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Effect of porous glass-ceramic materials addition on the cubic boron nitride (cBN) tools properties

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The results of physicochemical and mechanical investigations into the properties of bubble alumina (BA) and magnesium aluminosilicate (MA) addition to abrasive masses designed for cubic boron nitride (cBN) tools have been presented. Two kinds of addition were investigated by the following experimental techniques: scanning electron microscopy – microstructure, densimeter – helium density, microhardness test, dilatometer – α-TMA, wetting test. Bubble alumina fulfilled all the criteria of usability. Tools of 1A1 35×5×10×10 B126, 100, Pb21K with BA addition (0, 5, 10, 12 vol%) were made. A pre-performance investigation was done on grinding a LH-15 steel with tool speed of 30, 45, 60 m/s, microtopographies of wheels and work-pieces were described by the following roughness parameters: R_a (0.2–0.5 μm), R_z (1.16–2.2 μm), Δ_k (2–8 μm). The best results were obtained by using wheels with 10 vol% BA addition.

Keywords: cubic boron nitride (cBN) tools, vitrified bond, bubble alumina, magnesium aluminosilicate, wetting test, microhardness, pre-performance investigaton.

1. Introduction

There is recently a rapid development of new construction materials destined for the motor industry. They are mainly high nickel contents alloys, cobalt alloys and aluminium alloys with high magnesium contents. They are hard workable materials, especially by abrasive machining methods, as they are characterized by high ductility. This fact forces a development of new constructions of abrasive tools, especially internal grinding tools [1–7]. Conventional high porous cubic boron nitride (cBN) wheels do not provide such possibilities since they have fewer abrasive grains on the active surface, what results in thicker machined layers and an increase in chip volume. Such chips penetrate deeply into large open wheel pores causing local gumming up of grinding wheels and the deterioration of cutting abilities.

In order to increase the effectiveness of grinding of hard workable materials, we usually add to the vitrified bond of a grinding tool some additions of ceramic materials of spherical structure, which create closed pores (bubble alumina, vitreous microgranules) [4, 8]. Their role is such that, while grinding, their outer surfaces disintegrate, thus forming additional cutting edges and their empty interiors become temporary shallow chip stores [9–11].

In the early nineties the first bibliography announcements appeared about the properties of the new material, bubble alumina (trade name KKW, KKLS) manufactured by the Treibacher Company.

The grains of bubble alumina were spherical microgranules, partially empty, with sharp edges and outer surfaces consisting of several thick layers. They were obtained from fused special high purity alumina and from the melt atomized with compressed air.

Another suggested addition was magnesium aluminosilicate microgranules – known as Cenosfera^{TM}. It was a by-product of utilization of mine waste dumps. They were produced by Eko-Export Company. They were perfectly spherical, empty inside, with thin outer walls and diameter less than 63 μm. Their role was to make shallow chip stores in the effective grinding zone with simultaneous strengthening of bond bridges.

This article deals with the research on the physicochemical and mechanical properties of additions and the pre-performance investigation of grinding tools admixed with them.

2. Experimental

Two kinds of additions were assigned for the investigations:
- microgranules of bubble alumina from Treibacher (known as Alodour-KKW),
- microgranules of magnesium aluminosilicate from Eko-Export,

for which helium density, microhardness, TMA coefficient and wettability of bubble alumina or magnesium aluminosilicate substrates by vitrified bond (glass devitrificate of $ZnO–PbO–B_2O_3–SiO_2$ system – Pb21K) was described. Structural investigation by a scanning electron microscope (SEM) was performed.

Abrasive tools with the following characteristics: 1A1 35×5×10×10, B126, 100, Pb21K with 0, 5, 10 and 12 vol% addition of bubble alumina were investigated on the RUP 28P grinding machine with a high-speed Fisher spindle, by grinding LH15 steel with increased wheel speeds (30, 45 and 60 m/s). Surface microtopographies of the grinding wheels and work-pieces with height (R_a and R_z) and shape (Δ_k) parameters were described.

