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Characteristics of Lead-Free P/M Cu60-Zn40 Brass Alloys with Graphite[†]

IMAI Hisashi*, KONDOH Katsuyoshi**, KATANO Gen*** KOSAKA Yoshiharu**** and KOJIMA Akimichi*****

Abstract

Brass alloys are widely used as industrial materials because of their excellent characteristics such as high corrosion resistance, non-magnetism, and good machinability. In particular, machinable brass is obtained by adding lead. It is, however, necessary to reduce the use of lead from a viewpoint of the hazardous effects on the environment and humans. In this paper, the uniform distribution process of graphite particles into brass alloy by powder metallurgy (P/M), and machinable lead-free P/M brass with graphite additives have been described. The mixture powder of graphite particles and 60Cu-40Zn brass alloy was used as input raw materials, having mean particle sizes of 5 μ m and 40 μ m, respectively. It was consolidated at 1053K by Spark Plasma Sintering (SPS) to then be used as the compacts for extrusion. The additive of 1 wt% graphite particles in P/M extruded brass alloys was significantly able to improve their machinability as well as the conventional brass alloys with lead.

KEY WORDS: (60Cu-40Zn Brass) (Lead-free) (Spark Plasma Sintering) (Graphite) (Machinability)

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 machinability. In particular, machinable brass is obtained by adding lead^{1,2)}. However, it is necessary to reduce the use of lead from a viewpoint of the hazardous effects on the environment and humans^{3, 4)}. The additives of bismuth (Bi) and silicon (Si) to brass alloys as alternative elements of lead have been discussed to improve their machinability⁵⁾. Furthermore, a graphite particle, which is a solid lubricant and has significant effect of friction reduction⁶⁾, is available to be used as an additive to brass alloys because it is cheap and environmentally benign⁷⁾. It is, however, very difficult to uniformly disperse graphite particles in the brass matrix by ingot metallurgy (I/M) process due to the significantly large difference in the density between graphite and brass alloy, and to the floating of graphite by adhering to vaporized zinc (Zn)⁸⁾. In this paper, the uniform distribution of graphite particles into the brass alloy by solid-state process has been discussed to develop machinable lead-free brass by powder metallurgy (P/M).

The spark plasma sintering process was applied to consolidate the brass powder with no vaporization of Zn during sintering. The mechanical properties and machinability of P/M extruded brass dispersed with graphite particles were also investigated.

2. Experimental Procedure

A flowchart to prepare P/M brass alloys in this study is shown in **Fig.1**. Brass powder, used as raw material, was prepared by the water atomization using Cu60-Zn40 brass ingot without any Pb or Bi additions. It had a mean particle size of 40 μ m. Graphite, having a mean particle size of 5 μ m, was prepared to make the brass composite distributed with graphite. The graphitic additions to brass powder were 0wt%, 0.3wt%, 0.5wt%, 0.75wt% and 1wt%. Brass powder, and the graphite particles were mixed by dry blending. Spark plasma sintering (SPS Sumitomo Coal Mining, SPS-1030), conventional sintering, and green compaction were used to consolidate the powder. In order to establish the consolidation conditions by the SPS process, the brass powder with no graphite particle was compacted in the temperature range from 873 K to 1073 K for 1.8ks under 40MPa pressure in vacuum. As the other methods to consolidate raw powder, conventional cold compaction was employed by applying a pressure of 600 MPa at room temperature. Some green compacts were sintered for 1.8 ks in Ar atmosphere.

Each powder compact was preheated at 1053K for 180 s in Ar atmosphere in a muffle furnace (KDF S-70: DENKEN Co.). The extrusion ratio of 37 and a heating rate of 0.65 K/s were used. After heating the compact, it was immediately extruded by using the hydraulic press machine (2000 kN SHP-200-450: SHIBAYAMAKIKAI Co.).

