CUTTING PERFORMANCE OF ALUMINA – GRAPHENE OXIDE COMPOSITES

WYDAJNOŚĆ SKRAWANIA KOMPOZYTÓW O OSNOWIE TLENKU GLINU Z DODATKIEM GRAFENU

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Abstract: This paper discusses the influence of graphene oxide (GO) addition to alumina matrix and its impact on mechanical and cutting performance of obtained composites. The composites were prepared via powder metallurgy processing using the SPS method to consolidate powder mixtures. Applied method due to lowering the sintering temperature and time (in comparison to conventional sintering methods) leads to limiting the grain growth of alumina matrix. It has great impact on physical properties of produced sinters. Physical properties of Al_2O_3-GO composites such as density, hardness, Young's modulus and fracture toughness were analyzed. The maximum value of K_{IC} = 3.3 MPa*m$^{0.5}$ was reached for Al_2O_3+1 wt. % GO and for that sinter dry machining tests (performed on hardened 145Cr6 steel) were made. The results show that produced cutting tools are characterized with good cutting performance comparable with commercial cutting tool.
Keywords: graphene oxide, alumina matrix composite, SPS method, sintering temperature, dry machining test, cutting tool, cutting performance

Streszczenie: W artykule omówiono wpływ dodatku tlenku grafenu (GO) do osnowy Al_2O_3 na właściwości wytrzymałościowe i skrawne otrzymanych kompozytów. Materiały zostały wytworzone metodą metalurgii proszków, z wykorzystaniem do konsolidacji mieszanin proszkowych metody spiekania SPS. Zastosowana metoda pozwala na obniżenie temperatury oraz czasu spiekania (w porównaniu do konwencjonalnych metod spiekania), co prowadzi do ograniczenia rozrostu ziarna osnowy kompozytu. Ma to istotny wpływ na właściwości wytworzonych spieków.
Właściwości fizyczne kompozytów Al_2O_3-GO, takie jak gęstość, twardość, moduł Younga i odporność na kruche pękanie zostały zbadane. Maksymalną wartość K_{IC} = 3,3 MPa*m$^{0.5}$ osiągnięto dla kompozytu Al_2O_3 + 1 wag.% GO i ten materiał został poddany próbom

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skrawania. Wyniki prób skrawania pokazują, że wytworzone kompozyty charakteryzują się właściwościami skrawnymi porównywalnymi z tymi otrzymanymi dla narzędzi komercyjnych.
Słowa kluczowe: tlenek grafenu, kompozyt o osnowie tlenku glinu, metoda SPS, temperatura spiekania, test obróbki na sucho, narzędzie skrawające, wydajność skrawania

1. INTRODUCTION

There has been growing interest in graphene oxide (GO) due to its unique combination of electrical, optical and thermal properties [6] which makes it an ideal material as a reinforcing phase to composites [11]. Most of researchers used graphene oxide on polymer-based composites due to improved elastic modulus, electrical conductivity and thermal stability of polymer matrix. However, incorporation of graphene into a ceramic to improve its performance would have great potential [10]. Only small amount of GO should improve simultaneously mechanical, electrical and thermal properties of ceramic-based composites [5,8,9]. Such materials can be applied in many fields including bio-sensors, transparent conductors and cutting tools [1–3,12]. However, similarly as in case of carbon nanotubes fabrication of these composites cause many difficulties. One of the main challenge is how to uniformly disperse carbon filler in the matrix. To achieve homogeneous distribution of graphene oxide the powder metallurgy technique is used. The GO is first de-agglomerated using ultrasonication and then mixed with the ceramic powder in a solvent, using conventional or high energy ball milling to obtain well dispersed ceramic composites [4,7]. Uniform distribution and good interface between nano filler and ceramic should provide increase of mechanical properties i.e. hardness, fracture toughness. Increase of fracture toughness (K_{IC}) is especially important for cutting tools. Low value of K_{IC} causes chipping or cracking of cutting tools which is unacceptable and decreases it life-time. In this paper the authors focused mainly on the mechanical and cutting performance of SPS sintered alumina-based composites. Significant enhance in above mentioned properties may open a new field of applications for alumina – graphene oxide composites.

2. EXPERIENT

The composites Al_2O_3-x % wt. GO (where x = 0/0.5 /1 /2) were prepared by the use of powder metallurgy technique. Powder substrates used in this work were commercial α-Al_2O_3 powder (Taimei Chemicals CO., LTD.,) with the average particle size of 135 nm and graphene oxide produced in the Institute of Electronic Materials Technology (99.99% chemical purity). Moreover, pure alumina sample was sintered as a reference specimen.