3. Results and discussion

3.1. Certain physicochemical and mechanical properties of additions

The grains of bubble alumina were spherical microgranules of Al_2O_3, partially empty inside, with a diameter of less than 100 μm. SEM showed that their outer surfaces were stratified and had sharp, ragged edges (see Fig. 1). The cross-section showed that the grains were partially empty inside (Fig. 1) and had thick outer walls. Elementary

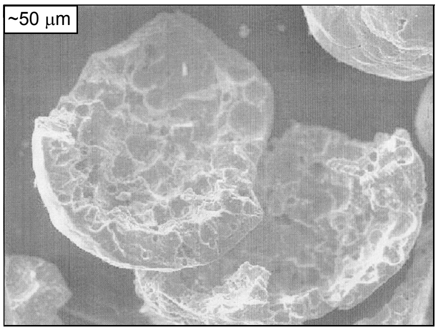

Fig. 1. Microphotographs of bubble alumina grains, SEM, magn. 1000x.

chemical analysis in the marked point showed the presence of aluminium, small amounts of zirconium, chromium and sulphur.

Their helium density (3.94 g/cm^3) was only a little lower than that of fused alumina (Al_2O_3 – trade name 99A, density 3.95–3.97 g/cm^3). Microhardness (~20 GPa) and linear expansion coefficient (7.8×10^{-6} 1/deg) were similar to these of 99A.

Wettability by vitrified bond, which is a basic criterion of usability of a material as a bond component for grinding tools, was investigated on a high-temperature Leitz–Watzler microscope by the sessil-drop method in the air atmosphere. A very good wettability was found of a substrate (bubble alumina plate) by the vitrified bond (glass devitrificate of $ZnO–PbO–B_2O_3–SiO_2$ system), the Θ angle (contact angle) was

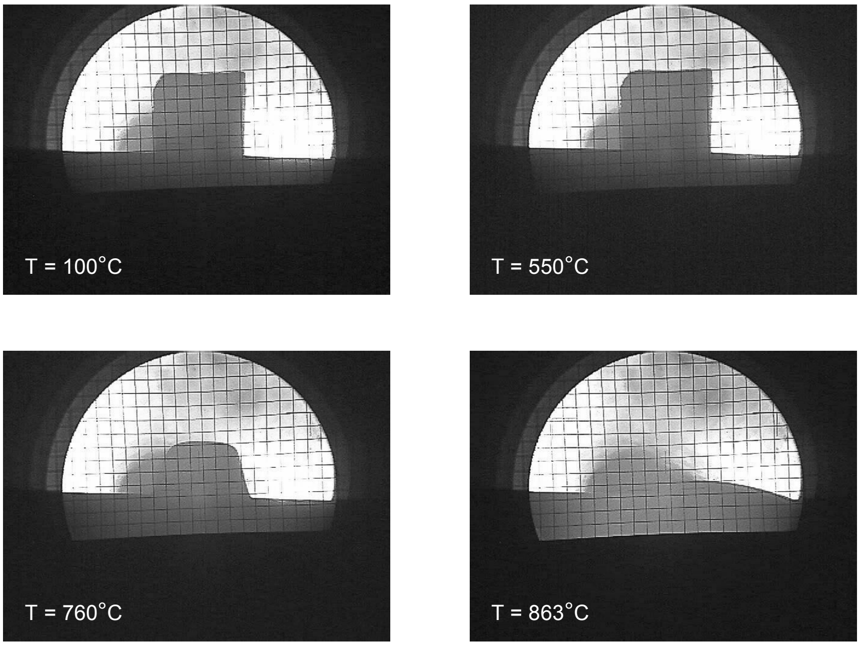

Fig. 2. Wetting of bubble alumina substrates by vitrified bond Pb21k.

22° in 863°C (see Fig. 2). The cross-section SEM photos showed the presence of an intermediate layer containing lead, zinc and aluminium. The obtained results confirmed the usability of that material as an addition to the vitrified bond for cBN tools.

