Consolidation of Free-Cutting Lead-Free Brass by Hot Extrusion and its Properties

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In this study, attempts were made to develop a method for consolidating of 6-4 brass chips and producing a free-cutting, lead-free brass alloy. Because chips of a lead-free brass alloy are not available commercially, a 6-4 brass alloy was cast. Next, chips in shapes similar to those produced as scrap were prepared by machining a Cu–Zn ingot. Cu2S powder was added to the brass chips as an alternative to lead, and they were mixed. The mixture was compressed in a mold and directly consolidated as an extruded rod by hot extrusion at 773 K. After extrusion, results of tensile tests conducted to examine the mechanical properties of the extruded rods showed that the tensile strength and elongation decreased with the addition of Cu2S. Cross-sectional microstructure observation showed that the microstructure became dense with an increase in the extrusion ratio. Energy dispersive X-ray (EDX) analysis showed a sulfur-rich area in the rods with a low extrusion ratio. In contrast, sulfur dispersed homogeneously in rods at a high extrusion ratio. The density increased by increasing the extrusion ratio and decreased by the addition of Cu2S. The hardness of the specimens containing Cu2S increased with an increase in the extrusion ratio, while the hardness of the Cu2S-free rod was very low. A cutting resistance test and chip observation indicated that an increase in the amount of Cu2S additive improved the machinability. After extrusion, almost satisfactory extruded rods were obtained, while a non-bonded region was observed around the top of each extruded rod.

Keywords: *hot extrusion, consolidation, 6-4 brass, free-cutting lead-free brass , Cu2S, machinability, cutting resistance*

1. Introduction

Brass system scraps are mostly recycled by recasting; however, this consumes a great deal of energy and the final product includes impurities. Therefore, direct consolidation of chips by employing energy-saving techniques has been investigated. In our laboratory, a preliminary technology for direct consolidation of powder and chips of Al and Mg alloys has been examined[1,2]. Application of this technology to brass could provide a recycling technology that is advantageous over recasting in terms of energy and cost savings. The main objective of this study is to develop a chip consolidation technology by a hot process.

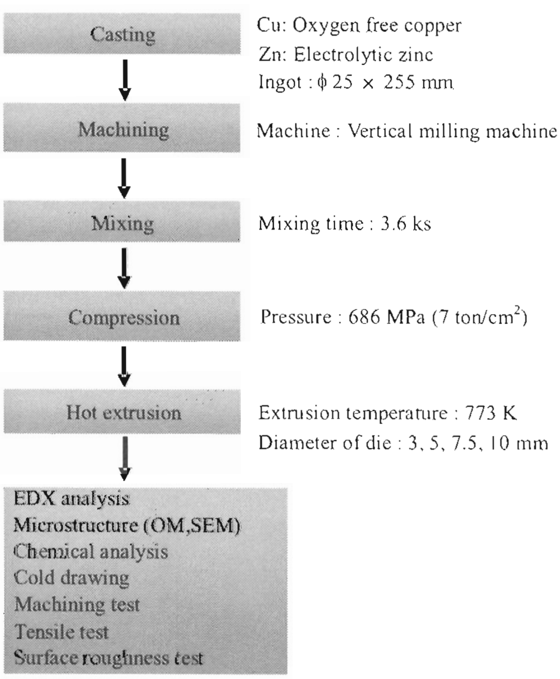

Figure 1 flowchart of experimental procedures.

Brass alloys contain lead elements to improve their machinability, as represented by the JIS C3604 standard. However, these regulations are being tightened worldwide because lead is harmful to the human body. According to the RoHS regulations, lead content in brass is not regulated up to 4%, but it is expected that these regulations will become more strictly. Currently, bismuth or graphite is added to brass alloys as an alternative to lead[3-6]. The problem with this is outbreak of toxic gases and heterogeneous dispersion of the additives in the brass matrix. Therefore, a method for producing free-cutting, lead-free brass using Cu_2S as an alternative to lead has been investigated in this study.

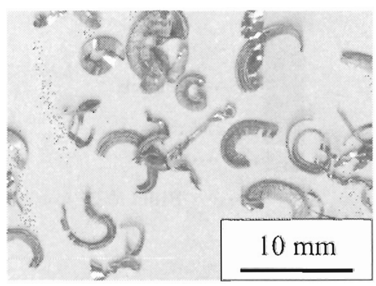

Figure 2 Shapes of machined brass chips.

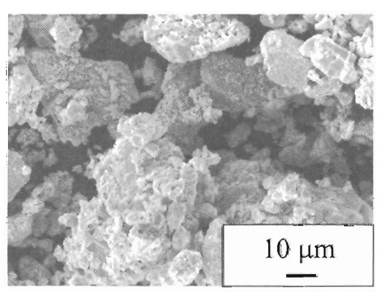

Figure 3 SEM image of the Cu_2S powder.

