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Mechanical and Damping Properties of Metallic Closed Cellular Materials Containing Organic Materials.

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A metallic closed cellular material containing organic materials for the smart materials has been developed. Powder particles of polystyrene coated with a nickel-phosphorus alloy layer using electro-less plating were pressed into green pellets and sintered at high temperatures. The metallic closed cellular material containing organic materials was then fabricated. On the fabricated metallic closed cellular materials, the cross-section was observed by a scanning electron micro-scope and the materials inside was analyzed by the laser Raman spectroscopy. Compressive test and measurement of internal friction were performed. The material inside the cells was seemed to be soot like carbon. The compressive tests showed that this material has the different stress-strain curves among the specimens that have different thickness of the cell walls. Each stress-strain curve has a long plateau region, the sintering temperatures of the specimens affect the compressive strength of each specimen, and energy absorbing capacity is very high. Young's modulus of this material depends on the thickness of the cell walls and the sintering temperature. Internal friction of this material is very large and depends on the sintering temperature. These results indicate that this metallic closed cellular material can be utilized as energy absorbing material and passive damping material.

Keywords: Metallic closed cellular material, energy absorbability, smart structure, electro-less plating, sintering, isostatic pressing, internal friction.

1. INTRODUCTION

Many current researches have been studied to develop the intelligent materials, smart materials and smart structures. Particularly, passive and active damping functions are becoming increasingly important in terms of vibration control of the structures and energy absorbing system has been required to protect persons from injury during impact of accident. Therefore, these materials, which have high-energy absorbability and damping function are required.

Recently, cellular materials are receiving renewed attention as structural and functional materials. Cellular materials have unique thermal, acoustic and energy absorbing properties that can be combined with their structural efficiency[1]. Therefore, many kinds of cellular materials have been tested as energy absorbing and damping materials. Particularly, the closed cellular materials are thought to have many favorable properties and applications. However, there is a lack of technique to produce such fine closed cellular materials except for the gas forming [2-7], the sintering of hollow powder particles[8,9] and the two-dimensional honeycomb structures[1]. Therefore, authors have developed a fabrication process of metallic closed cellular material containing organic materials for the intelligent materials or smart structures[10].

In this study, a metallic closed cellular material containing organic materials has been fabricated. The cross-section of this materials was observed and the materials inside was analyzed. The physical, mechanical ultrasonic, and damping properties of this closed cellular material containing organic materials are measured. And the effects of sintering temperature and thickness of the cell walls on the mechanical properties have been analyzed. The utility of this material is also discussed.

2. CONCEPTUAL PROCESS

The metallic closed cellular material fabricating process is shown in Fig. 1. The process is as follows: 1) Powdered polymer particles are coated with a metal layer using electro-less plating. 2) The powder particles are pressed into pellets (green compacts) by cold isostatic pressing. 3) After sintering at high temperature in a vacuum, the closed cellular material is produced.

3. EXPERIMENTS

3.1 Preparing the metallic closed cellular material

A thermal plastic polymer, polystyrene, particles of 10 μm diameter (Japan Synthetic Rubber Co., Ltd.) was selected for this study. These polystyrene particles were coated with 0.19μm - 0.52 μm thick nickel-phosphorus alloy layers using electro-less plating. These particles were pressed into pellets (green compacts) with about 8 and 16 mm diameters and 8 mm long by isostatic pressing at 200MPa and 90 °C. After this, these green compacts were sintered for 1 h at 800°C and 850°C in a vacuum. Then metallic closed cellular materials containing organic materials were fabricated.

3.2 Characterization

The microstructure of the powder particles, the green compacts before sintering, the cross-sections after

