Properties of Diamond Tool Binders with Fine Carbonyl Ni Powder Additions

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Abstract

Fine Ni powder is often added to Co and bronze-based metal binder powders for diamond tool segments. Ni is a lower cost substitute for extra-fine Co powder and increases the toughness of Co-Fe diamond binders at the expense of lower hardness and bend strength. In bronze-based diamond binder segments, Ni increases hardness and yield strength. Several grades of Ni powder are used commercially with both Co and bronze-based diamond binders. This paper compares properties of diamond binders containing carbonyl Ni powders including standard Inco ® T255, T123 PM and T 110 PM. Binder materials were made by ball milling or dry mixing fine carbonyl Ni and Fe powders with either XF Co or air atomized bronze (90/10 Cu/Sn) powders. Co-based powder blends were hot pressed at 20 - 35 MPa and 700 to 900 °C. Bronze-based powder blends were cold pressed and sintered at 840 °C. Apparent density, apparent hardness and bend strength (TRS) were compared for different binder compositions and processing conditions.

Introduction

Commercial diamond binders tend to be proprietary and complex in terms of composition. Interest in substitute diamond binders has been primarily driven by the high cost and unstable supply of Co. Ni and Fe commonly replace a portion of Co, however there is an associated loss in yield strength and hardness. In addition to the loss in mechanical properties, graphitization of diamond at elevated processing temperatures is catalyzed in the presence of Fe [1]. Ni on the other hand typically has a higher graphitization onset temperature than both Fe and Co [2]. Cu-based binders often have Co, Fe and Ni additions to improve hardness and strength. Co-free binders used in diamond cutting tools for hard materials such as granite often have Ni additions ranging from 10 to 25 wt.% with Fe (30 to 55 wt.%) and bronze (35-45 wt.%) as balance.

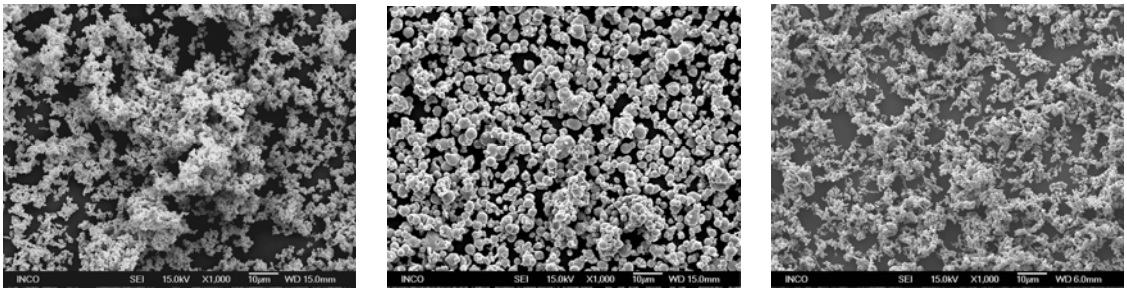
Little information exists in the literature pertaining to the influence of the various metals on the field performance of diamond tools. This paper summarizes some preliminary research recently undertaken by the authors to develop an understanding of the interaction of Ni in particular with the various alloying elements found in commercial diamond binders.

Materials and Results

Co-based Diamond Binders

Until recently, commercially available Ni powders have been coarser than extra-fine grade Co powders (XF Co), and provided a correspondingly lower sintering activity. Several grades of carbonyl Ni powder are used commercially with both Co and bronze-based diamond binders: Inco ® T123 PM, T255 or T287 and T110 PM. T123 PM is a fine, discrete Ni powder that mixes well with other metal powders. T255 and T287 are filamentary grade Ni powders, differing in apparent density and are often preferred by diamond tool producers for their finer primary particle size compared to T123 PM. T110 PM is a new extra-fine grade discrete Ni powder (XF Ni) with increased sintering activity.

The metal powders chosen for Co-based binders were as follows: Co - Umicore Extra-fine grade d_{50} = 3.6 μm; Ni - Inco T110 PM d_{50} = 1.5 μm; fine carbonyl Fe - BASF CN grade d_{50} = 6.5 μm. The morphology of the fine powders varies considerably, from sponge-like XF Co to loosely agglomerated XF Ni to discrete, nominally spherical fine Fe powder. Alloy composition contained up to 50 wt.% Ni whereas the Fe content was limited to 5% because of reported degradation of diamond at elevated hot compaction temperature [1,6].



