of the sintered materials is required. In this paper, vibration damping analysis of Cu-Sn/Carbon fiber sintered composite materials was performed by frequency response function of FFT analyzer, and the results was compared with Cu-Sn/Graphite sintered composite materials.

Cu, Sn elemental powders and Carbon fiber were used as initial substances. The powders and the fiber were mixed and pressed into a plate shaped compact with 200 MPa. Using a vacuum furnace, the green compact was sintered at 825-1075°C for 1 hour. By changing the mixing ratio and the sintering temperature, some kinds of the composite material plates were prepared. For the composite material obtained, microstructure, Vickers hardness, compression strength and vibration behavior were investigated.

The composite materials were consisted from the crystal grain of 17-70 μm, and the mixed Carbon fiber were dispersed in the microstructure. Twin crystal was also found in the composite materials obtained. Vibration damping behavior of the Cu-Sn/Carbon fiber sintered composite material was affected by solubility element, grain boundary, dispersed Carbon fiber, and twin crystal in composite material.

KEY WORDS
vibration damping coefficient, FFT analyzer, lumped mass model, frequency response function, Cu-Sn/Carbon fiber sintered composite material

1 Introduction
In Recent years, with expansion of demand of sintered parts, the parts which take into account vibration damping properties is required, in addition to high strength and high precision. Especially, in sintering parts used for environment consideration car¹, high speed rail way², multiple functions industrial machinery³, and precise electronics device⁴, by watchwords of “optimization of clearance of mechanical parts and low friction” and “oil lessness and low wear”, the sintering parts which has “small and light” and excel vibration characteristics has been required. In this paper, vibration damping coefficient of Cu-Sn/Carbon fiber was investigated by frequency response function of FFT analyzer.

Based on above background, in our previous paper, for Cu-Sn porous sintered material⁵, Cu-Sn/Al₂O₃⁶ and Cu-Sn/Graphite⁷ sintered composite materials, vibration damping analysis has been investigated. From the investigations, vibration damping behavior of porous Cu-Sn materials depend on fluid included in sintered material as well as inter friction of sintered materials. And, vibration damping behavior of the sintered porous material is affected by shapes of pore and open porosity⁸. On the other hand, for Cu-Sn/Al₂O₃, Cu-Sn/Graphite sintered composite materials, vibration damping coefficient was depended on the mixing ratio of disperse particle, and twin crystal is introduced in the Cu-Sn matrix phase cause by interface energy between matrix phase and disperse particle, and it was found that vibration damping behavior of Cu-Sn/Al₂O₃, Cu-Sn/Graphite sintered composite materials was affected by the twin crystal of Cu-Sn matrix phase⁹,¹⁰. However, effect of shape of dispersed particle is not clear yet. By addition of Carbon fiber into Cu-Sn matrix, it is expected that vibration damping behavior of sintered composite material is able to be control widely. Therefore, vibration damping analysis of Cu-Sn/Carbon fiber sintered composite materials was investigated by Frequency Response Function of FFT analyzer.

In industrial view point, Fe base sintered materials are used much more than Cu base one. Furthermore, as Cu-Sn alloy is used for spring material and electric contact material such as a
relax and a switching device, Cu-Sn alloy is not used as vibration damping material generally. However, vibration damping behavior of Fe base sintered material was affected by a little difference in the constitution such as sintering atmosphere, heat history, and microstructure. Therefore, high level technique is needed for measurement of vibration behavior. On the other hand, Cu-Sn alloy has high ability of sintering and capability of microstructure controlling. Therefore, in Cu-Sn base composite material vibration damping behavior is easy to measure clearly. Therefore, as experimental model materials for vibration damping analysis, vibration damping analysis of Cu-Sn/Carbon fiber composite sintered materials were measured by frequency response function of FFT analyzer in this investigation.

For vibration damping properties and microstructure of metal materials, already some investigation has been reported. For example, H. Miura, Y. Itou, Y. Tokunaga was investigated inter friction of sintered iron by transverse vibration method and discussed amplitude of vibration, and damping mechanism\(^9\). K. S. Umashankar, A. Abhinav, K. V. Gangadharan and D. Vijay investigated damping behavior for casted Al and sintered Al using attenuation wave train of a cantilever\(^9\). Y. F. Lugovskoi, L. I. Chernyshev measured vibration damping behavior of sintered high porosity materials and fiber mixed composite materials by vibrator and optical displacement gage\(^10\). S. Asano, T. Amaki investigate change of vibration damping behavior with strengthen treatment of Al and Al alloy using transverse vibration method\(^11\). These accurate and excellent investigations have been cleared vibration damping behavior of metal materials, and contributed to development of new products and materials development.

In recent year, with development of measurement technology, in the field of vibration analysis, a FFT analyzer have been used for vibration investigations. By using a FFT analyzer, vibration damping behavior of composite materials be able to be measure clearly. Therefore, vibration damping analysis of Cu-Sn/Carbon fiber composite sintered materials was measured by frequency response function of FFT analyzer. Furthermore, the results were compared with previous results of Cu-Sn/Graphite in this paper.