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2. Experimental procedure

A flowchart to prepare experimental procedure in this study is shown in Figure 1. Since lead-free 6-4 brass is not available commercially, together of oxygen-free copper and electrolytic zinc were melted in a graphite crucible to produce 6-4 brass for use as an experimental specimen. This melt was cast in a die 25 mm in diameter, and chips were prepared from an ingot using a milling machine to produce a compacting. Figure 2 shows the resulting chip. Cu_2S powder (additive amount 1, 5, and 10 vol%) with an average grain size of 10 μm was added to this chip. Figure 3 shows an SEM image of Cu_2S powder. With sufficient mixture for 3.6 ks, the mixtures were compressed into a billet for extrusion using a die 21 mm in diameter under 686 MPa at room temperature. Figure 4 shows a schematic illustration of the compaction process. The billet was

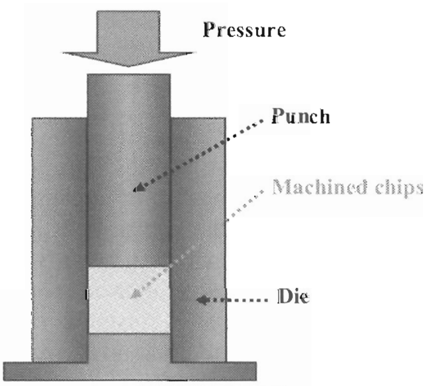

Figure 4 Schematic illustration of compaction process.

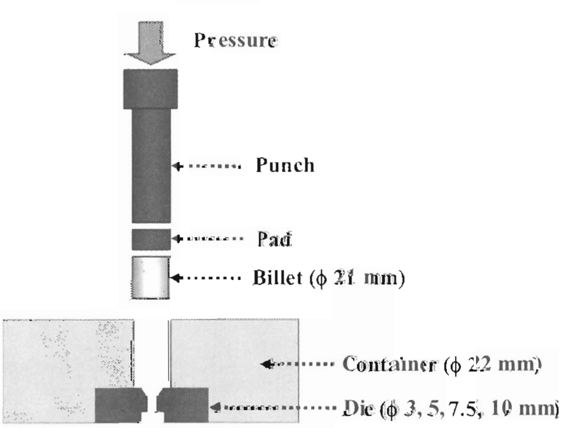

Figure 5 Schematic illustration of hot extrusion process.

extruded at 773 K to diameters of 10 mm (extrusion ratio 4.8), 7.5 mm (extrusion ratio 8.6), 5 mm (extrusion ratio 19.4), and 3 mm (extrusion ratio 53.8). Figure 5 shows a schematic illustration of the hot extrusion process employed to directly consolidate the brass chips. The extruded rods were examined appearance observation, cross-sectional observation, element analysis, densimetry, hardness testing, tensile testing, and cutting testing.

3. Results and discussion

The rods extruded to ϕ10 (extrusion ratio 4.8), ϕ7.5 (8.6), ϕ5 (19.4), and ϕ3 mm (53.8) in an extrusion container with a 22 mm inside diameter were examined for their appearance. Figure 6 shows the appearance of the billet and the extruded rods. While the extruded rod obtained was overall satisfactory, a part where the chips did not join was observed at the top of each extruded rod. The defective part was observed in the peripheral area of the extruded rods of ϕ10 mm (4.8), where the extrusion ratio was comparatively low. However, other than at the top, the rods were sufficiently dense, with an extrusion ratio greater than ϕ7.5 mm (8.6).

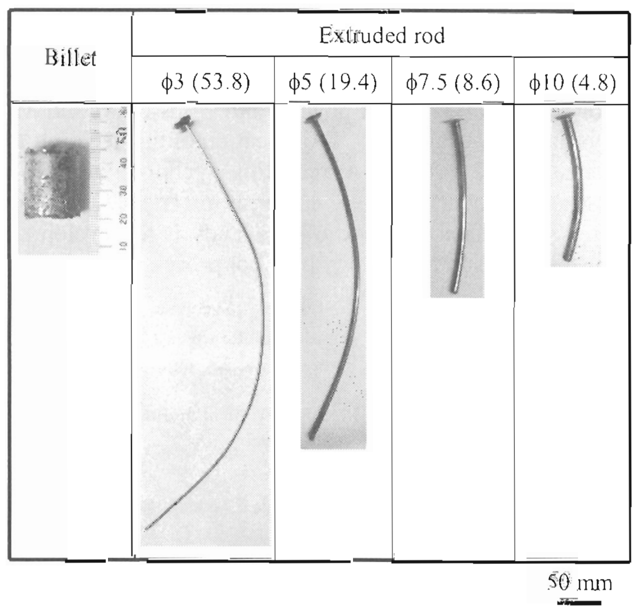

Figure 6 Billet and extruded rod.