In the first technological step the Al_2O_3-GO powders were ultrasonically dispersed in a solution of isopropyl alcohol for 30 minutes. After drying and sieving powder mixtures were consolidated using Spark Plasma Sintering (SPS) method. Parameters of the sintering process were as follows: temperature 1450°C, heating rate 250°C/min, dwell time 5 min., and vacuum atmosphere. The sinters were mechanically polished down to a grit size of 0.2 μm and subjected to further investigations. Fundamental properties of obtain materials such as density (Ultrapycnometer 1000 helium pycnometer Quantachrome Instruments), hardness (Vickers Hardness Tester FV-700e Future-Tech), Young's modulus (Optel ultrasonic refractometer) and fracture toughness (with the use of the indentation method under the load of 49.05 N) were

studied. Microstructure observations using a scanning electron microscope (Hitachi S5500) were executed as well.
The sinters were then processed to obtained square cross-section cutting tools according to ISO 1832:199,1 typ SNGN 120412 T02020 and then were subjected to dry machining test. The tests were performed with the use of a CNC machine (NL2000SY - Mori Seiki), parameters were as follow: cutting speed v_c = 370 m/min., cutting feed f = 0.08 mm/rot., and cutting depth p = 0.3 mm. The machined material was hardened 145Cr6 steel (hardness 50±2 HRC). The wear of tool was defined by a flank wear VB_C = 0.3 mm parameter (according to the PN ISO3685:1996 norm). After conducting machining tests the surface roughness parameter R_a was measured with the use of a profilometer (Hommel Tester T1000E). The machining tests results were compared with a commercial cutting tool TACN (Al_2O_3 + ZrO_2 + Ti(C,N)).

3. RESULTS

The SEM image of Al_2O_3-1 wt. % GO fracture is shown in Figure 1. The good connection between graphene oxide flakes and alumina matrix was observed. There were no voids or pores near GO flakes surface. Frequent problem occurring in Gn/GO composites is creation of large gaps in the ceramic matrix. Located, inside these gaps, flake of graphene does not have a good enough connection to the matrix material. It can act as concentrators of local stress and significantly degrade the mechanical properties of composites.

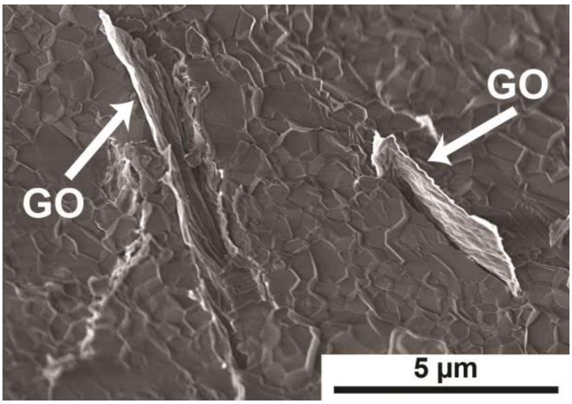

Figure 1. Fracture of Al_2O_3 + 1 wt. % GO

Besides of microstructure observation also physical properties of sinters were conducted. Relative density of composites illustrates Figure 2. For all specimens high values of relative density were obtained. Maximum density (almost 100%) was achieved for reference specimen.

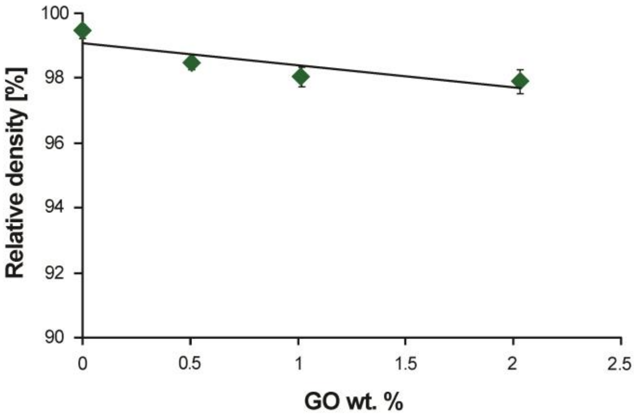

Figure 2. Relative density of Al_2O_3-GO composites

The density value insignificantly decreases with increasing weight content of graphene oxide but does not drops below 98%. Decrease of relative density could be caused by formation of GO agglomerates for composite with higher weight content of graphene oxide. In terms of Vickers hardness, inverse relation was observed (Fig. 3). Hardness value increase significantly (from 1664 HV3 to 1907 HV3) when compared unreinforced and 0.5 wt. % GO sinters. Further addition of graphene oxide results in increase of hardness value. Highest hardness value was obtained for composites with 1 weight percent of GO and reached 1939 HV3.