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The relative densities of consolidated specimens were measured by using Archimedes law. The microstructural observation by scanning electron microscopy (SEM, JSM-6500F: JEOL) installed 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 (RTC-1310A: ORIENTEC) with a strain rate of $5 \times 10^{-4} \text{ s}^{-1}$. The observation on fractured surfaces of the tensile test specimens were carried out by SEM. The machinability of 60Cu-40Zn brass with graphite particles was evaluated by using a drill tool (EX-SUS-GDS: OSG Co.), having 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.

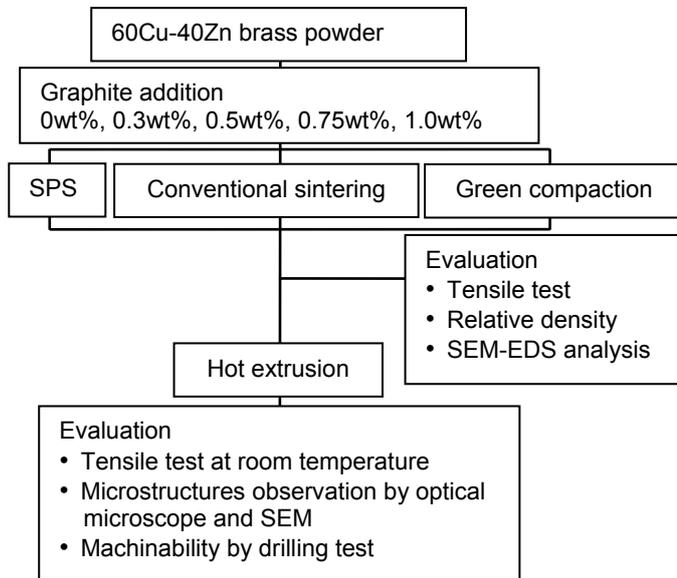


Fig.1 Flowchart of experimental procedures

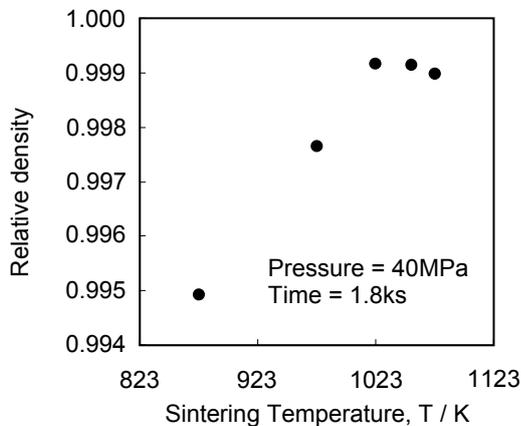


Fig.2 Dependence of the relative density on sintering temperature to consolidate brass powder by SPS.

3. Results and Discussion

Figure 2 shows the dependence of the relative density on the sintering temperature to consolidate brass powder by SPS. When using a sintering temperature over 1023 K, the materials show a relative density of 99.9% or more. Figures 3 and 4 show stress-strain curves from tensile tests of the sintered materials prepared by SPS and the SEM observation of the fractured surfaces of tensile test specimens, respectively. In the case of specimens sintered at 973 K, the elongation is small, and the intergranular gaps between primary particle boundaries are often observed in the fractured surface. On the other hand, a specimen sintered at 1053 K has a large elongation, similar to that in the cast alloy. In this specimen, fine dimple patterns, not intergranular gaps mentioned above, are observed. Therefore, sintered Cu-Zn alloys with a good metallurgical bonding can be obtained at SPS temperatures higher than 1053 K.