XF Ni **Carbonyl Fe** **XF Co**

Fig. 1 Metal powders used in this study: (i) XF Ni (Inco ® T 110 PM); (ii) Carbonyl Fe (BASF CN grade); (iii) XF Co (Umicore XF grade)

Co, Ni and Fe powders were mixed by ball milling with 12 mm alumina spheres for 16 h in isopropyl alcohol. Total fill ratio metal powder plus milling media was approximately 55%, with 25% of the charge being metal powder. The milling time was chosen to obtain good dispersion of the alloying elements without smearing the soft metal powder, as was seen in samples milled for much longer periods. Lot sizes varied from 100 g to 1 kg. Confirmation of the mixing method was made by elemental x-ray mapping of the green compact in the SEM (Fig. 2). Ni-Co-Fe blends were consolidated into 60 mm diameter x 12 mm thickness discs by hot compaction in argon. Compaction pressure was 20 MPa (3 tsi) and 35 MPa (5 tsi). The discs were hot compacted between 700 ^{0}C to 900 °C and held at high temperature for 15 and 30 minutes. The sintered cylindrical discs were cut into transverse rupture strength (TRS) bars for mechanical testing. Apparent density, apparent hardness and bend strength (TRS) were measured according to standard [4] and compared for different metal binder compositions. Optical microscopy and SEM with x-ray EDS and mapping were used for the microstructure study and analysis of inter-diffusion in Ni-Co-Fe system.

The apparent hardness of Co-Ni-Fe materials increased with increasing sintering temperature, in line with the corresponding increase in sinter density (Fig. 2). The Ni-free materials achieved apparent hardness values > 100 HRB above 800 °C, whereas the Ni-containing materials required sintering temperatures of at least 850 °C to achieve 100 HRB. Figure 3 also shows the effect of increasing Ni content on the apparent hardness of Co-5Fe; increasing Ni from 10% to 50% decreased HRB by approximately 16 points at a hot compaction temperature of 850 °C. Samples hot pressed at 35 MPa for 15 minutes still required a compaction temperature of 850 °C to achieve similar hardness to Ni-containing binder materials processed at 20 MPa for 30 minutes. TRS was highest for pure Co (Fig. 3). Bend strength of the Ni-containing materials was typically 15% lower than pure Co at sintering temperatures above 800 °C.

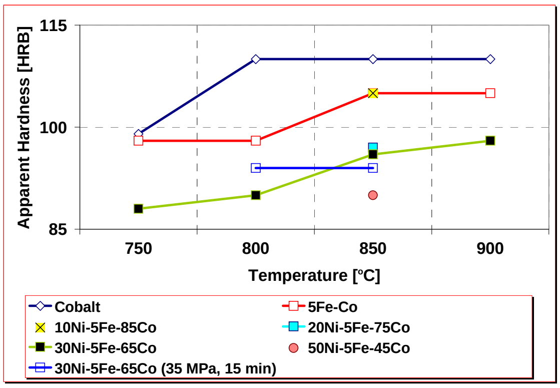


Fig. 2 Apparent Hardness of Co-Ni-Fe binders hot pressed at 20 and 35 MPa, 15 to 30 minutes

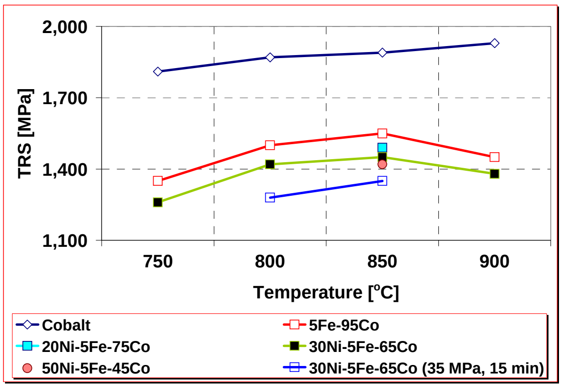


Fig. 3 Transverse rupture strength of Co-Ni-Fe binders hot pressed at 20 and 35 MPa, 15 to 30 minutes

Ni-Fe based binders

There is strong commercial interest to replace Co-based diamond binders with alternative, less costly metal binder systems. Fe-based binders with additions of Ni, Cu and Sn demonstrate properties that are comparable to Co and can be processed to near full density at similar sintering temperatures below 900 °C. An example of an Fe-Ni based commercial diamond segment is shown in Fig. 4. The Ni powder used was Inco T255 grade. The Fe and Ni are well distributed, with average grain size between 30 and 75 μm.

