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CONSOLIDATION BEHAVIOR OF Cu-Co-Fe PRE-ALLOYED POWDERS

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ABSTRACT

In the present investigation, the consolidation behavior of Cu-Co-Fe pre-alloyed powder for the diamond tools is discussed. Premixed salts of copper, cobalt, and iron were reduced in hydrogen atmosphere to develop the powder. Diamond-pre-alloyed powder composites were prepared by cold pressing followed by pressureless sintering and hot isostatic pressing (HIP). The synthesized powder contained two phases; copper as a major phase and cobalt-iron as a minor phase. The compaction behavior of the powder was slightly affected by the addition of 2 wt % of diamond to the powder. The smaller particle size and higher weight percentage of copper in the powder resulted into the better densification and consequently higher sintered density.

Keywords: Cu-Co-Fe prealloyed powder, Diamond tools, pressureless sintering and hot isostatic pressing

1. INTRODUCTION

The range of uses for diamond tools is partly determined by the physical and chemical properties of the matrix and above all its resistance to heat, chemical and mechanical loads as well as its wear resistance[1]. The cobalt metal powder, used in industry as a matrix material for rock cutting diamond tools, is an expensive and strategic material. Therefore, since last ten years, the research is focused on to develop alloy powders which could be the alternative or at least reduce the content of the cobalt in diamond tools. The development of pre-alloyed powders as a diamond tool matrix is the result of this ongoing research[2]. Commercially available powders containing Cu, Co and Fe in predetermined ratios have been produced and used in the construction diamond tools e.g. floor sawing, wall sawing and core drilling of reinforced concrete and asphalt. These powders can be processed exactly in the same equipment as usual cobalt powders. Due to sub-micronic size of these powders, the maximum density and hardness are achieved at temperatures as low as 650ºC, which offers several possibilities of savings[3, 4].

2. EXPERIMENTAL PROCEDURE

Nitrates of copper, cobalt and iron were mixed in the water and heated to dryness. The dried mixture of salts was reduced in hydrogen atmosphere to get Cu-Co-Fe pre-alloyed powder. The reduction temperature, heating rate and holding time were varied to obtain higher purity and smaller grain size.

Following the conventional route, the metallic powders were first dry mixed with 0.7wt % of an organic binder (PVA) as a pressing aid. Mixing was carried out using mortar and pesters.

Diamond particles of 40-60 US mesh were subsequently mixed in a concentration of 2 wt %. The compaction behavior of the synthesized powder mixture was studied by die pressing cylindrical green specimens at 500MPa pressure. Pressureless sintering of the specimens was carried out at 950°C for two different heating rates (5°C /min and 10°C /min). It was followed by hot isostatic pressing (HIPing) at 100MPa and 900°C in argon atmosphere for 30 minutes. The X-ray diffraction analysis of the powder samples was carried by PHILIPS PW 1800 XRD unit, using copper target (wavelength = 1.54 A°). The chemical composition and microstructure of the pre-alloyed powder was analyzed by using FEI and Jeol JSM 840A scanning electron microscope (SEM) attached with energy dispersive spectroscope (EDAX). The particle size of the powders was determined by laser particle size analyzer, GALAI-CIS-1.

3. RESULTS AND DISCUSSION

3.1 Characterization of the Cu-Co-Fe prealloyed powder

The selection of metal salts was found to depend on various factors like type of metal powders required, reduction temperature and impurities. Nitrates of said elements were taken as starting materials because of their high solubility in water and lower reduction temperature. The dried mixture of nitrates after reduction in hydrogen atmosphere at 650ºC gave the Cu-Co-Fe pre-alloyed powder.

Figure 1(a) shows chemical analysis of the Cu-Co-Fe powder with anticipated proportions of the copper, cobalt and iron. Carbon and oxygen are also present as impurities. The theoretical density of the Cu-Co-Fe pre-alloy (8.33 g/cc) is lower than that of cobalt alone (8.9 g/cc). Hence, the use of Cu-Co-Fe pre-alloyed powder could allow savings on raw material cost. X-ray diffraction pattern of the synthesized pre-alloyed powder (figure 1(b)) shows two phases; copper as a major phase and cobalt-iron in the form of solid solution of cobalt in iron as a minor phase. The crystallite size of both phases is found to be equal (~25 nm) as determined by Debye-Scherrer formula. Copper is a continuous phase in the powder because of its limited solubility in the Fe-Co solid solution with bcc lattice for the given reduction temperature (650°C). The average particle size of the Cu-Co-Fe pre-alloyed powder is 3.3µm which is less than that of commercially available prealloyed powder[3]. Figure 1(c) shows SEM micrograph of Cu-Co-Fe powder. Powder particles are in the form of irregular shaped agglomerates, which is a characteristic of the powder prepared by reduction technique. The agglomeration occurs due to a high surface area and the action of chemical and mechanical forces.