Another suggested addition are magnesium aluminosilicate microgranules which are a by-product of coal mine waste dumps utilization. They are perfectly spherical, empty inside, with thin outer walls, diameter less than 63 μm (Fig. 3). Elementary analysis in the marked point confirmed the presence of Al, Si, Mg, Na and Ca. Microhardness test showed that the microgranules are very soft (0.2–0.5 GPa) and have small density (1.85 g/cm^3). Wettability was investigated on a Leitz–Watzler microscope.

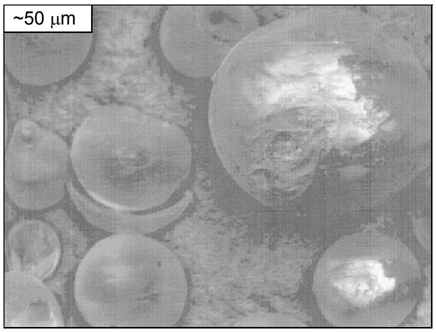

Fig. 3. Microphotographs of magnesium aluminosilicate microgranules, SEM, magn. 1000x.

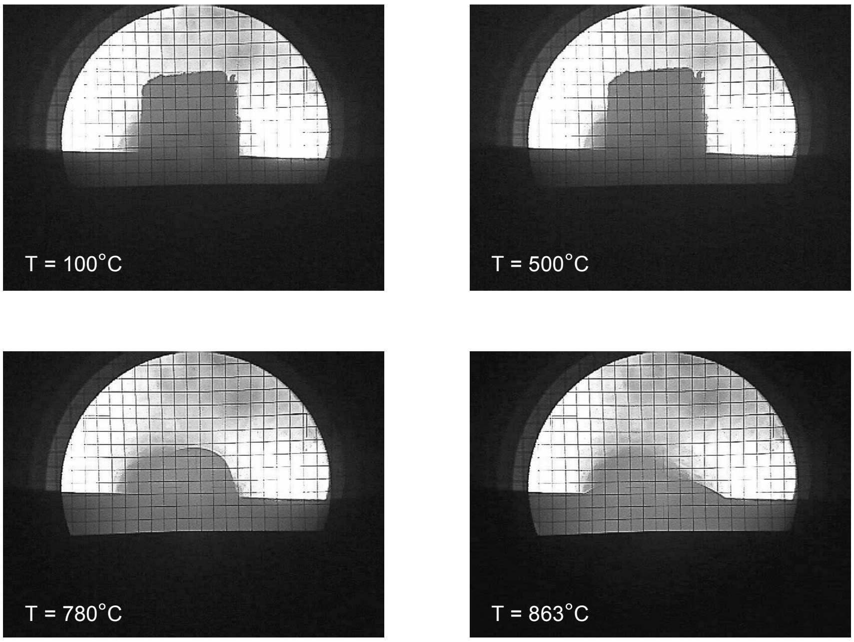

Fig. 4. Wetting of magnesium aluminosilicate substrate by Pb21K vitrified bond.

The substrate was a compressed magnesium aluminosilicate plate, on which a sample of bond (Pb21K) was placed. Swelling of the sample in high temperatures was observed, resulting from forming of gaseous CO_2 (Fig. 4). The value of contact angle was about 35°. The cross-section SEM photos showed that elementary substrate components diffused to vitrified bond and formed solid solution with the elementary bond components. The obtained research results concerning physico-mechanical properties excluded the usability of that material as an addition to vitrified bond for cBN tools.

3.2. Pre-performance investigation of wheels with bubble alumina addition

Grinding wheels 1A1 35×5×10×10 (Fig. 5) contained cubic boron nitride B126 made by General Electric, vitrified bond (glass devitrificate of ZnO–PbO–B_2O_3–SiO_2 system developed in Institute of Advanced Manufacturing Technology, Kraków, Poland), and additions of bubble alumina (0, 5, 10 and 12 vol%).