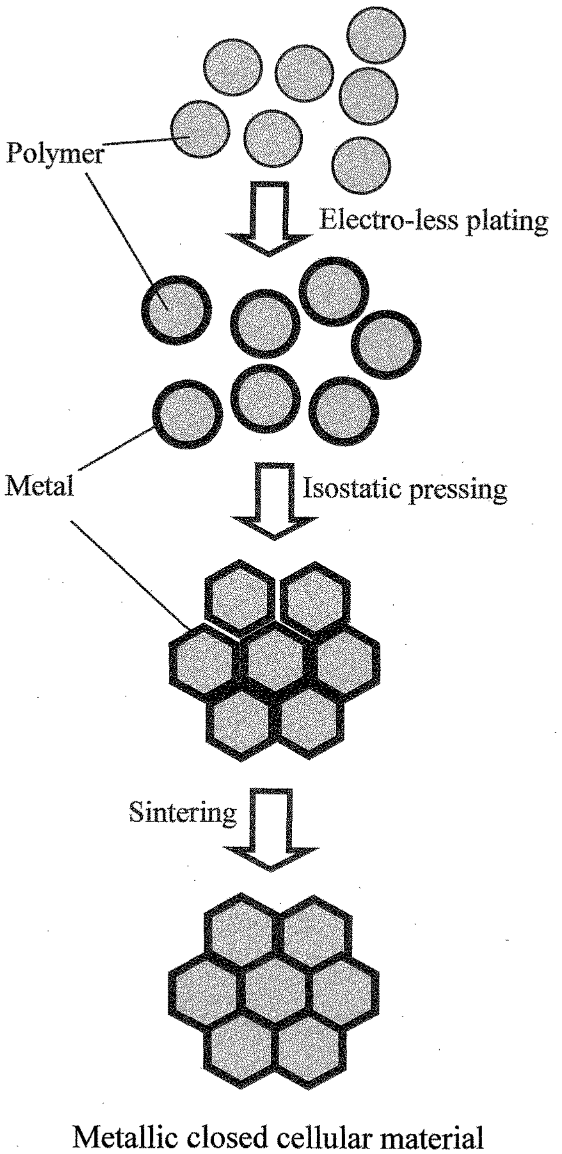

Fig. 1 Flow diagram of metallic closed cellular material fabricating process

sintering and fracture surface were observed using a scanning electron microscope (SEM) and the material inside the cell was analyzed using laser Raman spectroscopy. To observe the cross-section of this material, the specimen was cut and the cross-section surface was polished using emery paper (#600) and then 0.05μm Al_2O_3 powders. To measure the mechanical properties, compressive tests were performed at room temperature. In addition, damping tests were carried out to estimate the internal friction of this material. The measurement was carried out using an about 1.0mm thickness plate-type specimen and a free resonance vibration-type equipment (JE-RT, Nihon Techno-Plus Co., Ltd.). The internal friction was calculated by the half width method.

4. RESULTS

4.1 Micro-structural observation

Figure 2 shows an SEM image of the polystyrene powder particles coated with Ni-P alloy layers and Fig. 3 shows an SEM image of the green compact after cold isostatic pressing. The polystyrene particles were deformed to polyhedrons by isostatic pressing. The surface of the polystyrene particles coated with the nickel-phosphorus alloy exhibited facets. An SEM image of the cross-section of this material after sintering at 800°C is shown in Fig. 4. In this figure, the cell walls of the nickel-phosphorus alloy are observed as bright parts and the material inside the cell walls is observed as the darker parts.

Figure 5 shows the result of the laser Raman spectroscopy. Figure 5 (a) shows the laser Raman analysis result of each point and Fig.5 (b) shows the reference data of soot, polysthrene and grafite. These result shows that the material inside the cell is soot like carbon.

4.2 Compressive test

Compressive tests were carried out at room temperature. A typical example of the compressive test results is shown in Fig. 6 (a) and (b). Figure 6 (a) shows stress-strain curves of the specimens sintered at 800°C and Fig. 6 (b) shows stress-strain curves of the specimens sintered at 850°C. The stress-strain curve shows a linear elastic region, a long plateau where the stress gradually increases and a wavy region where the stress repeatedly decreases and increases. A specimen sintered at 850°C has higher strength than that of specimens sintered at 800°C.

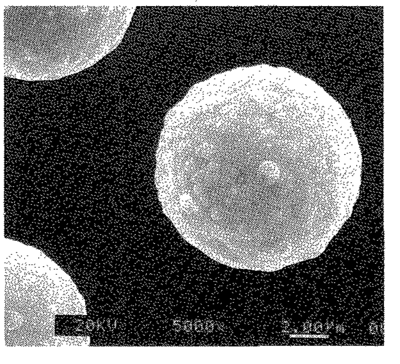

Fig.2 SEM image of polystyrene particles coated with Ni-P alloy layer.

4.3 Damping measurement

The internal friction of this material is measured by a free resonance vibration-type equipment. Figure 7 shows one example of the result of the internal friction measurement. The internal friction was calculated by half-value method. The internal friction of this material is 4.25 x10^{-3} (sintered at 850℃) and 5.41x10^{-3} (sintered at 830℃). To compare with these results, the internal friction of pure aluminum was measured and its value was about 5.25x10^{-3}. These results suggest that the internal friction would decrease as the sintering temperature increases.