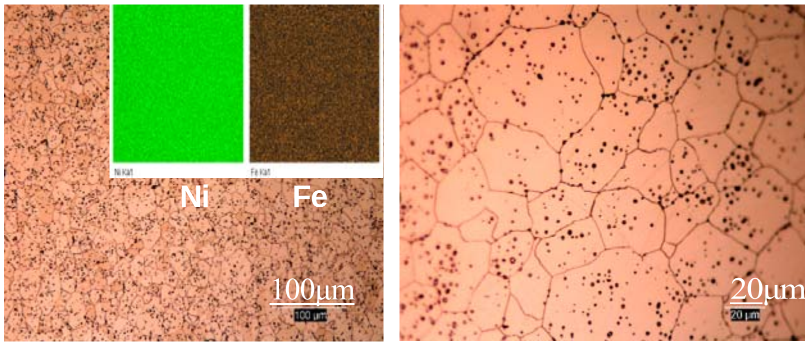


Fig. 4 Optical micrographs of commercial diamond segment with Fe-Ni (T255) binder. Etched 2% nital.

Initial mixing trials with Ni and Fe powder by ball milling were not successful. Simple dry mixing for 30 minutes in a Turbula blender was therefore chosen. In order to determine the effect of Fe:Ni ratio on mechanical properties, various amounts of Fe were added to Ni, cold compacted at 410 MPa and free sintered at 840 °C for 30 minutes ($90N_2/10H_2$). In Figure 4, physical properties including apparent hardness and tensile strength were generally highest when Fe:Ni ratio was below 30% or above 70%, corresponding to the highest relative sintered density.

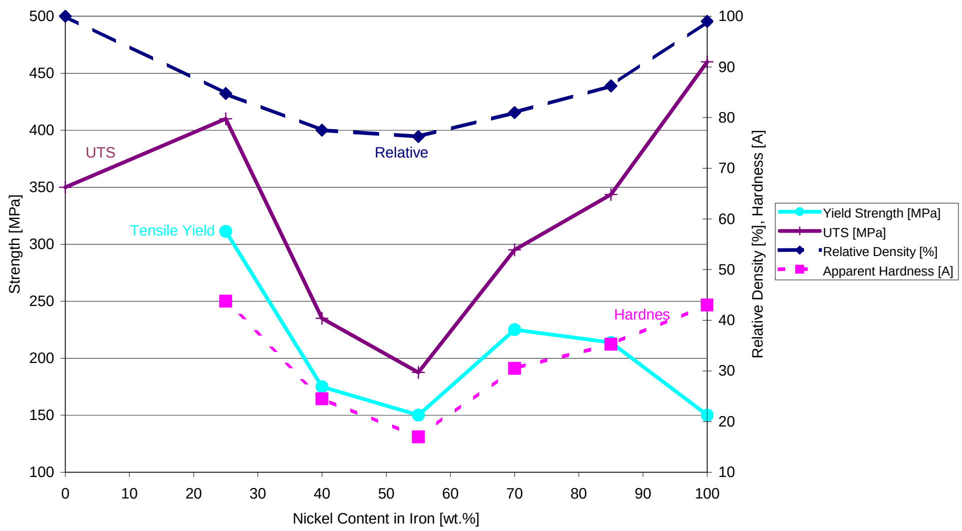


Figure 5. Summary of physical properties of Fe-Ni diamond binder materials

Bronze-based diamond binders

The bronze powder chosen for cold compaction processing in this study was an air atomized 90 Cu/10 Sn, –325 mesh powder (ACuPowder) as shown in Fig. 6. Approximately 1.5% Zn is added to the bronze prior to atomization in order to provide an irregular shape to the powder for higher green strength.

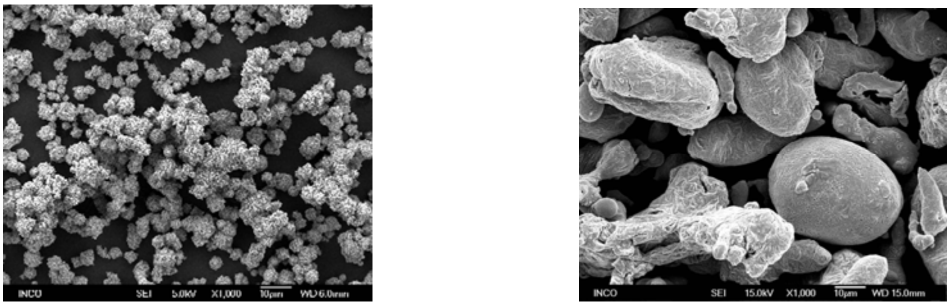


Fig. 6 T123 PM Ni powder (left) and air atomized 90/10 bronze (ACuPowder 5631-C) (right) used in bronze-based diamond binders for this study.

