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Mechanical Properties and Machinability of Extruded Cu-40%Zn Brass Alloys with Bismuth via Powder Metallurgy Process†

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Abstract

In this paper, the uniform distribution process of bismuth particles in Cu-40Zn brass alloy by powder metallurgy (P/M) and machinable lead-free P/M brass with bismuth are described. Cu-40Zn Brass with bismuth powders produced by the rapid solidification processing were used as raw materials, having mean particle sizes of 150 µm. Three kinds of billets were prepared for the extrusion, namely green compact, sintered billets by using spark plasma sintering (SPS) and cast ingot. Bismuth dispersed in brass powder formed grains and dissolved into the powder surface by the heat treatment at the temperature over the melting point of bismuth. The behavior of bismuth existing in the primary particle boundary caused a decrease in the elongation of the extruded brass. Drill cutting ability was improved for the extruded material with the continuous machining chip. The shape of the machining chip was affected by the combination of brass matrix and the distribution of bismuth.

KEY WORDS: Cu-40Zn Brass, Lead-free, Bismuth, Machinability, Machining chip

1. Introduction

Cu-Zn alloy (brass) is widely used as an industrial material because of its excellent characteristics such as high corrosion resistance, non-magnetism, and good forginability. In particular, machinable brass is obtained by adding lead [1, 2]. However, it is necessary to reduce the quantity of the lead in the material from a viewpoint of the hazardous effects on the environment and humans [3, 4]. The addition of bismuth (Bi), silicon (Si), selenium (Se), and graphite to brass alloys as alternative elements to lead have been discussed to improve machinability [5)-7)]. The quantity of Bi dissolved in copper is 0.5 wt%, similar to lead, and the adverse effect on the human body from Bi is small. However, Bi disperses as several tens of microns in brass cast ingot shown in Fig.1. Therefore, the machinability of brass with Bi is inferior to that with lead[8)], and cracks are generated from Bi particles in the secondary phase. In this paper, the uniform distribution of Bi particles in the brass alloy by powder metallurgy (P/M) was examined to develop machinable lead-free brass. Brass alloy powder supersaturated with Bi by the rapid solidification processing was produced. Fine Bi particles were dispersed uniformly in the brass matrix by the deposit of Bi during billet molding and hot extrusion process. The mechanical properties and machinability of P/M extruded brass dispersed with Bi particles were investigated.

2. Experimental procedure

A flowchart describing the preparation of brass alloys in this study is shown in Fig.2. Brass powder, used as raw material, was prepared by the water atomization using Cu-Zn40 brass ingot with Bi additions. It had a mean particle size of 150µm. The Bi additions to brass alloy were 0, 1.0, 2.2, 2.62, 2.91, 3.23 and 5.0wt%. The thermal behavior due to microstructure changes of the as-received powder during annealing was investigated by differential thermal analysis (DTA) and thermo-gravimetric analysis (TG) (DTG-60: SHIMADZU Co.) under a heating rate of 10 K/min and 2 K/min in Ar gas atmosphere from room temperature up to 1273 K.

Spark plasma sintering (SPS: SPS SYNTEX INC., SPS-1030) and green compaction were used to consolidate the powder. In the case of SPS, the condition for consolidating the high-density sintered compact was selected using the temperature of 1053 K for 1.8ks under 40MPa pressure in vacuum [9)]. On the other hand, the conventional cold compaction was employed by applying a pressure of 600 MPa at room temperature by using the

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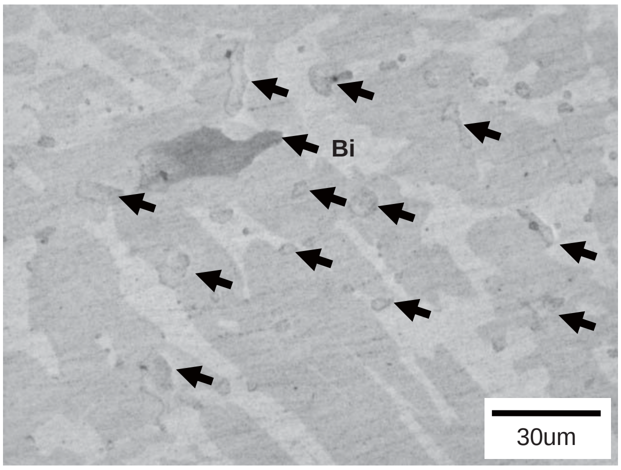

Fig.1 Optical microstructure of cast ingot brass with 2.2wt% Bi elements indicated by arrows.