Fig. 5. Cubic boron nitride (cBN) tools with vitrified bond and bubble alumina addition.

A pre-performance investigation was performed in the Manufacturing Engineering Department of the Technical University of Koszalin (Poland) on a research-stand with a grinding machine RUP 28P equipped with a high-speed Fisher spindle. Blanks of ball bearings, made of LH15 steel were ground in the following conditions:

– grinding depth a_e = 0.01 mm/pass,
– work feed V_{fa} = 10 mm/s,
– grinding speed V_s = 30, 45 and 60 m/s,
– workpiece rotational speed U_w = 250 rev/min.

The measured quantities were:

– time of the removal of a given volume of ground material Q_w = 1200 mm^3 ($a_{e\ \mathrm{total}}$ = 0.5 mm),
– surface roughness after grinding R_a and R_z,
– circular deviation Δ_K.

On the basis of the investigation it was found that the higher percentage of bubble alumina in a wheel, the much better its cutting abilities. The result was shortening the time needed to remove a given volume of material (Fig. 6). It was caused by the increased number of cutting edges, what came from emerging of chipped edges of

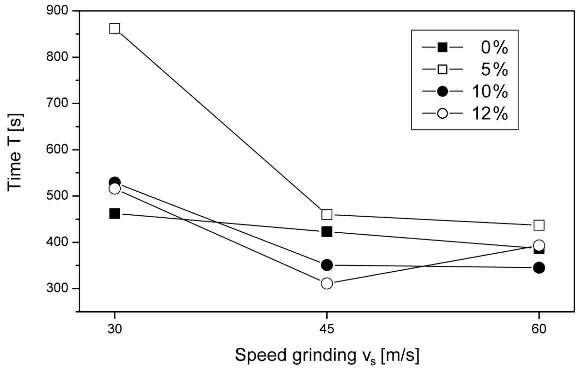

Fig. 6. Grinding material volume (Q_w = 1200 mm^3) removal time as a function of wheel speed grinding.

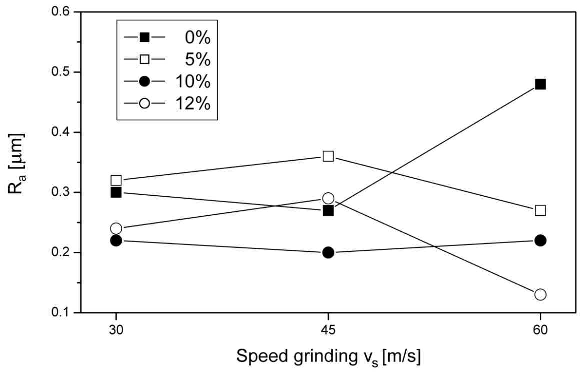

Fig. 7. Roughness of grinded workpieces surface, expressed by R_a parameter as a function of wheel speed grinding.

bubble alumina and opening of chip stores. The wheels did not show any symptoms of gumming up.

The increase in cutting efficiency was fostered by an increase in grinding speed of wheels, especially above 45 m/s.

The increase in the number of cutting edges caused by an increased portion of bubble alumina had a positive impact on decreasing of the machined surface roughness, what was particularly evident at high grinding speed (Fig. 7). In this respect, a wheel having 12% bubble alumina stands out. It ensures the machined surface roughness R_a of about 0.2 µm.

3.3. Wear investigations of grinding wheels

In order to examine the wear of grinding tools with varying contents of bubble alumina, the grinding process was performed until 18000 mm^3 of material were ground off in the following conditions (Fig. 8):

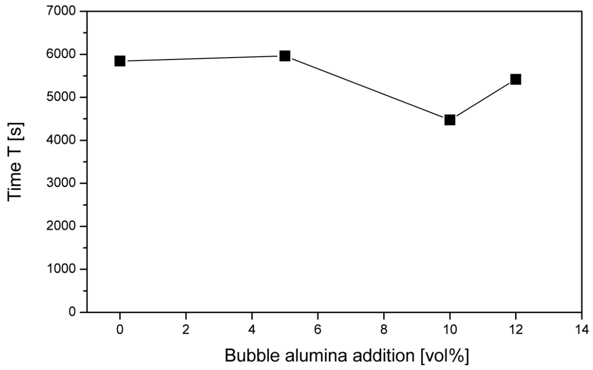

Fig. 8. Grinding material volume (Q_w – 18000 mm^3) removal time as a function of bubble alumina percentage participation.