### 2 Experimental procedure

**2.1 Preparation of Cu-Sn/Carbon fiber sintered composite materials**

Pure Cu powder (Average particle size 36 μm, Fukuda metal Foil & Powder), pure Sn powder (Average particle size 38 μm, Kojundo Chemical Laboratory), and Cabon fiber (Average fiber length 130 μm, Toray) were used as initial substances. The powders and fiber were mixed, and Cu/Sn/Carbon fiber premixed powder was prepared. The mixing ratio of Cabon fiber were set to 5%, 10% as same manner of the previous paper\(^6,7\). These premixed powder was pressed with 200 MPa, and plate shaped compacts of \(L = 120 \text{ mm}, W = 20 \text{ mm}, t = 10 \text{ mm}\) were made. The compacts were put into a vacuum furnace, and were evacuated up to \(5 \times 10^{-4} \text{ Pa}\) vacuum degree using diffusion pump. The green compact was heated with 10°C/min. from room temperature to sintering temperature, and was kept in sintering temperature for 60 min. Fig. 1 shows the sintering temperature for Cu/Sn/Carbon fiber premixed compacts. The sintering temperature was controlled within 800-1075°C according to solidus line in Cu-Sn phase diagram\(^5\). For the Cu-Sn/Carbon fiber composite materials obtained, measurements of densities, microstructure observation, micro Vickers hardness testing, compression test, and vibration damping test were performed. The vibration damping testing of the test piece by a FFT analyzer was performed as same method of previous paper\(^6,7\). And, for the value measured by the FFT analyzer, the damping coefficient was calculated as same manner of previous paper\(^6,7\).

### 3 Results and Discussion

Fig. 2 shows relative density of Cu-Sn/Carbon fiber sintered composite materials. In the figure, relative density of Cu-Sn/Graphite sintered composite materials obtained from our previous paper was also indicated for comparison\(^2\). As the sintering was performed with vacuum atmosphere of conventional normal sintering, the sintered Cu-Sn/Carbon fiber composite materials had the low densities a little. However, the density of Cu-Sn/Graphite sintered composite materials achieved to 80-93%, and was similar to one of the Cu-Sn/Carbon fiber composite materials. The damping coefficient of Cu-Sn porous materials depend on the relative density of the sintered material. However, as discussed in our previous paper, the damping coefficient of Cu-Sn porous materials affected by open pore and close pore ratio, and it is able to be thought that the present density of Cu-Sn/Graphite sintered composite materials did not greatly affect the damping coefficient of sintered material. Therefore, the present sintered Cu-Sn/Carbon fiber materials was used for vibration damping test.
Fig. 3 shows microstructure of Cu-Sn/Carbon fiber composite sintered materials. The composite materials were consisted from the crystal grain of 17-70 μm, and the mixed Carbon fiber were dispersed in the grain and grain boundary. Twin crystal was also found in the composite materials obtained.

Fig. 4 shows Vickers hardness of Cu-Sn/Carbon fiber composite sintered materials. In the figure, Vickers hardness of sintered Cu-Sn alloy was also indicated\(^6\). The testing was performed under the
next conditions i.e. Load: 50 g, Loading time: 30 s, Repeat times: 5. Vickers hardness of Cu-Sn/Carbon fiber composite sintered materials was measured at random points in the matrix phase. The indentation size in Vickers hardness test was about 30-40 μm, and the hardness indicates average value in the matrix phase. Vickers hardness increased with Sn addition into Cu\(^6\)\(^7\). However, addition of the carbon fiber brought decreasing of Vickers hardness. The relative density of the composite material was reduced by addition of Carbon fiber, and the density affected Vickers hardness of the composite material. However, as shown in Fig. 3, with increasing of addition of Carbon fiber, amount of the twin crystal was decreased, therefore, we considered that Vickers hardness of the composite material was decreased.

As well known, the Vickers hardness is related to plastic deformation of the material. Therefore, Vickers hardness is used as an index of a plastic deformation ability of the material. To improve plastic deformation ability of the material, anneal treatment is frequently performed in the material process, and hardness of the material is lowered. However, in the case of materials such as Cu and Ni, twin crystal grows in the annealing treatment. As the twin crystal is one kind of material defect, the twin crystal affects to the plastic deformation ability of the Cu or Ni material. In the sintered Cu material, by deformation of the Cu powder in the compaction process, twin crystal frequently grows in the microstructure as shown in Fig. 3. Therefore, increasing of addition of Carbon fiber, amount of the twin crystal was decreased, and we considered that Vickers hardness of the composite material was reduced.