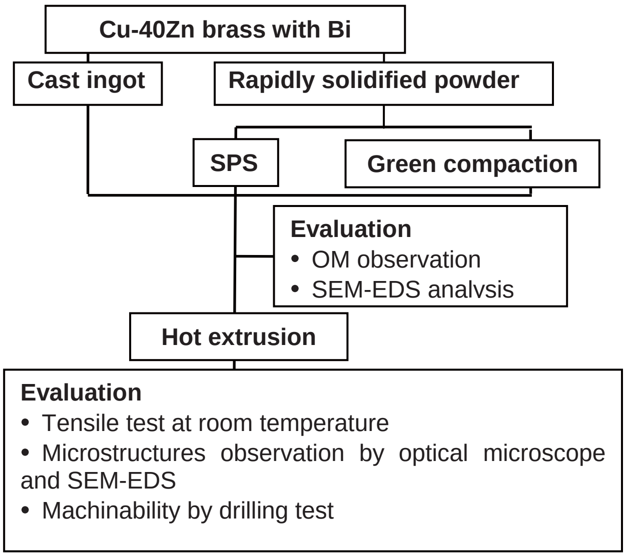

Fig.2 Flowchart of experimental procedures.

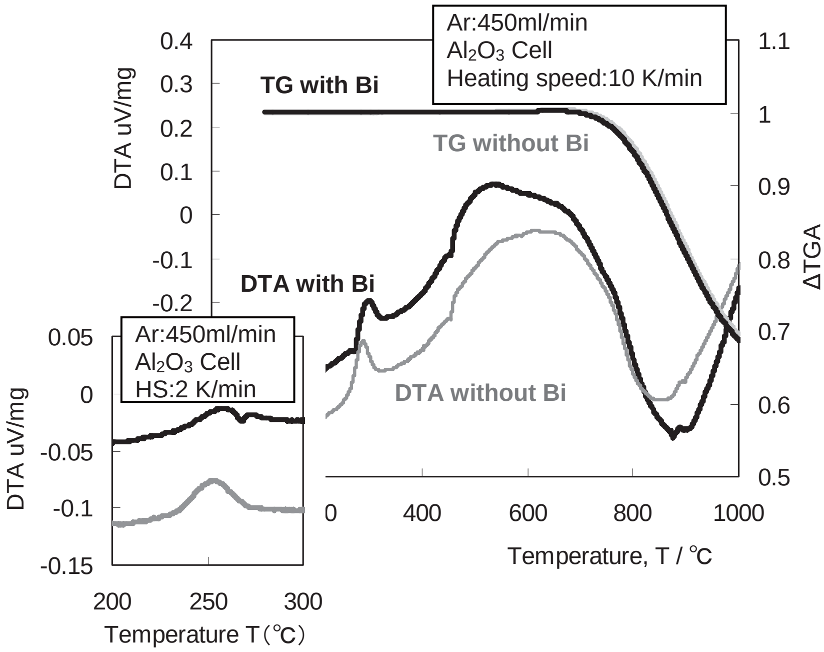

Fig.3 Thermo gravimetric analysis and differential thermal analysis profiles of Cu-Zn40 brass powder with and without Bi.

hydraulic press machine (2000 kN SHP-200-450: SHIBAYAMAKIKAI Co.). A cast ingot of the same composition was prepared as a comparison material.