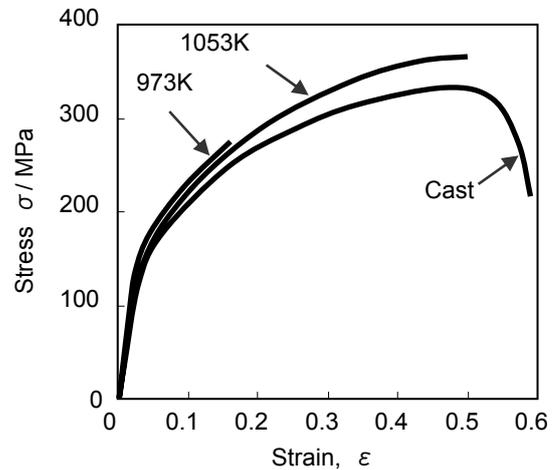


Fig.3 Stress-strain curves of P/M sintered and I/M cast Cu60-Zn40 materials.

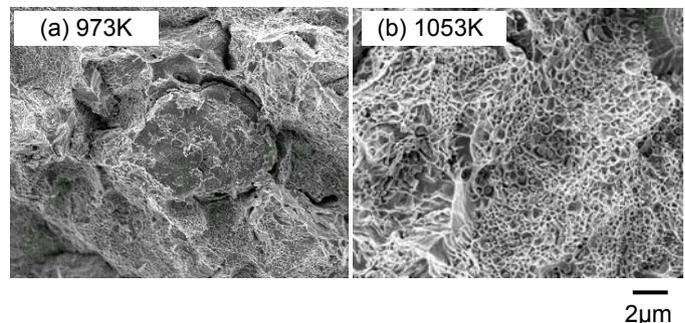


Fig.4 SEM observation of fractured surfaces of tensile test specimen of sintered compaction material via SPS at 973 K (a) and 1053 K (b).

Figure 5 shows SEM-EDS result of line analysis on the SPSed material at 1073K. No void due to zinc evaporation is observed at the surface area. At the same time, there is no change in the chemical compositions at the surface close to the primary particle boundary of sintered materials. It is considered that the SPS process is effective in consolidating Cu60-Zn40 brass alloy powder without any composition changes.

Figure 6 shows the microstructures of extruded Cu-Zn alloys with 0.5wt% graphite particles. While the graphite particles are continuously distributed along the extrusion directions in the case of the conventional sintered and green compacts shown in (b) and (c), they exist independently in the matrix of the extruded alloy via SPS as shown in (a).

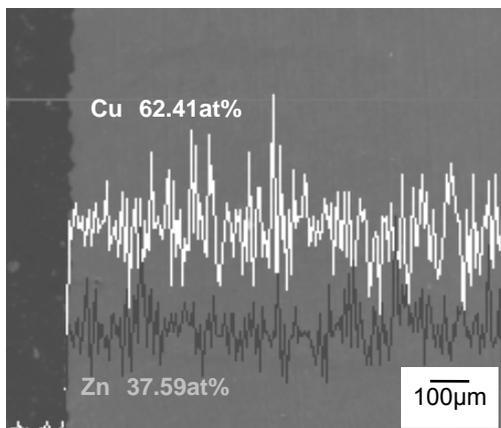


Fig.5 SEM observation and EDS line analysis of Cu and Zn on SPSed compact

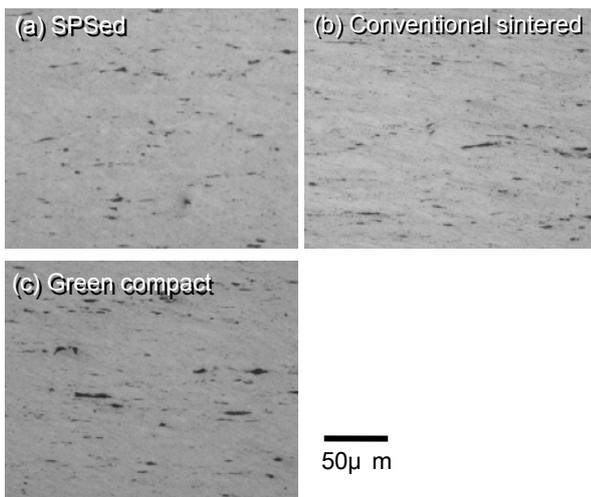


Fig.6 Optical microstructures of extruded Cu-Zn alloys in using P/M compacts with 0.5wt% graphite.