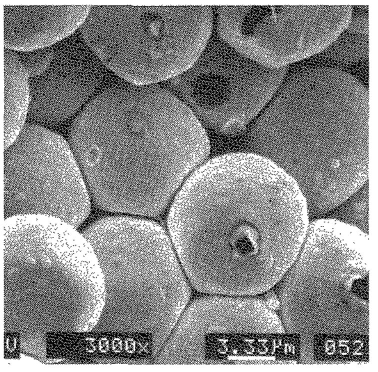

Fig.3. SEM image of green compact after isostatic pressing.

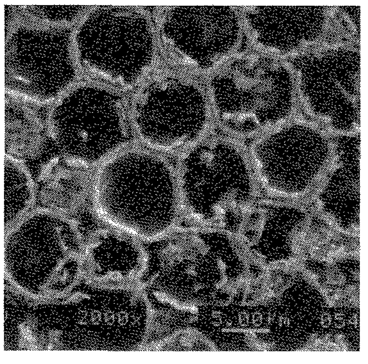

Fig. 4. Cross-section of the metallic closed cellular material.

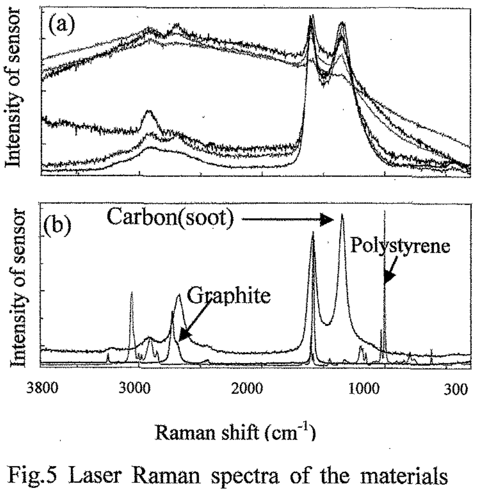

Fig.5 Laser Raman spectra of the materials inside cell walls.

5. DISCUSSION

5.1 Metallic closed cellular material

A metallic closed cellular material has been fabricated in this study. The density of this material was from 2.2 g/cm^3 to 3.1g/cm^3 , which was smaller than or same as that of an aluminum . As Fig. 3 shows, the polystyrene particles were deformed to polyhedrons by isostatic pressing.

Figure 4 shows that cell walls of a nickel-phosphorus alloy are observed as bright parts and the material inside the cell walls is observed as darker parts. Unfortunately, the result of the laser Raman analysis shows that the polystyrene was carbonized during heating. This result indicates that the organic material remains inside of the cell walls after heat treatment and this metallic closed cellular material containing the organic material can be produced using this technique.

5.2 Energy absorption

As shown in Fig. 5, the stress-strain curve has a linear elastic region, a long plateau region and a wavy region. It seems that the presence of the plateau in the compressive stress-strain curve is responsible for the high energy absorption. Therefore, this metallic closed cellular material seems to have high-energy absorbing capacity. These results show that this material can be utilized as an energy absorbing material.

After the linear elastic region, a few cracks occur in the direction parallel to the stress axis. It is postulated that the fracture initiates from a defect in this material. Therefore, if this metallic closed cellular material has only few defects, the plateau area of the stress-strain curve will continue longer during the compressive test. The compressive stress of the specimens sintered at 850℃ is higher than that of the specimens sintered at 800℃. It should be thought that the specimen sintered at 850℃has fewer defects than specimen sintered at 800℃.

5.3 Young's Modulus

Young's modulus of this material was measured using the data in linear elastic region for each specimen, and the relationship between Young's modulus and thickness of the cell walls of this material is shown in Fig. 8. The relationship between Young's modulus and sintering temperature is also shown in this figure. As the thickness of cell walls increases, the Young's modulus of the specimens increases. Therefore, Young's modulus of the specimens depended on the thickness of the cell walls of the specimen. The thickness of the cell walls of this material can be controlled by metal coating process. Therefore, Young's modulus of this material can be controlled by changing the thickness of the cell walls and the sintering temperature.