Each billet was preheated at 873K for 180 s using a heating rate of 0.65 K/s in Ar atmosphere in a muffle furnace (KDF S-70: DENKEN Co.). Then, it was immediately extruded by using the hydraulic press machine and an extrusion ratio of 37.

The microstructural observation by scanning electron microscopy (SEM, JSM-6500F: JEOL) equipped with X-ray energy dispersive spectroscopy (EDS EX-64175JMU: JEOL) was carried out on the consolidated specimens. Mechanical properties of sintered specimens and their extruded materials were evaluated by a tensile testing machine (Autograph AG-X 50kN: SHIMADZU) under a strain rate of 5×10^{-4} s^{-1}. The observation of fractured surfaces of the tensile test specimens were carried out by using SEM. The machinability of Cu-40Zn brass with Bi was evaluated by a drilling test using a drill tool（EX-SUS-GDS: OSG Co.）, having a 4.5mm diameter, under dry conditions. The rotation speed of the drill was 900rpm, and applied load during drilling was 9.8N. The drilling time to make a hole with a 5 mm depth was measured. After repeating this drilling test 10 times, the average drilling time was used as machinability parameter.

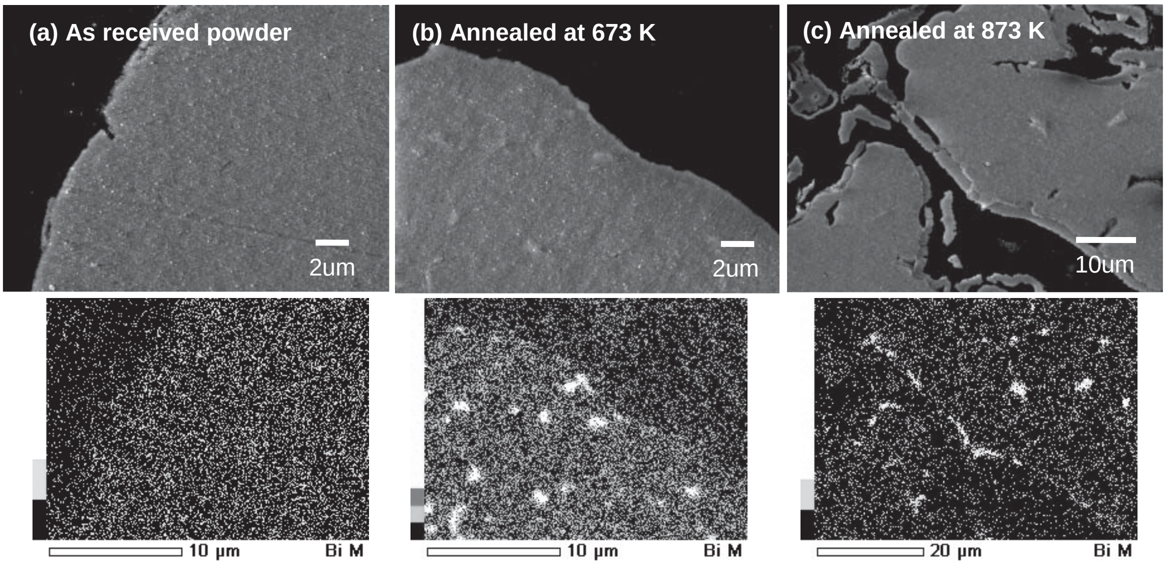

Fig.4 SEM-EDS observation on the cross section of as atomized powder and annealed powder of Cu-Zn alloys with 2.2wt% bismuth.

