Cu-Co-Fe PRE-ALLOYED POWDER AS A MATRIX MATERIAL FOR DIAMOND TOOLS

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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. 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 productive usage of diamonds within the cutting tool depends on the capability of the matrix to hold the diamonds and thus its support to cutting process. There is no universal, all-purpose bond. In practice, every tool manufacturer employs his own thoroughly tested compositions and sintering compositions. Metal bond constituents in widespread use are based on copper and copper alloys, iron, cobalt, as well as high-melting point carbides and metal powders. The presence of carbides and high melting point metals fillers (e.g. Ti, Cr, W, Zr, Si and Mo) in tool matrix increases the abrasion resistance. Besides, powder characteristics such as particles size distribution, particle shape and sinterabilty also affects the selection of the binder for stone and rock cutting application [1, 2].

The cobalt metal powder, used in industry as a matrix material for granite cutting diamond tools, is an expensive and strategic material. Therefore, since last ten years, the research is focused on developing the 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 [3]. 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 750ºC, which offer several possibilities of savings [4,5].

2. Experimental Procedure

Following the conventional route, the experimentally developed Cu-Co-Fe pre-alloyed 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 2wt %. 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 matrix 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). This shows that 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 pre-alloyed powder. 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 pyroletic technique. The agglomeration of the powder particles is due to the high surface area and the action of chemical and mechanical forces.

3.2 Compaction studies

Figure 2 shows the variation of the green density of the powder compacts without addition of diamond against the applied pressure. The plastic flow of copper helps to increase the contact area between irregular particles and the creation of interparticle locking. Also, the presence of hard Fe-Co phase leads to significant plastic deformation of copper and consequently a high green density. It is also noteworthy that the compaction behavior of the powder is slightly affected by the addition of 2wt % of diamond to the powder. At lower compaction pressure, the diamond particles, which are extremely hard, oppose the compressive forces of compaction and consequently result into the decrease in green density of the pre-alloyed powder. However, at higher compaction pressure, diamond particles help to deform copper due to their large size and result into slight increase in green density as shown in fig.2.

3.3 Sintering Studies

Figure 3 shows density variation of Cu-Co-Fe powder mixed with diamond powder sintered freely at different heating rates. The smaller particles 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). SEM images (Fig.1 (d)) of sintered specimens heated at 5°C/min shows non-geometrical sintering. The hot isostatic pressing (HIPing) without traditional glass encapsulation 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 the sites, from where the diamonds are dislodged due to impact loading. It is due to the plastic deformation (more ductility) of copper, which results into a weak holding of the diamond in the matrix. Figure also shows slight attack on the diamond surface due to pre-alloyed powder. 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 compaction behavior of the powder is affected by the plastic deformation of copper and the stress concentration effect produced by the presence of hard Fe-Co phase. At lower compaction pressure, the addition of diamond particles results into the decrease in green density of the pre-alloyed powder. However, at higher compaction pressure, diamond particles help to deform copper and result into slight increase in green density.
2. 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.
3. 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.

References

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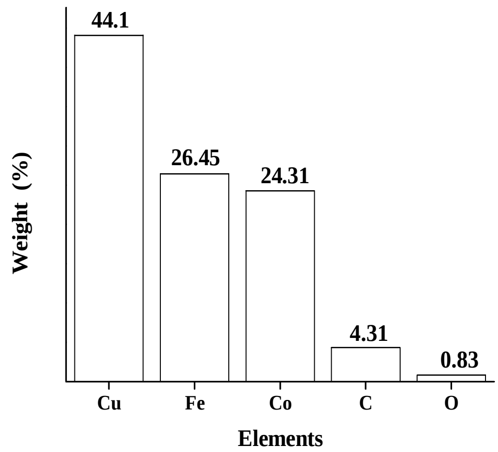
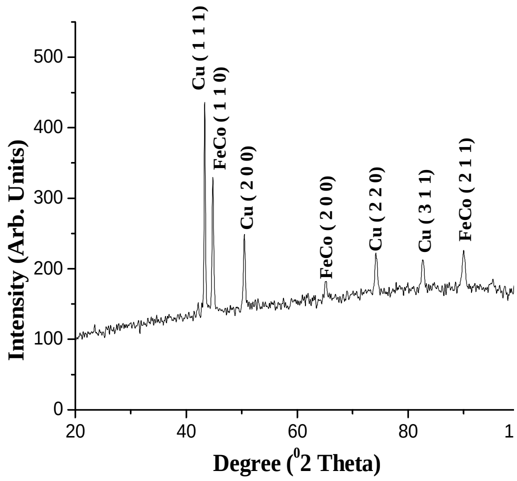
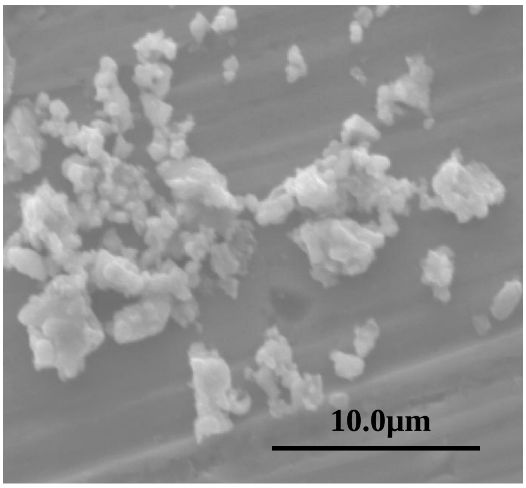


