

DIAMOND-MAX BONDING PHASE COMPOSITES WITH NANOMETRIC TiCN ADDITION FOR APPLICATION IN CUTTING TOOLS

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Introduction

Commercial polycrystalline diamond compacts (PCD) are used in drilling and other machining applications. Their thermal stability (TS), defined as resistance to stresses – temperature inflicted graphitization in an inert atmosphere, is significantly compromised by compacting with a cobalt binding phase. One of the possibilities to preserve the acceptable thermal resistance of PCD is to keep the cobalt content at the lowest possible level. The second popular method of obtaining diamond composite with high TS is its infiltration with silicon forming SiC instead of allowing to form graphite. However, the SiC formation is associated with an increase in volume blocking PCD porosity during compacting and adversely affecting the porosity and roughness of the tool surface[1]. The PCDs with silicon bonding phase could be use only in drilling application. In such situation the development of new bonding phase is very much needed.

A Ti_3SiC_2 based on $M_{N+1}AX_N$ (M - metal, A - element of A group like IIIA or IVA, X – carbon or nitrogen) “nanolaminates” might make an interesting bonding phase alternative. It is stable up to 1400-1450°C [2], has a hexagonal $P6_3/mmc$ layered structure and combines high stiffness of ceramic materials with some ductility characteristic for metals. The latter property helps to fill most voids between compacted diamond crystallites [3]. Voids removal is crucial as otherwise the diamond particle is only locally bounded with binder or other diamond keeping diamond under compressive force state, i.e. preserving diamond stability. The simultaneous presence of multiple empty spaces leads to a tensile force state on the diamond surface, leading to its local graphitization. To still better fill in the voids the microcrystalline Ti_3SiC_2 was mixed with nano crystalline TiCN. This paper presents results of microstructure and selected - mechanical studies of high- temperature sintering of microcrystalline diamond and Ti_3SiC_2 powders with nano-crystalline TiCN.

Experimental

Materials, procedures and apparatus

The mixtures containing 70 wt.% diamond (3-6 μ m MDA, Element Six), 25 wt.% of Ti_3SiC_2 (SHS technique, AGH, Poland) and 5wt.% nanometric TiCN (Neomat Co, Lithuania) powders, as well as 70wt.% diamond and 30wt.% Ti_3SiC_2 (as a reference binder) were prepared. Before sintering, powders were baked at 870 K for 30 min under 0.8 Pa pressure. Next, they were sintered using a Bridgman-type high-pressure apparatus at 8.0 ± 0.2 GPa and at temperature of 2070 ± 50 K. Samples were heated in an internal graphite heater with an inside diameter of 15mm. The microstructure investigation were performed using scanning (Jeol) and transmission (Tecnai FEG 200kV) microscope. Samples for microanalysis and Vickers hardness measurement were prepared through lapping on a cast iron plate with diamond paste.

Results and Discussion

The reference compacts with 30wt. % of Ti_3SiC_2 show good distribution of binding phase in channels in-between the diamond crystallites (Fig.1). The contrast changes from light-grey to dark-grey point towered multiphase final binder composition. The presence of frequent but relatively small (i.e. staying well below sub-micron range) very dark areas indicated pores is evident. The compacts with 25 wt.% of Ti_3SiC_2 and 5wt.% TiCN present similar good distribution of binding phase as a reference compact (Fig.2). Additionally, the binder phase show averaged contrast in SEM (SE) imaging indicating its good homogenization and lack of voids or cracks. The transmission microscopy observations confirmed fine crystalline character of the binding material (Fig.3). Also in this case it has a multiphase character containing SiC, TiC and possibly TiCN crystallites (high thickness of FIB cut foils result in strong absorption of light elements preventing differentiating between the latter).