Figure 7 shows the dependence of the tensile properties of extruded material on the content of graphite particles. Both the tensile strength and elongation decrease with increasing the graphite content. This indicates that the bonding between graphites and the brass matrix is poor, and their interfaces cause the formation of micro-gaps resulting in decreased tensile strength and elongation to failure. The difference of the tensile strength of extruded materials is small between the SPSed material and the conventional sintered and green compacts when including the same content of graphite particles. On the other hand, the elongation to failure of the extruded alloys in using SPSed material is larger than that in using the conventional sintered or green compacts.

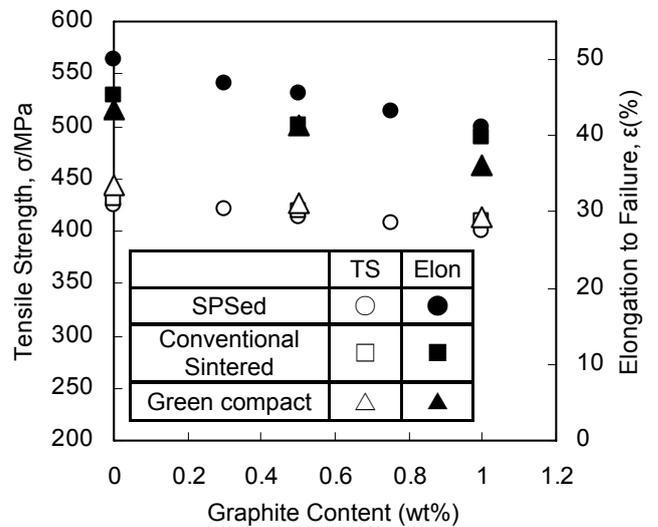


Fig.7 Dependence of tensile properties of extruded P/M Cu-Zn alloys on graphite content.

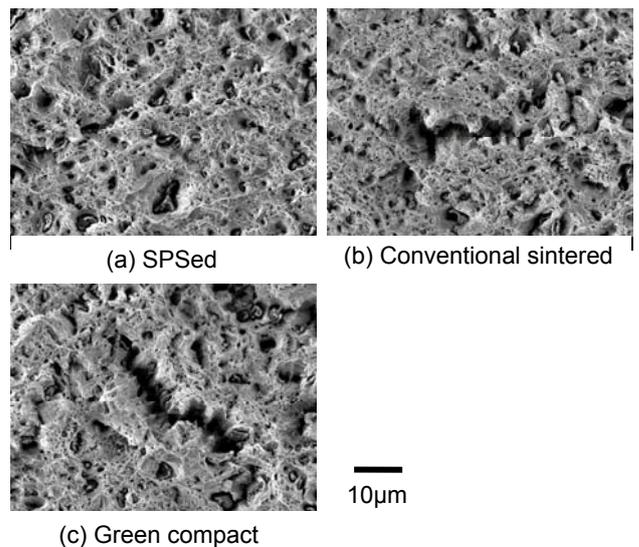


Fig.8 SEM observation on fractured surfaces of tensile test specimen of extruded Cu-Zn alloys when using P/M compacts with 0.5wt% graphite.