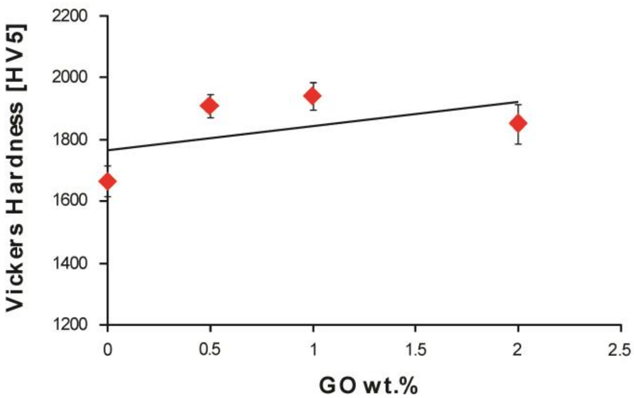

Figure 3. Influence of graphene oxide content on hardness of alumina-based composites

One of the basic parameters which tell about the possibility of the use of material on the cutting tools application is fracture toughness. Low value of K_{IC} can causes critical failure of cutting tool at unexpected time which is unacceptable in industrial practice. For this reason, the fracture toughness measurements were also carried out.

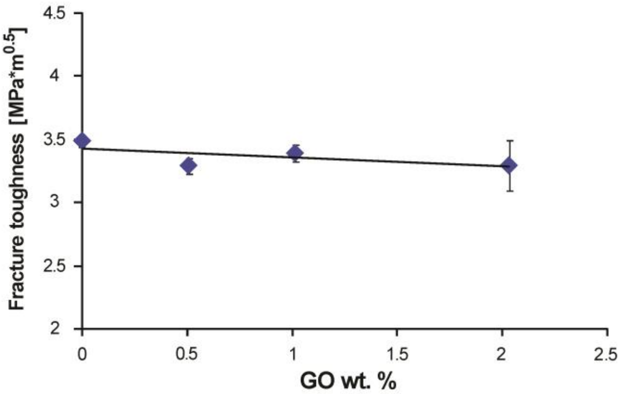

Figure 4. Fracture toughness of alumina/graphen oxide composites

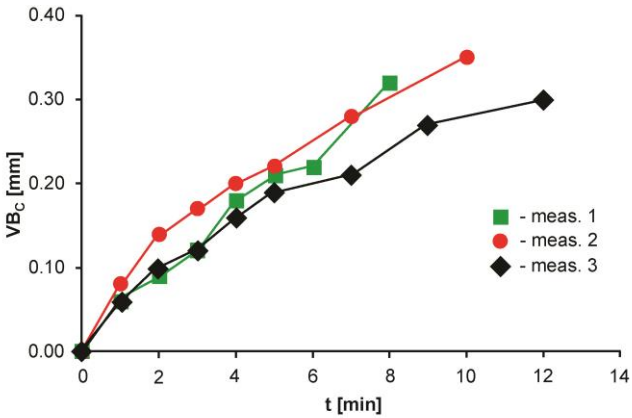

Figure 5. Machining tests results for Al_2O_3–1 wt. % GO composite tool

For all sintered materials K_{IC} value is almost the same (Fig. 4). Slightly decrease in values of fracture toughness for composites compared to unreinforced alumina can be observed. The highest value, $K_{IC} = 3.4$ MPa*m$^{0.5}$ was achieved for composites with 1 wt. % of graphene oxide. Taking into account the highest values of hardness and fracture toughness for machining test were selected composites containing 1 wt. % of graphene oxide.

The machining test results are summarized in Figures 5 (Al_2O_3–1 wt. % GO) and 6 (commercial sample). For both samples 3 machining test were conducted and its values were averaged. Average tools life were 9.2 ± 2.4 min and 9.6 ± 0.6 min respectively for Al_2O_3–1 wt. % GO and commercial tool (TACN). Greater standard deviation of tool life results, for a composite with graphene oxide, may indicate the presence of some heterogeneity in the structure of the material. It can be due to inhomogeneous distribution of graphene oxide in a ceramic matrix. Considering the fact that machining hardened steel (50 HRC) with cutting speed $v_c = 370$ m/min can be considered as high speed machining, it should be noted that the both cutting tools showed good cutting performances.

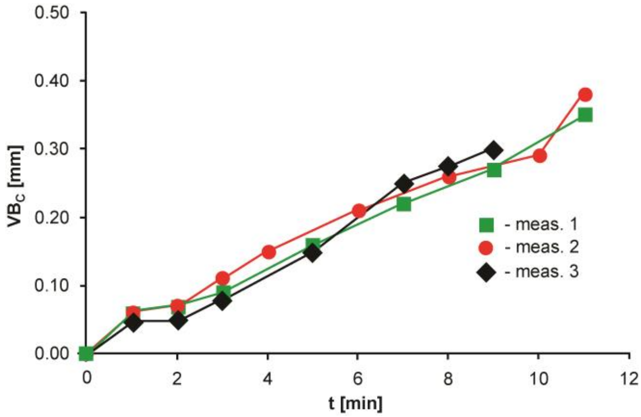

Figure 6. Machining tests results for commercial composite tool (TACN)