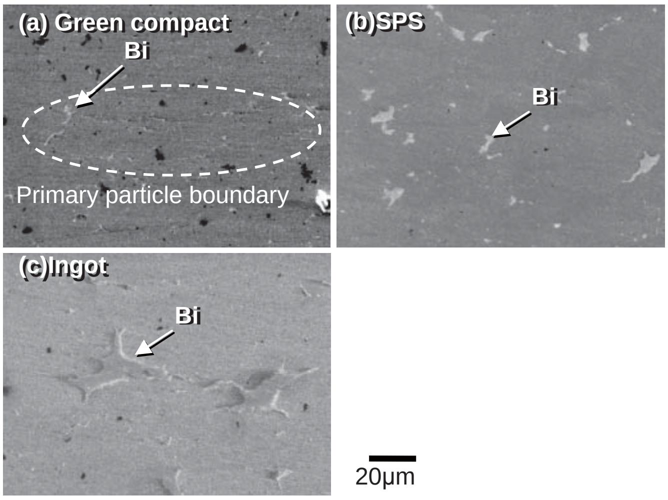

Fig.5 SEM observation of extruded Cu-Zn alloys using P/M and I/M billets with 2.2wt% bismuth.

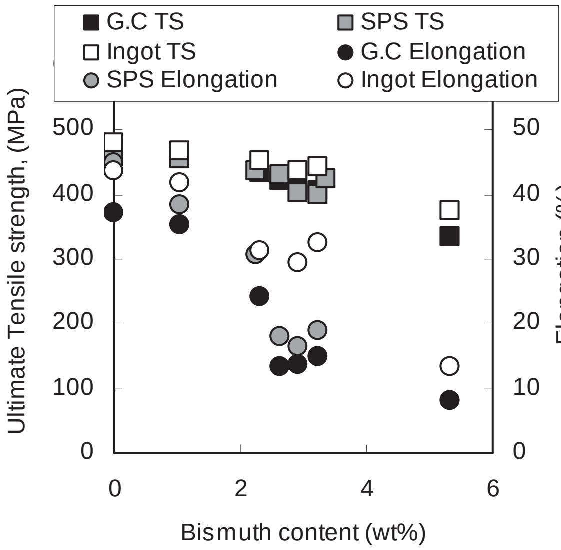

Fig.6 Dependence of tensile properties on Bi content of extruded P/M and I/M Cu-Zn alloys.

3. Results and discussion

Figure 3 shows DTA-TG profiles of raw brass powder with and without Bi. Weight loss was detected in both TG results from 903 K. This behavior is caused by zinc evaporation [(10)], and it has no relation with the addition of Bi. Exothermic heat reaction at 623 K and endothermic heat reaction at 723 K were detected in both DTA results. Raw powders were produced by using a rapid solidification process. The powders contained only the β´ phase. The exothermic reaction at 623 K corresponds to the transformation from the β' phase to the α phase. On the other hand, the endothermic reaction at 723K corresponds to the transformation from the β' phase to the β phase [(11)]. The unique behavior of DTA in row powder with Bi was the endothermic reaction at 443 K which corresponds to the melting of Bi.

Figure 4 shows SEM-EDS observations on the cross section of brass powder with Bi. Heat treatment at the temperature which exceeds the melting point of Bi (544.4 K), caused Bi to disperse in the powder form grains and dissolve into the powder surface. Figure 5 shows SEM observation of extruded brass alloys using P/M and I/M billets with Bi. Bi exists along the primary particle boundaries in extruded material of green compact. It seemed that Bi dissolved into the powder surface during billet preheating and expanded along primary particle boundaries. For extruded material of SPS billet, Bi exists as grains of about 5-10um size. Bi took the shape which existed at the triple point of intersection of primary particle boundaries in the sintering material. Therefore, Bi did not become of spherical shape. On the other hand, Bi grains of 20-30 um size, which were in cast ingot, existed in the extruded material of cast billet.

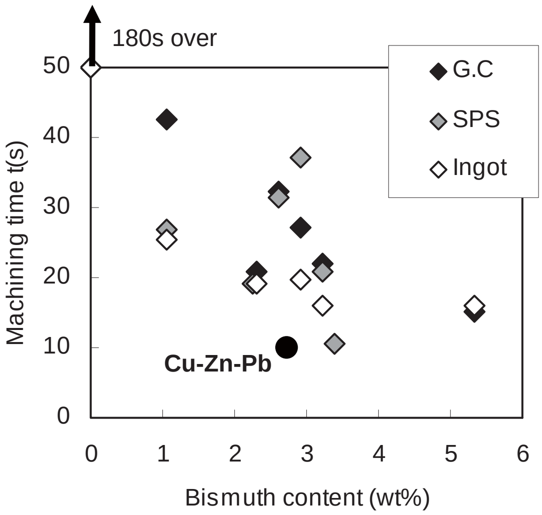

Fig.7 Machinability dependence on Bi content of extruded P/M and I/M Cu-Zn alloys.