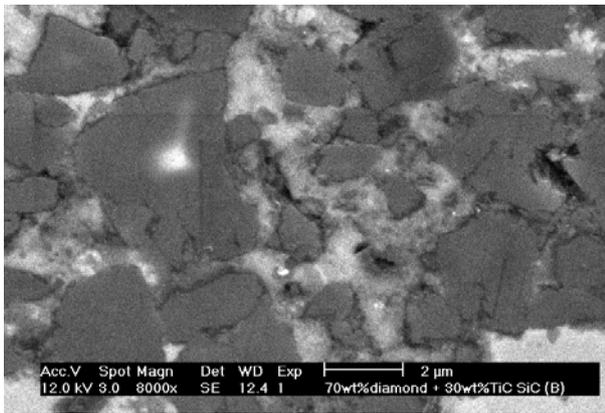


Fig.1 SEM image of diamond+Ti₃SiC₂ composite

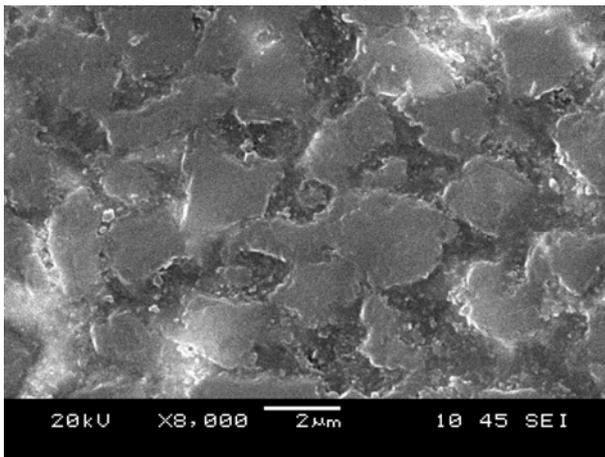


Fig. 2. SEM image of diamond+Ti₃SiC₂+TiCN composite

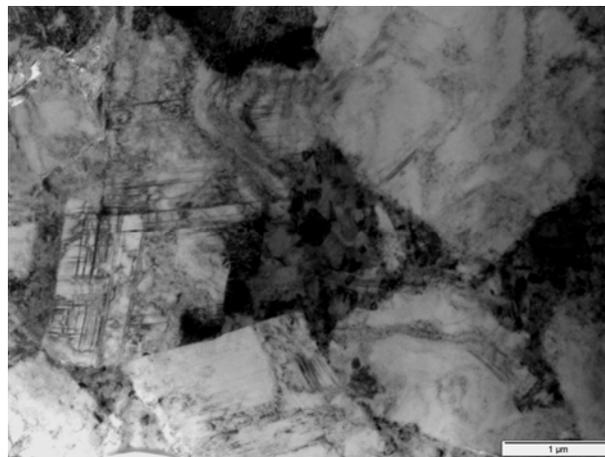


Fig.3 TEM image of diamond+Ti₃SiC₂+TiCN composite

The diamond crystallites are characterized by their light contrast, square shape and parallel sets of faults. The crystallites in binder phase staying in contact or at least close to diamond crystallites are usually in nano-meter range

The density, hardness and Young modulus of investigated compacts are presented at the Table 1. The addition of nano-size particles of TiCN helped to rise by ~10% both the composite hardness and stiffness.

Table 1. Selected physical and mechanical properties of PCD with 25 wt.% Ti₃SiC₂, 5wt.% of TiCN and PCD with 30 wt.% Ti₃SiC₂.

Bonding phase	Density* (g/cm ³)	Hardness ** HV1	Young mod. (GPa)
30wt.%Ti ₃ SiC ₂	3.608	4440±290	567
30wt.%Ti ₃ SiC ₂ 5wt.%nanoTiCN	3.50	5060±300	706

* Average measurement for three samples.

** Average of five hardness measurements, $\alpha = 0.05$.

Conclusions

The final product is formed of a skeleton-like diamond structure with pores filled with carbides, silicides and nanometric TiCN.

The limited ductile behaviour of the Ti₃SiC₂ phase helped to fill most of bigger voids between diamond grains, securing thermodynamic conditions for retaining the presence of diamond, i.e. limiting major graphite presence in the final composite.

The addition of nanometric TiCN phase into the Ti₃SiC₂ binding phase helped to eliminate the compacts residual porosity and farther stabilize conditions for retaining the diamond phase.

The newly developed binder, i.e. admixing of nano-crystalline TiCN into the Ti₃SiC₂ helped both to rise hardness and Young modulus of diamond compacts by ~10%.

Acknowledgment

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References

- [1] Barsoum M.W.: M_{N+1}AX_N phases: new classes of solids thermodynamically stable nanolaminates, Prog. Solid State Chem., 2000, 28, 201-281.
- [2] Mlungwane K., Sigalas I.J., Hermann, The development of a diamond-silicon carbide composite material, Industrial Diamond Review 4 (2005) pp.62-65.
- [3] Jaworska L., Szutkowska M., Morgiel J., Stobierski L., Lis J., Ti₃SiC₂ as a bonding phase in diamond composites, Journal of Materials science, Letters 20 (2001) pp.1783-1786.