Effect of Chromium Precipitation on Machinability of Sintered Brass Alloys Dispersed with Graphite Particles

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The machinability of high strength lead-free brass was investigated in this study. Copper-40 mass% zinc (Cu-40Zn) brass powder with chromium was prepared by the water atomization. Chromium was used for strengthening of brass matrix. Graphite particles as machinable element were added to the as-atomized powders by conventional mixing process. Spark plasma sintering process was used to consolidate the above elemental mixed powder (X K SPSed material) at 873 K and 1053 K. The sintered materials at 1053 K were heat-treated for the precipitation of much Cr (HT material) at 1053 K for 12 h in Ar atmosphere. The machinability was evaluated by a drilling test using a drill tool under dry conditions. The matrix hardness of sintered material was higher than that of HT material. On the other hand, the machinability of sintering material was higher than that of HT material. The trade-off relationship between the matrix hardness and machinability of the brass alloys was not established. The solution of chromium content dissolved in the brass matrix of sintered material at 873 K, 1053 K and HT material was 0.55 mass%, 0.42 mass% and 0.19 mass%, respectively in SEM-EDS observation. The chromium carbide increased with decreasing chromium solution in the brass matrix. The generation of hard chromium carbide and decrease in the relative graphite particle caused to inhibit the machinability of HT material. [doi:10.2320/matertrans.M2011051]

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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, good formability. The high strength brasses contain some elements such as aluminum, iron, manganese, tin, nickel. Their elements work as solute strengthening of both \( \alpha \) phase and \( \beta \) phase, or precipitation strengthening. Cibula¹ has investigated the brass containing iron, boron and zirconium to refine grains causing higher YS according to the Hall-Petch relation. These alloys with fine grains have not yet been obtained by conventional melting and casting processes. The previous research by these authors showed the high strength brass containing a little chromium, iron and tin was produced by rapid solidification process.² The additive chromium was super-saturated in the brass matrix because its solid solution in the brass was small. The precipitation strengthening has been expected to be the same as the case of Cu-Cr alloy.³ Using rapid solidification process, the solute strengthening is considered by solution quantity over the solid solubility limit.³ However, high strength brasses are lower machinability than the conventional machinable brass.

The conventional machinable brass alloys contain a few percents of lead.⁴,⁵ Recent years, it is necessary to reduce the content of lead in materials from a viewpoint of the hazardous effects on the environment and humans.⁶,⁷ Graphite particle is a common solid lubricant and has an abrasive characteristic.⁸–¹⁰ Graphite particle is also cheap and environmentally benign,¹¹ which is expected to be used for machinable element of brass alloys. It is, however, very difficult to uniformly disperse graphite particles in the brass matrix by ingot metallurgy (I/M) process due to the large density difference between graphite and brass alloy, and to the floating of graphite particles by adhering to vaporized zinc in heating and casting.¹²,¹³ The other hand, 60–40 brass dispersed with graphite particles was obtained by using the powder metallurgy (P/M) process in previous author’s research.¹³ The brass dispersed with graphite particles had good balance of machinability and suitable mechanical properties.

In this paper, high strength and machinable brass alloys with chromium and graphite particles were produced by powder metallurgy process. The brass powder with chromium was made by water atomization process. Its process is well known to include fine microstructures and non-equilibrium phases because of their rapid solidification and cooling process. By using the atomized powder mixed with graphite particles, graphite is dispersed in the brass matrix of the wrought alloys. The effect of the precipitation of chromium and the chemical compound of chromium and graphite particles on the machinability of the brass alloy was investigated in this study.

2. Experimental Procedure

Cu-40 mass%Zn (Cu-40Zn) alloy powder containing chromium was prepared by water atomization, having a mean particle size of about 150 \( \mu m \) (produced by Nippon Atomized Metal Powder Co., Ltd.). The chromium additions to brass were 1.0 mass%. Graphite, having a mean particle size of 5 \( \mu m \), was prepared as a machinable element. Graphite particles were natural graphite (produced by Chiuetsu Graphite Works Co., Ltd.). 1.0 mass% graphite particles were added to the as-atomized powder. The as-atomized powder and graphite particles were elemental mixed by the

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ball milling machine (AV-2: ASAHIRIKA) for 4 h under 120 rpm without media balls. Spark plasma sintering (SPS-1030: SPS SYNTEX INC.) was used to consolidate the above elemental mixed powder. The condition of the consolidation was preformed using the temperature of 873 K and 1053 K for 1.8 ks under 40 MPa pressure in vacuum.14) The materials were named X K SPSed. Some sintered materials at 1053 K were heat-treated at 1053 K for 12 h in order to investigate the effect of the precipitation of chromium elements on their mechanical property and machinability. The materials were named HT. Mechanical property of sintered materials was evaluated by a Vickers’s hardness machine (HMV: SHIMAZDU).