Fig. 5 shows compressive stress-strain curves of the Cu-Sn/Carbon fiber composite sintered materials. The compressive strength was increased with addition of Sn into Cu matrix. However, strength of the composite materials did not change with addition of a fiber. It was suggested that the strength of the composite materials

![Fig. 5 Stress-strain curves of Cu-Sn/Carbon fiber sintered composite materials.](image_url)

![Fig. 6 Frequency response function of Cu-Sn/Carbon fiber sintered composite materials.](image_url)
depended on the Cu-Sn matrix.

Fig. 6 shows frequency response function of the Cu-Sn/Carbon fiber sintered composite material. In the figure, (a) is the effect of the Sn addition, and (b) indicates effect of the carbon fiber addition. Characteristic vibration frequency of the composite material decreased with addition of Sn. Though, Plastic deformation resistance is risen with Sn addition as shown in Fig. 8. However, as spring rate constant, namely Young’s modulus of the composite materials fell down, it was considered that the characteristic vibration frequency decreased with addition of Sn.

On the other hand, in case of addition of Carbon fiber, characteristic vibration frequency of the composite material also decreased with addition of Carbon fiber. As shown in Fig. 7, phase boundary of Cu-Sn matrix and fiber doesn’t stick because wettability between Cu and carbon is poor. Therefore, it was considered that Young’s modulus of the composite material fell down and characteristic vibration frequency of the composite material decreased. For each test piece, only single resonance peak was found in frequency range of 1kHz below, and it was found that vibration mode of the test piece indicated first mode.

Fig. 7 shows vibration damping coefficient of Cu-Sn/Carbon fiber composite materials. In the figure, vibration damping coefficient of Cu-Sn/Graphite composite materials was also indicated. Vibration damping coefficient of Cu-Sn/Carbon fiber composite materials were increased with addition of Carbon fiber. In case of Cu-Sn/Graphite composite materials, addition of graphite particle in Cu-10 mass% Sn caused decreasing of vibration damping coefficient. However, vibration damping coefficient of Cu-10 mass% Sn/Carbon fiber composite materials increased with addition of the Carbon fiber.

Fig. 8 shows grain sizes of the Cu-Sn/Carbon fiber composite materials and Cu-Sn/Graphite composite materials. In the figure, grain sizes of Cu-Sn/Graphite composite materials were also indicated. Both grain-sizes are same mostly. It is considered that...
there is no effect against vibration damping coefficient.

Fig. 9 shows length of twin crystal of the Cu-Sn/Carbon fiber composite materials and Cu-Sn/Graphite composite materials. However, vibration damping coefficient of the Cu-Sn/Carbon fiber composite materials and Cu-Sn/Graphite composite materials did not depend on length of twin crystal. Therefore, the vibration damping coefficient had no connection with the size of twin crystal.

Fig. 10 shows number of twin crystal of the Cu-Sn/Carbon fiber composite materials and Cu-Sn/Graphite composite materials. Using optical microscope, number of twin crystal was measured in area of 200 × 150 μm in the composite materials. As shown in the figure, vibration damping coefficient depend on number of twin crystal. Therefore, addition of Carbon fiber into Cu-Sn matrix brought to twin crystal by interface energy between dispersed particle and matrix phase, and it is considered that vibration damping coefficient depend on twin crystal of matrix Cu-Sn. Additionally, vibration damping coefficient of Cu-10 mass% Sn/Carbon fiber composite materials increased with addition of the Carbon fiber. As shown in Fig. 3, in the case of Cu-10 mass% Sn/Carbon fiber composite materials, Carbon fiber dispersed in fine grain of Cu-Sn matrix phase. Therefore, it was considered that friction between Carbon fiber and Cu-Sn matrix phase affected the vibration damping coefficient of Cu-10 mass% Sn/Carbon fiber composite materials.

4 Conclusion
(1) In this paper, vibration damping coefficient of Cu-Sn/Carbon fiber was measured using frequency response function of FFT analyzer.
(2) By controlling amount of Sn into Cu and sintering temperature, Cu-Sn/Carbon fiber composite materials were able to be fabricated.
(3) Deformation resistance of Cu-Sn matrix increased with addition of Sn. However, stress-strain curve of Cu-Sn/Carbon fiber composite materials did not change with Carbon fiber addition.
(4) Characteristic vibration frequency of Cu-Sn/Carbon fiber sintered composite material fell with addition of Sn and Carbon fiber, because the Young’s modulus of Cu-Sn/Carbon fiber composite materials was reduced by addition of Sn and Carbon fiber.

(5) Vibration damping coefficient of Cu-Sn/Carbon fiber composite materials increased by addition of Carbon fiber. It is considered that addition of Carbon fiber introduced twin crystal into Cu-Sn matrix, and the twin crystal increased vibration damping coefficient of Cu-Sn/Carbon fiber composite materials.

(6) In the case of Cu-10 mass% Sn/Carbon fiber composite materials, Carbon fiber dispersed in fine grain of Cu-Sn matrix phase. Therefore, it was considered that friction between Carbon fiber and Cu-Sn matrix phase affected the vibration damping coefficient of Cu-Sn/Carbon fiber composite materials.

References