Polycrystalline diamond (PCD) materials can be found in a wide range of applications, from machining of abrasive alloys, wood and plastics, to wire drawing and rock drilling. PCD compacts consist of diamond powder that has been sintered at high pressure (5.5 GPa) and temperature (>1400 °C) onto a WC/Co substrate. During this process the cobalt from the substrate melts, infiltrates and causes the diamond grains to bond to each other, thus creating a strong network of diamond grains. The cobalt metal is left behind as small pockets within the composite material. An unfortunate consequence of the residual cobalt, is that it leads to a degree of thermal instability when the material is exposed to temperatures exceeding 700 °C [1]. The cobalt metal acts as a carbon solvent and will graphitise diamond at atmospheric pressure and elevated temperatures. In this study, PCD material was heated in an inert atmosphere and the various microstructural changes were investigated, in order to gain an understanding of this thermal degradation process.

Cobalt based PCD samples were heated in an argon atmosphere for various times and temperatures. Temperatures of 700 °C, 750 °C, 800 °C and 850 °C were used at time intervals of 30 min, 2 hours, 4 hours and 6 hours. X-ray diffraction (XRD) was performed to determine the resulting phases and lattice parameters. In-situ XRD was performed in vacuum at 800 °C in order to track the changes in the material as a function of time. Transmission electron microscopy (TEM) using the techniques of High Angle Annular Dark Field (HAADF) Scanning-TEM (STEM) and Electron Energy Loss Spectroscopy (EELS) were used in order to investigate the chemical changes of this material during the heat treatment.

The cobalt lattice parameter decreased as a function of heating temperature (Figure 1) and time. The formation of graphite was preceded by η-phase formation at the cobalt/diamond interface (Figure 2). At heating temperatures of 800 °C and above, graphite formed in the cobalt pools (Figure 3). The results of this study were used to propose a possible mechanism, whereby the dissolved tungsten in the cobalt pool will combine with dissolved carbon and cobalt to form η-phase instead of graphitic carbon. The dissolved tungsten will then delay the process of graphite formation in the cobalt pool. If the tungsten levels are depleted or if the rate of carbon influx is too high, then graphitic pools will form in the cobalt pool. In this model, dissolved tungsten in the binder is thought to be beneficial to the thermal resistance of PCD.

References

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Fig. 1: X-ray diffraction pattern showing a shift in cobalt lattice parameter as a function of temperature for 2 hour exposure.

Fig. 2: Bright-field TEM image showing a degraded cobalt pool after heating at 700 °C for 2 hours. Dark particles identified as the η-phase carbide with the aid of EDS analysis and electron diffraction.

Fig. 3: HAADF-STEM image with EELS spot analysis of a degraded cobalt pool after heating at 800 °C for 2 hours. The EELS analysis show the presence of graphite inside the cobalt pool.