The microstructure observation by optical microscope and 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 to investigate the morphology and distribution of graphite and chromium.

In this study, the high strength brass alloys was tried to make for mainly the optical components. These parts have many screw holes. Therefore, the specimen’s machinability was evaluated by drilling test. In the drilling test, a drill tool (EX-SUS-GDS: OSG Co.) having a 4.5 mm diameter was used under dry conditions. The rotation speed of the drill was 900 rpm, and applied load during drilling was 14.7 N. The drilling time to make a hole with a 5 mm depth was measured. The drilling speed was value divided drilling depth in drilling time. After repeating this drilling test 10 times, the average drilling speed was used as a machinability parameter of the specimen.

3. Experimental Results

Figure 1 shows microstructures of sintered materials by using the optical microscope. The graphite particles were distributed on the primary particle boundaries in all samples confirmed from the low magnification photographs. In the case of the high magnification observation, there were fine precipitations in 873 K SPSed specimens. On the other hand, few precipitations in the brass matrix were detected in 1053 K SPSed and HT specimens. The some reaction layers were confirmed around the graphite particle. The tendency was confirmed on the almost observed area.

The dependence of Vickers micro hardness and drilling speed on each sintered material.

![Fig. 1: Microstructures observation of the cross section of sintered materials by optical microscope. (a) 873 K SPSed, (b) 1053 K SPSed, (c) HT.](image)

![Fig. 2: Dependence of Vickers micro hardness and drilling speed on each sintered material.](image)
shows SEM image and EDS analysis results. From this result of Fig. 3 and Fig. 4, there was no reaction layer on the graphite particles in the 873 K SPSed. There were also fine chromium precipitations in the same material. On the other hand, the reaction layers of chromium and carbon were confirmed in the interface of brass powder and graphite particle in the 1053 K SPSed and HT. The reaction layer in HT was thicker than that of 1053 K SPSed material. From the point analyses by using EDS, chromium content in the brass matrix of 873 K SPSed, 1053 K SPSed, and HT were
0.55 mass%, 0.42 mass%, and 0.19 mass%, respectively. The content of chromium solution in HT matrix was lowest compared with another specimens. The solid solubility of chromium in copper alloy is very small and there is no compound between chromium and copper. Therefore, it was consider that supersaturated solution of chromium diffused on the primary particle boundaries according to the increasing a temperature and the chromium reacted graphite particles.

Figure 5 shows the XRD analysis results. There was chromium peak in the XRD result of 873 K SPSed result. This peak was considered to show the fine chromium precipitation. Other hand, the chromium peak was disappeared in both XRD results of 1053 K SPSed and HT. There were also chromium carbide (Cr$_{23}$C$_6$) peak in the both results.

The quantity of Cr$_{23}$C$_6$ was compared by using eq. (1).

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V = \frac{\text{Integrated value of Cr}_{23}C_{6} \text{ peak}}{\text{Integrated value of } \beta \text{ brass main peak}} \tag{1}
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Table 1 shows the calculated volume fraction of Cr$_{23}$C$_6$ in the specimens. The volume fraction of Cr$_{23}$C$_6$ in HT specimen was largest in the specimens. Chromium, precipitating and diffusing to the brass powder surface, reacted with the graphite. The hardness of the chromium carbides is generally high.\textsuperscript{15} It was considered that the increase of the quantity of chromium deposition caused the decrease of the matrix hardness, and that the volume increase of the chromium carbide was a cause of the low drilling speed.

### 4. Conclusion

Cu-40 mass% Zn-1.0 mass% chromium alloys dispersed with graphite particles were prepared by using powder metallurgy process in order to produce high strength and good machinable brass alloys. Effect of the precipitation of chromium and the reaction between chromium and graphite on the mechanical properties and machinability of consolidated material were examined. The results in this study are summarized as follows.

(1) The 873 K SPSed had highest hardness and machinability in the materials of this study. The conventional relationship of trade-off balance between machinability and hardness of sintered materials was not confirmed in the samples of this study.

(2) There were fine precipitation of chromium in the 873 K SPSed and little chromium carbide existed at the particle boundaries in the sintered material. These fine precipitation and solid solubility of chromium was effect to the increasing the hardness of brass matrix. On the other hand, chromium carbides Cr$_{23}$C$_6$ existed in the 1053 K SPSed and HT materials and there were few fine precipitation of chromium in both samples. The relative quantity of graphite decreased with increasing the chromium carbides.

(3) The increase of chromium precipitation caused the decrease of the matrix hardness and the increase of chromium carbide Cr$_{23}$C$_6$. The increasing chromium carbide was a cause of decreasing relative quantity of graphite as machinable elements and increasing hard compounds. As a result, the machinability of 1053 K SPSed and HT materials decreased compared with 873 K SPSed material.

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