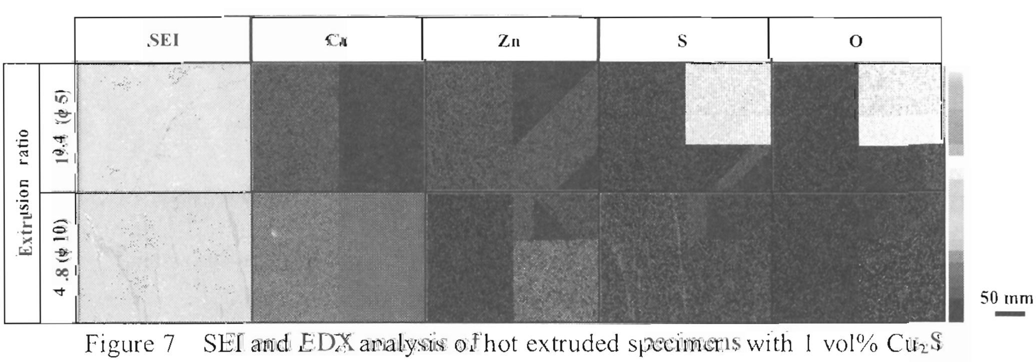

Figure 7 SEI and EDX analysis of hot extruded specimens with 1 vol% Cu_2S at different extrusion ratios.

Figure 7 shows the EDX element analysis results obtained by SEM. A sulfur-rich area was observed in the extruded rod of ϕ10 mm (4.8); however, sulfur dispersed uniformly in extruded rods less than ϕ7.5 mm (8.6). It is believed that the dispersion of Cu_2S proceeded because the chips were crushed with an increase in the extrusion ratio.

Figure 8 shows the effect of the extrusion ratio on the density and hardness of the extruded rods with 1 vol%. The data for casting and billets are shown for comparison. The data indicate that the density and hardness of the extruded rods increased with the extrusion ratio. This is because the increased extrusion ratio made the microstructure finer. Figure 9 shows the effect of the amount of Cu_2S added on the density and hardness of the extruded rods of ϕ7.5 mm (extrusion ratio 8.6). The density decreased with an increase in amount of Cu_2S. This is because Cu_2S has a lower density than 6-4 brass. The hardness of extruded rods varied the content of the Cu_2S additive showed almost the same degree. However, extruded rods that were free of Cu_2S showed a significantly low value. It is believed that this contributes to dispersion strengthening because Cu_2S was added as the second phase.

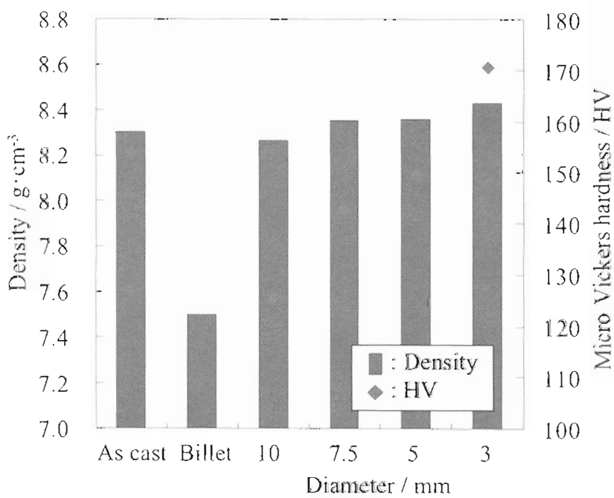

Figure 8 Density and hardness of extruded rods with 1 vol%Cu_2S at different extrusion ratios, castings and a billet.

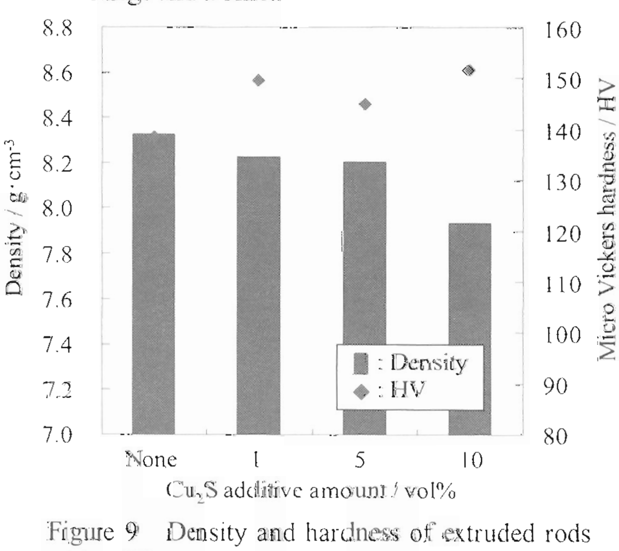

Figure 9 Density and hardness of extruded rods with different amounts of Cu_2S additive at an extrusion ratio of 19.4.