5.4 Internal friction

The internal friction of this material ($4.25\ x10^{-3}$ (sintered at 850℃) and $5.41x10^{-3}$ (sintered at 830℃)) is the same as pure aluminum (about $5.25x10^{-3}$). These results suggest that this material can be utilized as a passive damping material. In addition, as the sintering temperature increases, the internal friction would decrease. Therefore, the internal friction of this material can be controlled by changing the sintering temperature. The results of the compressive tests show that the yield stress and Young's modulus is lower than that of another structural metal. As shown in Fig. 6 and Fig. 8, the yield

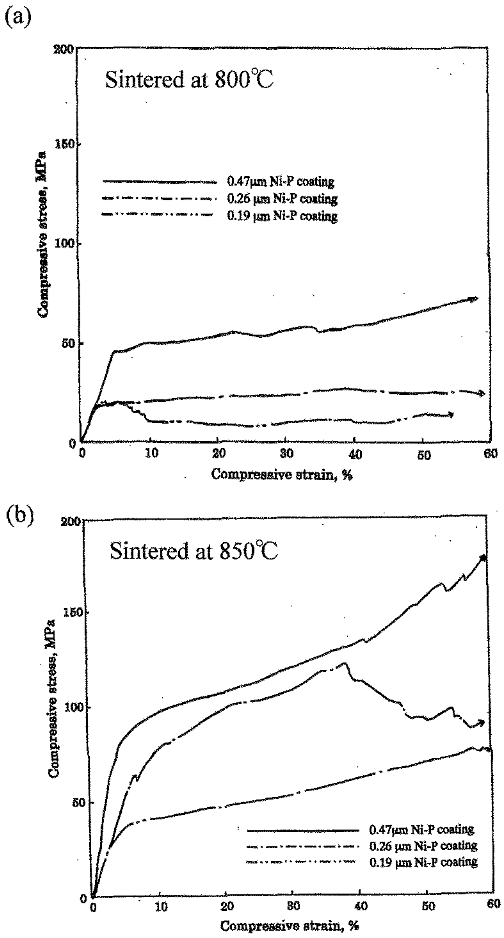

Fig. 6. Compressive stress-strain curve for metallic closed cellular materials; (a) sintered at 800°C and (b)sintered at 850°C.

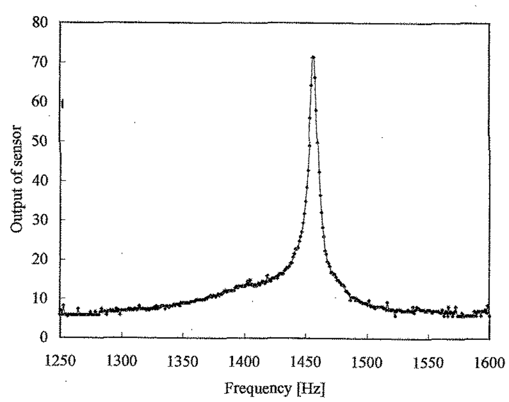

Fig.7. Relationship between the frequency and the intensity of the sensor.

stress and the Young's modulus of this material can increase by changing the thickness of the cell walls and sintering temperature. Therefore, the suitable conditions to fabricate a strong and stiff closed cellular material, which has a high damping capacity, would be found.

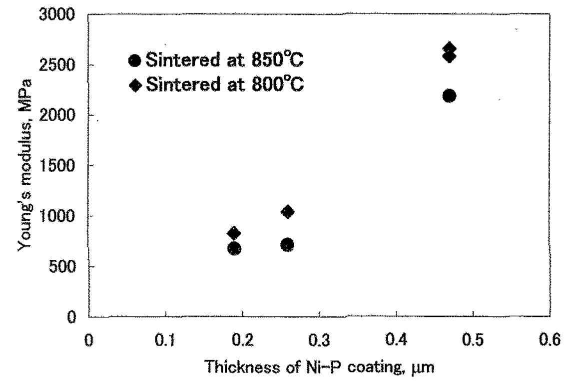

Fig. 8. Relationship between thickness of the cell walls and Young's Modulus of closed cellular materials.

6. CONCLUSION

A metallic closed cellular material containing organic materials has been developed. This metallic cellular material was light and had high-energy absorption and large internal friction. Young's modulus depended on the thickness of the cell walls of the specimen and sintering temperature. The obtained results emphasized that this metallic closed cellular material can be utilized as the energy absorbing material and passive damping material.

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