Fine Ni and Fe metal powders were prone to segregation within the coarser bronze-based powder due to differences in particle size and powder morphology. The soft metal powder also tended to smear on the surface of the milling media. Although XF Ni (Inco ® T110 PM) offers the potential to lower sintering temperatures for Ni-containing bronze binders, or Ni backing layers between shank and bronze-based segments, T123 PM was chosen for preliminary trials due to its ease of use (Fig. 6). BASF CN grade carbonyl Fe powder was also used for the bronze binder materials (Fig. 1).

As a result of the behaviour of Fe and Ni observed in the preceding section, a 4:1 Fe Ni ratio was selected for testing in bronze powder mixes. While Fe additions to bronze maintained ductility with an increase in apparent hardness from 18 to 53 HRA, the addition of Ni to bronze without Fe created a less ductile material resulting from the formation of Ni-Sn intermetallics (Fig. 7).

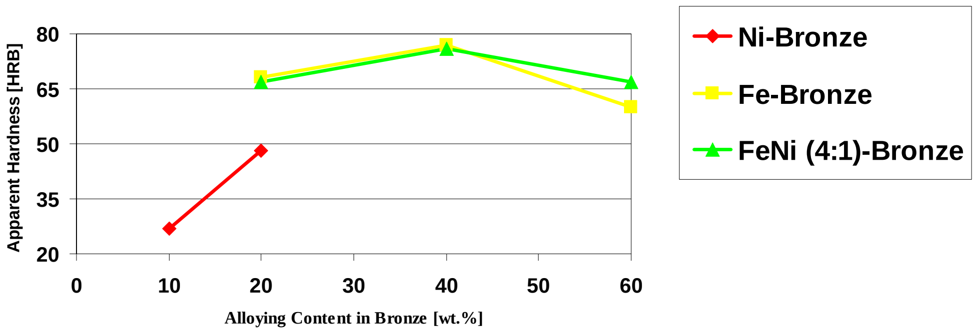


Fig. 7 Apparent hardness of Ni and Fe additions to bronze-based diamond binder materials, free sintered 840 °C for 30 minutes.

Ni additions to bronze containing 15% Fe maintained some ductility with higher yield strength than bronze-Fe (260 vs. 220 MPa). Metallography revealed a dual phase structure of Ni-Fe and bronze, with evidence of interdiffusion at the phase boundaries. EDS mapping revealed that diffusion of Fe into Ni impeded diffusion of Sn and prevented the formation of brittle Ni-Sn phases.

Conclusions

The addition of Ni increased sinter density of both Co (if sintered at temperatures above 800 °C) and bronze-based diamond binder materials. The interaction between Ni and Fe is much more pronounced than between Fe and Co or Cu, with strong evidence of Fe diffusion into Ni at temperatures above 800 °C.

For Co-based binders, XF Ni required sintering temperatures greater than 750 °C in order to develop sufficient strength. The sintering activity of XF Ni is lower than that of XF Co at temperatures below 800 °C, as a result of the sponge-like morphology of XF Co compared to discrete particles of XF Ni powder. When sintered at temperatures above 800 °C, the addition of up to 50 wt.% Ni to Co-5Fe resulted in mechanical properties approximately 10% lower than pure Co binders. Sinter density was > 98%, apparent hardness approached 100 HRB and TRS was > 1600 MPa.

In bronze-based binders there is an important interaction between Ni, Fe and Sn. In the absence of Fe, Sn readily diffuses into Ni resulting in a loss in apparent hardness and embrittlement of the binder material through the formation of Ni-Sn intermetallic phases. The addition of Fe together with Ni impedes diffusion of Sn and improves the mechanical strength. Sinter densities of free sintered bronze binders containing 5-25 wt.% Ni and 15-30 wt.% Fe were over 90%. The addition of Fe and Ni increased tensile yield strength to > 200 MPa, apparent hardness to > 60 HRB and TRS > 800 MPa.

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