Thermal Protection Shield Concept for Diamond Impregnated Tools

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Abstract

For dry machining of mineral materials the Institute of Materials Engineering pursues a novel thermal protection shield concept for diamond tools, in which thermal insulating materials in diamond composite structures act as heat shield, which protects diamonds in deeper layers against high temperature and graphitisation. Before the effectiveness of this concept could be investigated suitable composites have to be manufactured. In this paper the powder metallurgical production processes of diamond-alumina-cobalt-composites with varying alumina and cobalt particle sizes, their microstructures and porosities are described. It could be observed that the distribution of small-sized alumina particles (< 70 µm) in the cobalt matrix is uniform and the porosity of the composite decrease.

Keywords: diamond impregnated tool, thermal protection, heat shield concept, pressureless sintering

In comparison to conventional tools based on tungsten carbide diamond tools become more important for the machining of mineral materials due to their better mechanical and physical properties, particularly their extreme hardness [1,2,3]. During the machining processes the tribological contact between the diamond tool and the mineral material result in the deterioration of the diamonds owing to the low fracture toughness and the heat sensitivity of the diamonds, that graphitise and oxidise at temperatures above 500°C in air [3,4]. To reduce such deteriorations diamond tools are cooled with water during machining and so the major problem is to guarantee water supply on building sites and the risk of contaminating occupied buildings by concrete/rock-water-mixtures. Therefore a dry machining of mineral materials has significant advantages. However, during a dry application of conventional diamond tools the tribological and thermal wear will increase. In the case of diamond impregnated composites not only diamonds directly exposed to contact with mineral materials, but also diamonds in deeper layers of the segments will be damaged due to the heat transfer [5]. The Institute of Materials Engineering pursues a novel thermal protection shield concept for powder metallurgically produced diamond impregnated composites [6]. Thermal insulating materials such as alumina are inserted into the composite structure to act as a heat shield, which protects the diamonds in deeper layers against high temperatures and resulting damages. Consequently a new improved cutting behaviour can be expected.

To realise the thermal protection shield concept the embedding of diamond and alumina particles with varying particle sizes has been investigated at first. Diamonds (Element Six) with particle sizes between 300-450 µm and alumina (Munk + Schmitz GmbH) with three different particle sizes: 350-500 µm, 150-210 µm and below 70 µm have been employed. Pure cobalt powders with particles sizes between 45-90 µm (GTV GmbH) and particle sizes below 40 µm (Eurotungstene Poudres) have been used as metal binder. By addition of a small amount of a pressing additive based on wax six different powder mixtures were produced in a tumble mixer, table 1. Each mixture has been filled into a mould (ø = 15 mm, h = 10 mm) and pressed uniaxially with a compacting pressure of 550 MPa. The green compacts have been subsequently sintered free standing in a vacuum furnace at 1373 K (~ 0.73 T_m) for 4 hours. The structures of the various samples have been investigated by light microscopy and the porosities have been measured by digital image analysis.

The microstructure investigation of the sintered samples shows that in all three samples with mixed cobalt particle sizes ($co_{cf}/d/a_c$, $co_{cf}/d/a_m$, $co_{cf}/d/a_f$) the areas of fine cobalt fill the pores between the coarse cobalt leading to decent sintering results. The coarse cobalt particles are at the beginning of the intermediate stage of sintering associated with neck formation of different progress. In these three

Table 1. Composition of the used powder mixtures in vol.-%

	cobalt		diamond	alumina		
	45-90 µm	< 40 µm	300-450 µm	350-500 µm	150-210 µm	< 70 µm
$co_{cf}/d/a_c$	63	27	5	5		
$co_{cf}/d/a_m$	63	27	5		5	
$co_{cf}/d/a_f$	63	27	5			5
$co_f/d/a_c$	0	90	5	5		
$co_f/d/a_m$	0	90	5		5	
$co_f/d/a_f$	0	90	5			5