3.2 Compaction studies

Figure 2 shows the variation of green density of the powder due to the applied pressure. The powder without addition of diamond does not show work hardening with the increase in the compaction pressure owing to the room temperature ductility of copper and irregular shape of the particles. Due to its low yield stress and the stress concentration effect produced by the presence of a second hard Fe-Co phase, copper exhibits significant plastic deformation and consequently a high green density. The plastic flow of copper helps to increase in contact area between irregular particles and the creation of interparticle locking.

It is also noteworthy that the compaction behavior of the powder is slightly affected by the addition of 2 wt % of diamond to the powder. At lower compaction pressure, the diamond particles which are extremely hard oppose the compressive force during compaction and consequently result into the decrease in green density of the pre-alloyed powder. However, at higher compaction pressure, comparatively large sized diamond particles help to deform copper and result into slight increase in green density.

3.3 Sintering Studies

Figure 3 shows sintering behavior of Cu-Co-Fe powder mixed with diamond powder as a function of heating rate. The smaller particle size and higher weight percentage of copper in the Cu-Co-Fe powder leads to the better densification and consequently higher sintered density. It is the diffusion rather than plastic flow of copper which is more dominant during sintering at high temperature (950°C). The sintering density of the powder is not significantly affected by the increase in the heating rate (from 5°C/min to 10°C/min). Maximum relative sintered density obtained after sintering is 97.4 %. Thus, it becomes possible to obtain the full density by hot isostatic pressing without subjecting the specimen to traditional glass encapsulation.

The hot isostatic pressing (HIPing) of Cu-Co-Fe - Diamond sintered specimens results maximum sintered density due to initial less amount of porosity (2.6 %). Full density is obtained for the specimens who were earlier sintered at 950°C in hydrogen atmosphere (heating rate: 10°C /min) and subjected to HIPing at 100MPa and 900°C in argon atmosphere for 30 minutes. The high sinterability of Cu-Co-Fe powders suggests the possibility of using pre-sintering followed by HIPing as an alternative fabrication route for pre-alloyed based diamond tools.

Figure 4 shows fractograph of sintered Cu-Co-Fe powder with diamond particles. The sites, from where the diamonds are dislodged due to impact loading could be seen in the figure. It is due to the plastic deformation (more ductility) of copper which results into a weak holding of the diamond in the matrix. Figure 5 shows slight attack on the diamond surface due to pre-alloyed powder. The fractured matrix surface shows a ductile failure under the impact loading with the characteristic dimples. The diamond / matrix interface indicates that the bonding between the diamond and powder is held by weak mechanical forces with little contribution coming from chemical bonding. However, it is important to note that no optimizations were made with varying diamond concentration and size or with respect to mixing other powders with Cu-Co-Fe powder, which could potentially strengthen the bonding.

4. CONCLUSIONS

1. The Cu-Co-Fe pre-alloyed powder can be produced by using chemical solution technique. Premixed salts of copper, iron and cobalt reduce above 650ºC to form pre-alloyed powder. The synthesized powder contains two phases; copper as a major phase and cobalt-iron as a minor phase.

2. Due to its low yield stress and the stress concentration effect produced by the presence of a second hard Fe-Co phase, copper exhibited significant plastic deformation and consequently a high green density. The compaction behavior of the powder is slightly affected by the addition of 2 wt % of diamond to the powder.

3. The smaller particle size and higher weight percentage of copper in the Cu-Co-Fe powder leads to the better densification and consequently higher sintered density.

4. High temperature pressureless sintering followed by hot isostatic pressing maximizes sintered density of the Cu-Co-Fe - Diamond composite. It also suggests the possible route for processing of these pre-alloyed powders for the consolidation of diamond tools.

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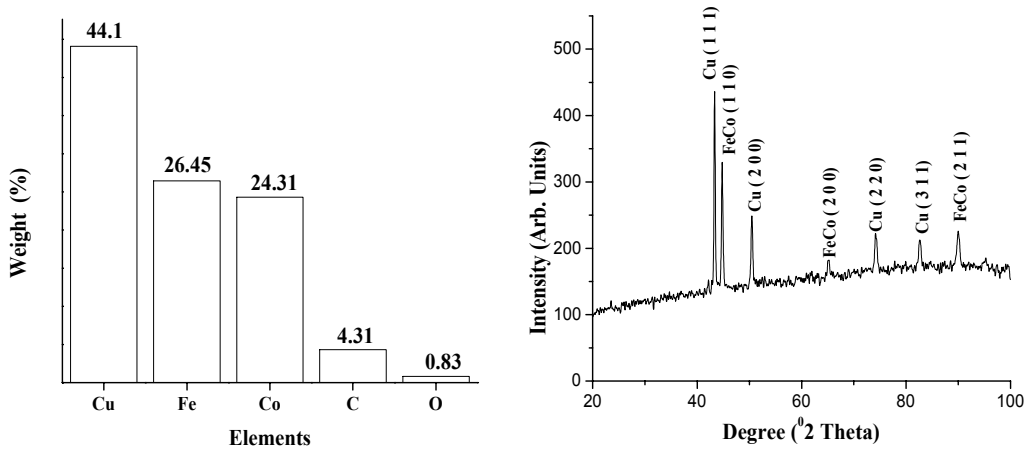
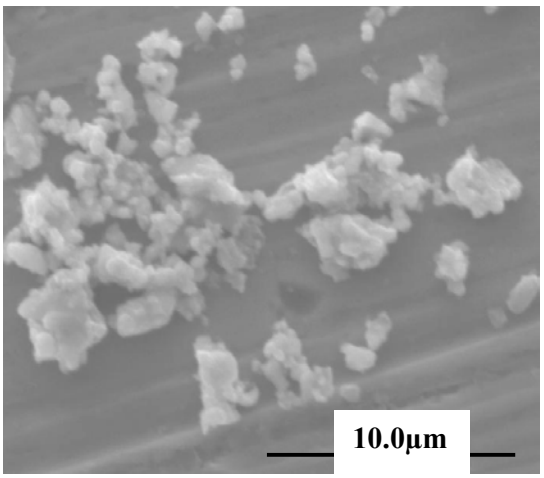
FIGURES