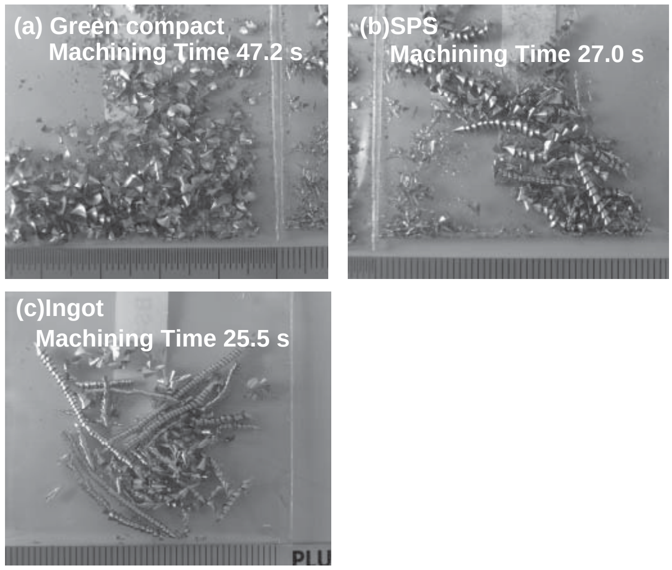

Fig.8 Appearance photograph of the machining chips of extruded material with 1.0 wt% Bi and the average of machining time.

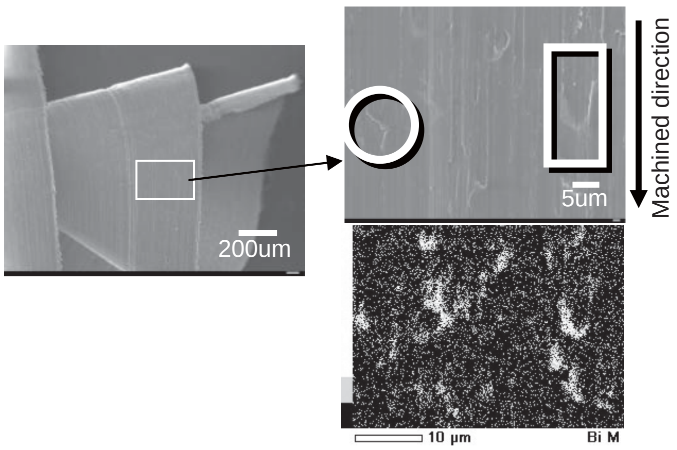

Fig.9 SEM-EDS observation on the surface of machining chip on extruded material with Bi.

Figure 6 shows the dependence of the tensile properties of extruded material on the content of Bi. Both the tensile strength and elongation decrease with increasing the Bi content regardless of billet condition. Especially, the decrease of the elongation for Bi content was remarkable. Comparing the billet condition, the elongation of P/M extruded brass alloys with over 2.5 wt% Bi greatly decreased. From SEM observation results on the fracture surface of tensile test specimens, both dimple fracture surface and cleavage fracture surface exist in each extruded material. It was confirmed from EDS analysis results that Bi existed in the cleavage fracture surface. For extruded material of green compact, the crack originated in the primary particle boundaries existing on the whole fracture surface of a tensile test specimen and the concentration of Bi was confirmed at several places of the crack.