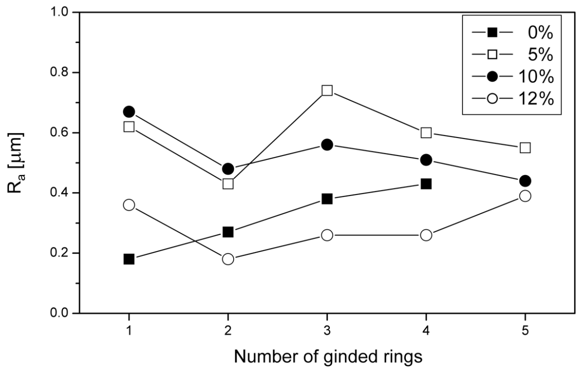

Fig. 9. Roughness of grinded work pieces surface, expressed by R_a parameter as a function of grinded rings number.

– grinding speed V_s = 60 m/s,
– grinding depth a_e = 0.01 mm/pass,
– workpiece rotational speed U_w = 250 rev/min.

After grinding off 3600 mm^3, the wheel diameter, its circular deviation and the machined surface roughness were measured. It was found that the shortest machining time was ensured by the wheel having the most bubble alumina (12%), but the smoothest surface was obtained by wheels with 10% of bubble alumina (Fig. 9).

It was determined by the suitable openness of the active surface structure of the wheel and its self-sharpening and restoring grinding ability. During work, wheels with greater percentage of bubble alumina (10, 12%) maintained a constant profile height and the heights of the vertices specified by the R_z parameter. Dispersion of vertices for those wheels was somewhat greater than that for wheels without additions, what can result from the structure openness and greater porosity of bond bridges.

Circular deviation of the examined wheels stabilized after a grinding-in period and no increase tendency was observed. A total circular deviation ($P + V$) oscillated about 5 μm. The increase in bubble alumina contents influenced the decrease in machined surface roughness.

4. Conclusions

Basing on the investigation results the following conclusions can be drawn:

1. Microgranules of bubble alumina are characterized by thick layers structure of an inner surface with many sharp, irregular edges, empty inside, helium density a little lower than fused alumina (3.94 g/cm^3), high microhardness (20 GPa), the same TMA coefficient as fused alumina (7.8×10^{-6} 1/deg) and very good wetting of bubble alumina substrates by Pb21k vitrified bond (contact angle $\Theta < 22°$). Bubble alumina fulfilled all the criteria of usability for cBN tools.

2. Microgranules of magnesium aluminosilicate are characterized by perfectly spherical shape with a thin, smooth inner layer, very low helium density (1.85 g/cm^3), low microhardness (0;2-0;.5 GPa) and wetting of magnesium aluminosilicate plate by Pb21k vitrified bond with high contact angle $\Theta \approx 35°$ because of diffusion of MA elementary components to the vitrified bond with solid solution formation. So these facts showed that magnesium aluminosilicate did not fulfill the criteria of usability for cBN tools.

3. Four groups of tools 1A1 35×5×10×10, B126, 100, Pb21K with 0, 5, 10 and 12 vol% addition of bubble alumina are characterized by very good performance properties throughout the work. The wheels enabled an increase in volume effectiveness while providing relatively the lowest machined surface roughness.

4. The higher addition, the smaller machined surface roughness. Thanks to increased porosity, the wheels did not gum up and were characterized by good reconditioning and stabilization of the state of the active surface.

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