The tensile test was conducted using an Instron type universal testing machine at a tensile speed of 2 mm/min and gauge length of 25 mm. Figure 10 shows the tensile test results. The data for extruded rod of ϕ3 mm (extrusion ratio 53.8) are shown for comparison. The tensile strength of the extruded rod of ϕ5 mm (19.4) decreased with an increase in the amount of Cu_2S. However, the tensile strength (503 MPa) of the extruded rod of ϕ3 mm (53.8) was greater than that (440 MPa) of the Cu_2S additive-free extruded rod. In addition, the elongation of the extruded rod decreased with an increase in the Cu_2S additive amount.

A cutting test of the extruded rod and HM-30 (Bi free-cutting brass) were performed under various conditions. The cutting resistance was calculated using a calibration curve prepared in advance. Figure 11 shows a cutting test result. The cutting resistance of the extruded rod decreased with an increase in the amount of added Cu_2S. Therefore, the cutting resistance of the extruded rod with 10 vol% Cu_2S was almost the same as that of HM-30. In addition, the chip management was good because the chip shape was a division or curl type.

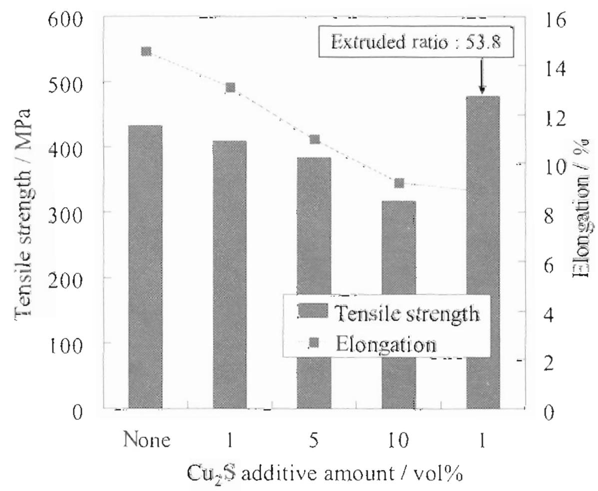

Figure 10 Tensile strength and elongation of extruded rods with different amounts of Cu_2S additive at an extrusion ratio of 19.4 and 53.8.

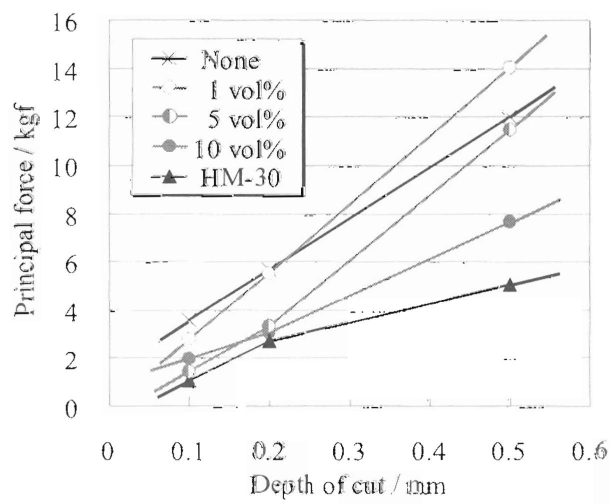

Figure 11 Cutting resistance of specimens under various cutting conditions.

4. Conclusions

A method for producing free-cutting, lead-free brass using Cu_2S as an alternative to lead, thereby dealing with environmental problems of lead, was investigated by powder metallurgy and hot extrusion. The results obtained from this study are as follows:

(1) A compression molding of chips can be consolidated by hot extrusion.
(2) The extruded rods became dense and the Cu_2S additive dispersed by increasing the extrusion ratio.
(3) The density increased with an increase in the extrusion ratio and a decrease in the amount of Cu_2S added.
(4) The hardness increased with the extrusion ratio. In addition, the hardness increase in extruded rods containing Cu_2S was higher than for those not containing Cu_2S.
(5) The tensile strength and ductility decreased with an increase in the amount of Cu_2S added.
(6) The cutting resistance decreased with an increase in the amount of Cu_2S added.

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