Figure 7 shows the machinability of extruded brass alloys with Bi as evaluated by drilling tests. The data for Cu-Zn-3%Pb (current machinable brass), are also plotted as references. None of extruded brass alloys without Bi were able to be penetrated by drilling for 180 s. Brass alloys with Bi content of 0.1 wt% or more exhibited a better machinability. The average drilling time decreases with increasing Bi content. Comparing different extruded material with same quantity of Bi, the machinability of extruded material of SPS or cast ingot were more improved than the extruded material of green compact. One of the reasons for this behavior is the shape of machining chip. A macrograph of the machining chips of extruded materials with 1.0 wt% Bi is shown in Fig.8. The machining chips became of continuous spiral shape for shorter cutting time. Discharging efficiency of the machining chips in drilling is important for the continuous spiral machining chips [12]. Figure 9 shows SEM-EDS observation on the surface of machining chip

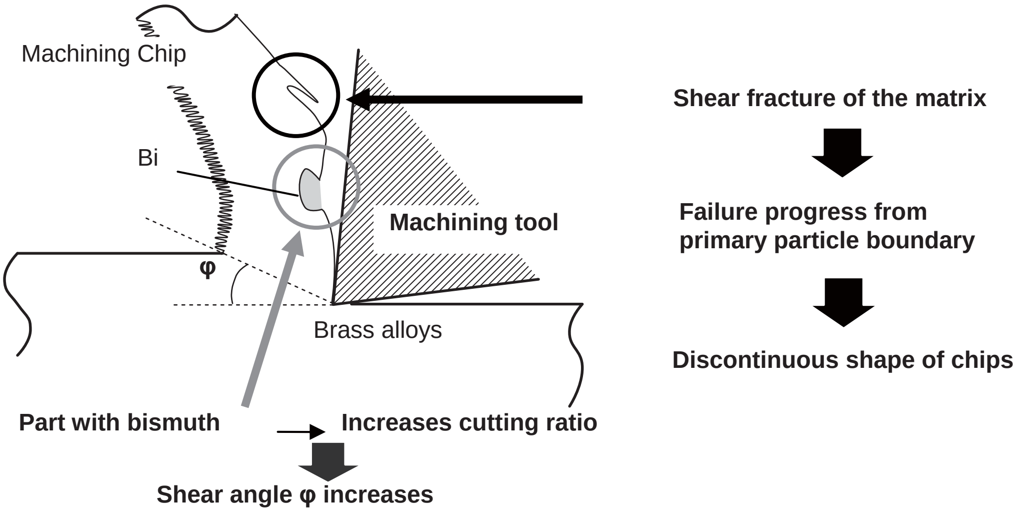

Fig.10 Model of the machining mechanism of brass extruded material with Bi.

on extruded material with Bi. There were perpendicular splitting in the cutting direction and grooves on the surface of machining chips. From the result of EDS analysis, the concentration of Bi was confirmed in the part in the groove. The model for the machining mechanism of brass extruded material with Bi is illustrated in Fig.10. The part with Bi is mainly cut further than other parts when machining by drilling tool. The cutting ratio relatively increases on the part. Therefore, the shear angle increases and the machining chip becomes curved. On the other hand, the brass matrix is broken by the effect of curvature. The machining chips of P/M extruded brass with Bi, in which the primary particle boundaries exist, break along them causing the fracture of the matrix. The machining chips of P/M extruded materials are difficult to become of continuous shape further than that of I/M extruded material.

4. Conclusions

Brass alloys with Bi were prepared by using powder metallurgy processes. Effects of the consolidation process conditions and Bi content on their mechanical properties and machinability were examined. The results in this study are summarized as follows.

(1) Bi dispersed in brass powder forms grains and dissolves into the powder surface by heat treatment at temperatures about the melting point of Bi.

(2) Bi was extended along the primary particle boundary in extruded material of green compact, and existed as a grains of about 5-10um, which were at the triple point of primary particle boundaries in the sintering powder, in extruded material of SPS billet. The behavior of Bi existing in the primary particle boundary caused a decrease in the elongation of the extruded brass.

(3) The machining chips of P/M extruded brass with Bi became of discontinuous form by primary particle boundary. This tended to increase the machining time since discharge efficiency of the machining chips is inferior in P/M extruded brass with Bi.

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