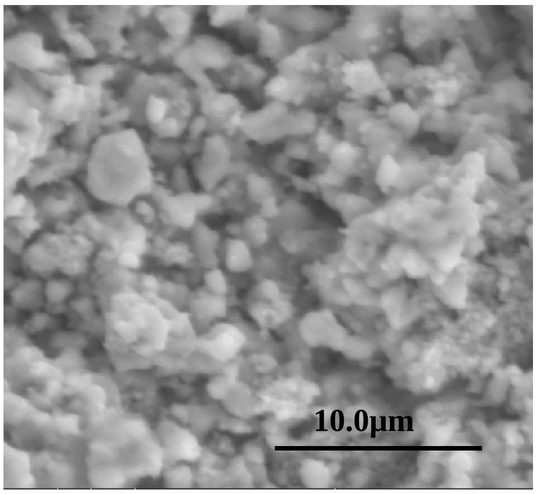
(a) Chemical analysis



(b) X-ray diffraction pattern



(c) SEM image of the powder



(d) SEM image of sintered compacts

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

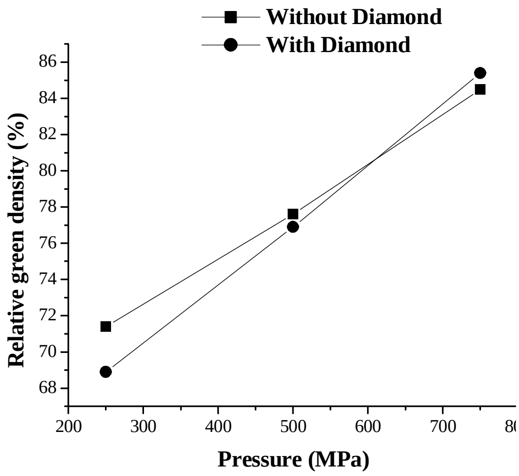


Fig. 2 Green density of Cu-Co-Fe powder as a function of compacting pressure

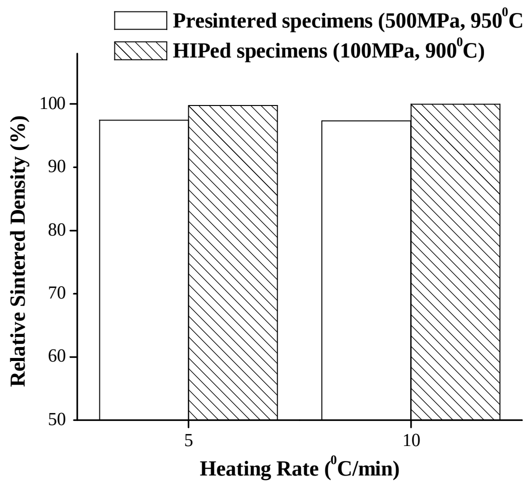


Fig. 3 Effect of hot isostatic pressing (HIPing) on Cu-Co-Fe - Diamond specimens presintered at different heating rates

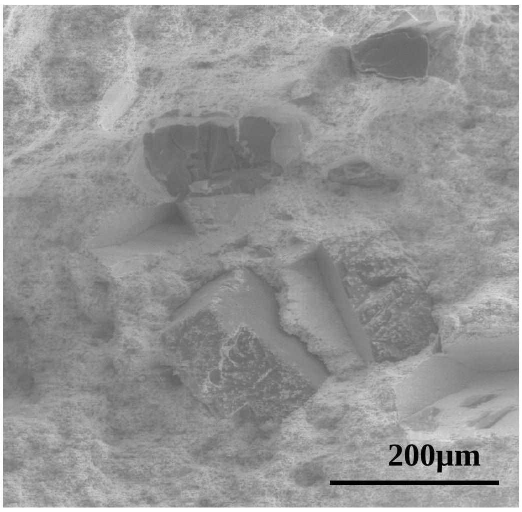


Fig. 4 Fractograph of the Cu-Co-Fe – Diamond Composite

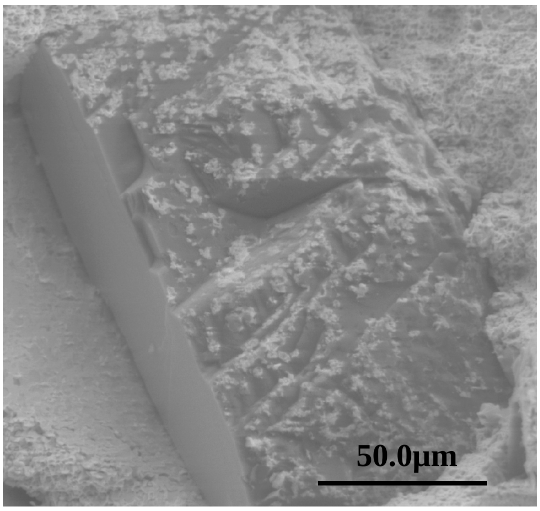


Fig. 5 Diamond particle in the Cu-Co-Fe matrix