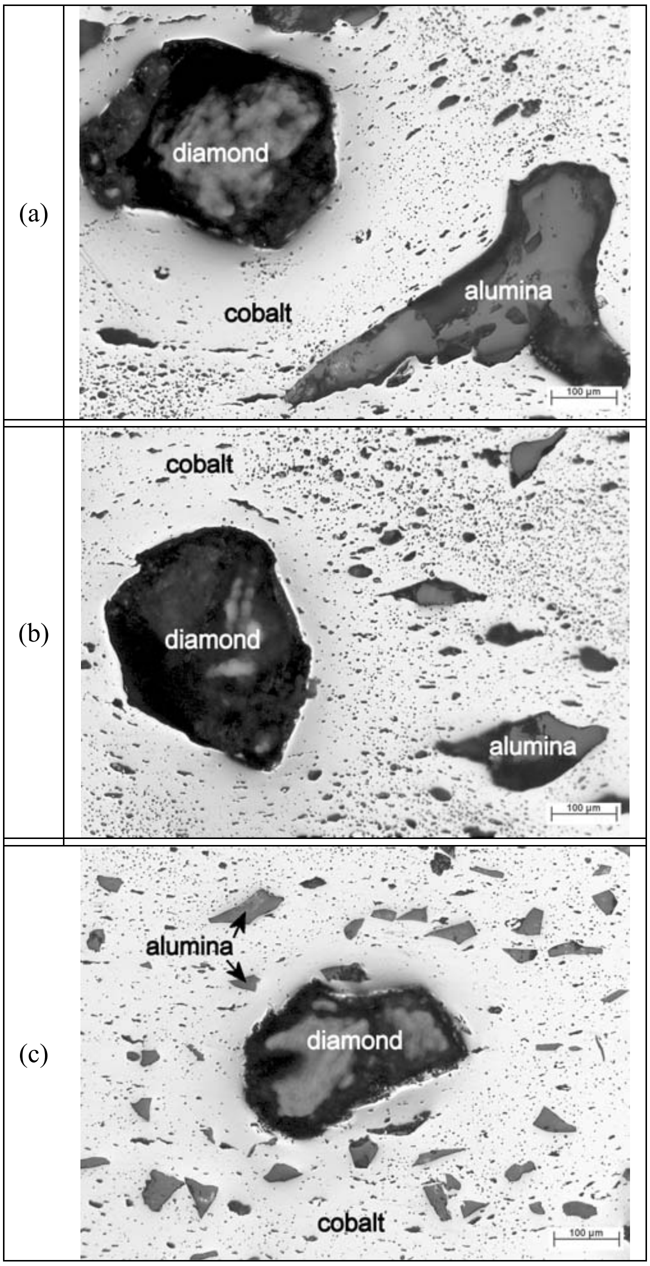

Fig. 1. Diamond-alumina-composites with varying lumina particle sizes after pressureless sintering in a vacuum furnace at 1100°C for 4 hours.
(a) $co_f/d/a_c$, (b) $co_f/d/a_m$, (c) $co_f/d/a_f$

samples the alumina particles as well as the diamonds seem to be sufficiently embedded in the cobalt binder. With decreasing particle size of the alumina ($co_{cf}/d/a_f$) the alumina particles are more homogenous distributed in the metal matrix. The microstructures of the three sintered samples with only fine cobalt particle sizes ($co_f/d/a_c$, $co_f/d/a_m$, $co_f/d/a_f$) seem to be more compacted in comparison to the three samples mentioned above, figure 1 (a, b, c). The solid state sintering of the fine cobalt particles is in the intermediate stage. Significant neck growth can be observed and the original grain boundaries are not identifiable. The alumina particles and the diamonds are well embedded in the fine cobalt matrix. Similarly to the samples before the distribution of the alumina particles in the cobalt becomes more homogenous with decreasing particle sizes ($co_f/d/a_f$), Figure 1 (c). The measurement of the porosity shows that the porosity of the examined samples is still high, up to 18 %. With lower particle sizes of the alumina the porosity is decreased to approximately 13 % for the samples with mixed cobalt particle sizes ($co_{cf}/d/a_f$) and to approximately 6 % for the samples with fine cobalt ($co_f/d/a_f$). It is irrelevant, if diamonds or alumina particles are inserted in the cobalt matrix. Rather the particle size and the amount of material inserted are important for the composite-porosity.

The investigations presented are the fundamental steps towards the realisation of the thermal protection shield concept for diamond impregnated composites. Alumina particles with various particle sizes are successfully inserted into the cobalt matrix. With decreasing particle size of the alumina the compactibility of the diamond-alumina-composite increases. The diamonds as well as the alumina particles can be sufficiently embedded in the cobalt matrix with mixed particle sizes. Further improvement can be achieved by the application of pure fine cobalt powder. But for the solid state sintering of the cobalt particle sizes employed the sintering parameters are not sufficient to reach the final stage of sintering in a pressureless sintering. In addition to the optimisation of the sintering parameters the use of cobalt powder with finer particle sizes, alloying additions or the encapsulation of the powder mixtures combined with sintering under pressure are further approaches to achieve diamond-alumina-composites of high density. The influence of insulating materials on thermal stability, strength, hardness and particular the behaviour of the corresponding diamond composites during machining are topics of further investigations. Appropriate machining tests under real conditions with special emphasis on heat development and wear resistance will be conducted to evaluate the efficiency of the thermal protection shield concept.

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