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Figure 8 shows the fractured surfaces observed by SEM after the tensile test. While the brittle fractures originated from the graphite particles of brass extruded materials in using conventional sintered (b) and green compacts (c), the SPSed material indicates no fracture or crack. This could be attributed to the uniform distribution of graphite particles in the extruded material via the SPS process. Cu-Zn particles were effectively sintered in SPS resulting in a good metallurgical bonding between Cu-Zn matrix powders, and hence the graphite particles were not extended along the extrusion direction as shown in Fig.6 (a). **Figure 9** shows the machinability of extruded Cu-Zn alloys with graphite as evaluated by drilling tests. The data for Cu-Zn-3%Pb (current machinable brass), Cu-Zn-2.2%Bi, and Cu-Zn-3%Si bronze alloys are also plotted as references. Cu-Zn alloys with no graphite and 0.3 wt% graphite were not able to be penetrated by drilling for 180 s. Cu-Zn alloys with the graphite content of 0.5 wt% or more exhibited a better machinability in all the tests that were carried out 10 times. The average drilling time decreases with increasing the graphite content because of the lubricant property of graphites. The machinability of the SPS-extruded brass alloy was not inferior to that of the conventional sintering-extruded and cold compacting extruded materials. This is due to the incomplete bonding between Cu-Zn particles when using the conventional sintered and cold compacts, and resulting a better machinability. SPS-extruded alloy containing 1.0 wt% graphite reveals a good machinability comparable to that of the conventional sintered or green compacted alloys. The machinability of the present alloys is now compared with that of practical alloys. The extruded Cu-Zn alloys with graphite have a noticeably better machinability as compared to the Cu-Zn-3%Si alloys. On the other hand, their machinability is slightly poorer than that of Cu-Zn-3%Pb (13.6 s) and Cu-Zn-2.2%Bi (14.5 s) alloys, which contain effective additives with a volume fraction equivalent to 0.5 wt% graphite particles.

4. Conclusions

Cu-Zn alloys dispersed with graphite particles were prepared by using powder metallurgy processes. Effect of the consolidation process conditions and graphite particle content on their mechanical properties and machinabilities were examined. The results in this study are summarized as follows.

- (1) The use of the SPS process resulted in improved tensile properties of the sintered material and extruded alloy. The SPSed compact had a strong metallurgical bonding between Cu60-Zn40 particles, and revealed a high ductility comparable to the conventional cast alloy.
- (2) The graphite particles were independently distributed, not extruded along the extrusion direction of the extruded alloys, they exhibited a larger elongation that of P/M brass alloys by using the conventional sintered or green compacts. From the observations of fractured surfaces of extruded materials via SPS process, it was concluded that the fractures did not originate from the graphite particles or the intergranular gaps between the primary brass powders.
- (3) The addition of 0.5 wt% graphite significantly improved the machinability. Cu-Zn alloys with 1 wt% graphite showing a good machinability comparable to that of the practical machinable Cu-Zn alloys because of the lubricant property of graphite itself. Although the SPS-extruded alloys had a good bonding between the Cu-Zn particles, their machinability was slightly poorer than that of the conventional sintering-extruded materials.

Acknowledgments

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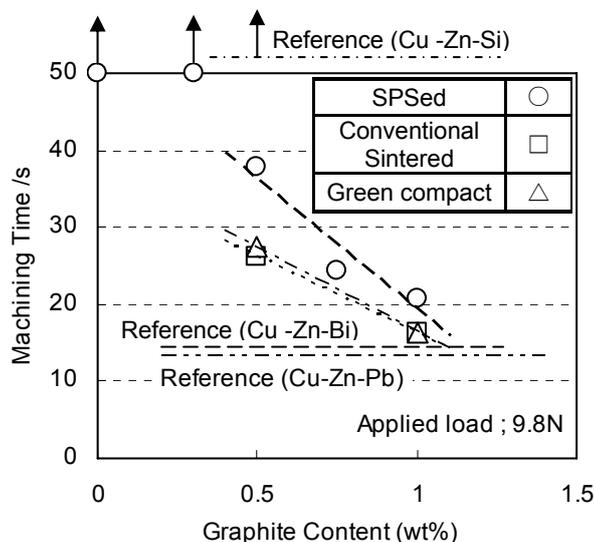


Fig.9 Machinability dependence of extruded Cu-Zn P/M alloys on graphite content.

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