(a) Chemical analysis (b) X-ray diffraction pattern



(c) Scanning electron microscopic image

Fig. 1 Characterization of synthesized Cu-Co-Fe pre-alloyed powder

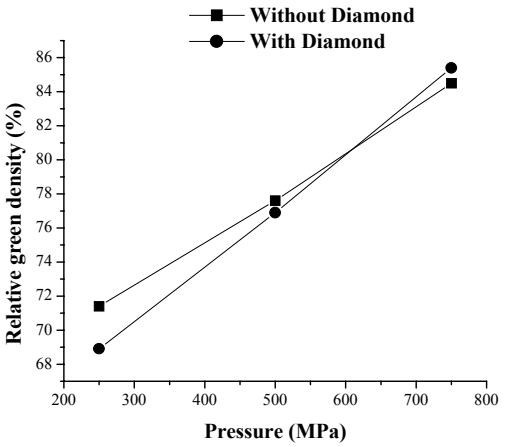


Fig. 2 Green density of Cu-Co-Fe powder as a function of compacting pressure

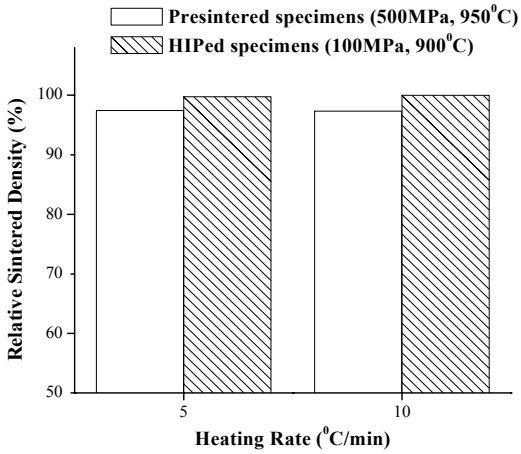


Fig. 3 Effect of hot isostatic pressing (HIPing) on Cu-Co-Fe - Diamond specimens presintered at different heating rates

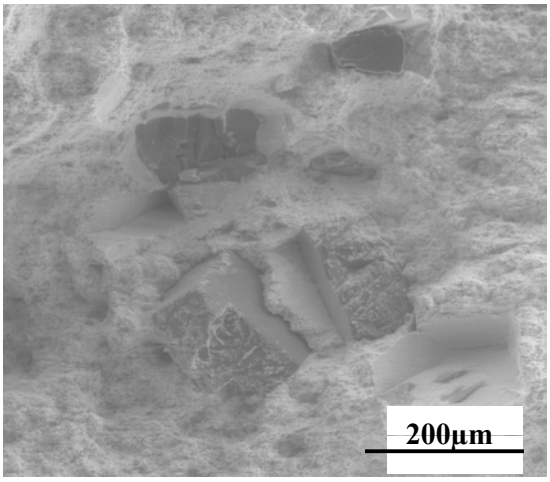


Fig. 4 Fractograph of the Cu-Co-Fe – Diamond Composite

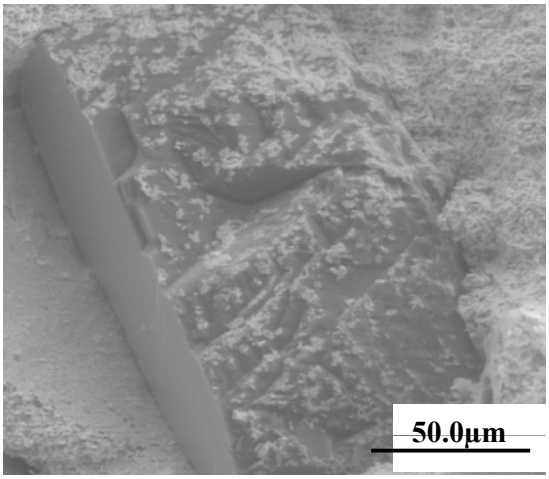


Fig. 5 Diamond particle in the Cu-Co-Fe matrix