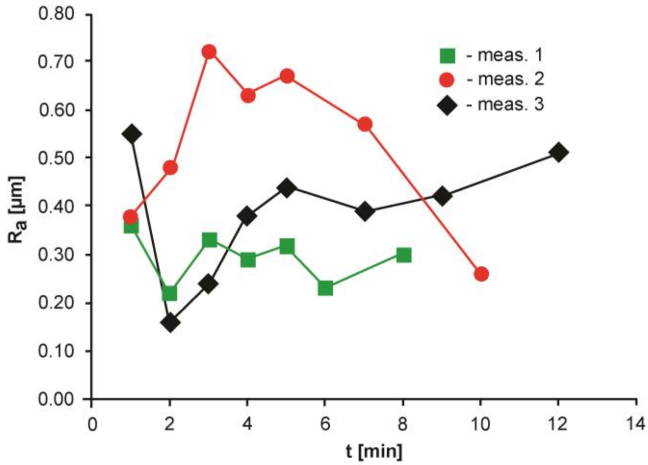

Figure 7. Surface roughness of 145Cr6 steel results after machining using Al_2O_3 – 1 wt. % GO composite tool

Surface roughness (R_a) of machined materials, using both Al_2O_3/GO and TANC cutting tools, achieved values in the range of 0.2-0.7 μm, which corresponds to the finishing process. The results are summarized in Figure 7 (Al_2O_3–1 wt. % GO) and 8 (commercial sample). At a small cutting depth (p = 0.3 mm) a tangled chips were obtained (according to the classification of chips shapes - ISO 3685:1996 Type 4.3), which in most cases did not flowed either in cutting tool direction nor to the machining surface.

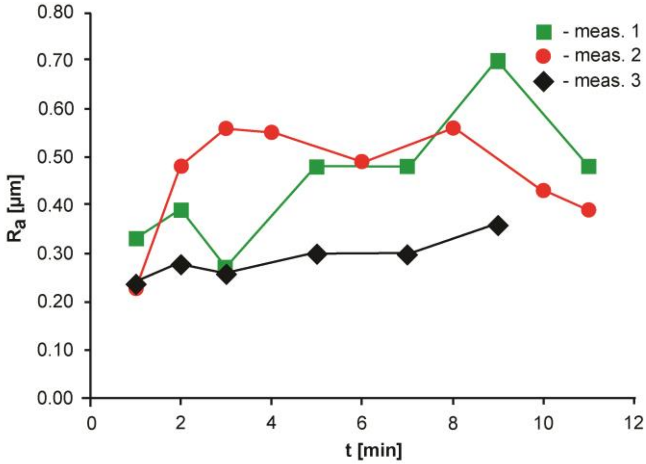

Figure 8. Surface roughness of 145Cr6 steel results after machining using commercial composite tool (TACN)

4. CONCLUSIONS

Microstructure observations indicates a good interface between GO flakes and alumina matrix.
Produced sinters are characterized with high relative density (over 98%)
Increase of GO weight content in Al_2O_3 caused increase in Vickers hardness up to 1939 HV5.
Addition of graphene oxide to alumina matrix does not significantly affects on fracture toughness of composites.
Due to the fact that the average cutting tool life of Al_2O_3/GO and TACN are similar, manufactured tools are suitable for dry machining of hardened steel.
Low values of surface roughness of machined materials indicate that Al_2O_3/GO cutting tools can be applied to finishing.

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REFERENCES

[1] ALLEN M.J., TUNG V.C., KANER R.B., *Honeycomb carbon: a review of grapheme,* Chem. Rev. 2010, 110, 132–145.
[2] BRONISZEWSKI K., WOŹNIAK J., CZECHOWSKI K., JAWORSKA L., OLSZYNA A., *Al_2O_3-Mo cutting tools for machining hardened steinless steel*, Wear 2013 303 87-91.
[3] CHOI W., LAHIRI I., SEELABOYINA R., KANG Y.S., *Synthesis of graphene and its applications: a review*, Crit. Rev. Solid. State. Mater. Sci.2010, 35,52–71.
[4] FAN Y.C., WANG L.J., LI J.L., LI J.Q., SUN S.K., CHEN F., CHEN L.D., JIANG W., *Preparation and electrical properties of graphene nanosheet/Al_2O_3 composites*, Carbon, 2010, 48 (6) 1743–1749.
[5] LI X., CHEN X., YAO Y., LI N., CHEN X., *High-stability quartz crystal microbalance ammonia sensor utilizing graphene oxide isolation layer*, Sensors and Actuators B, 2014 196183-8.
[6] NOVOSELOV K.S., GEIM A.K., MOROZOV S.V., JIANG D., ZHANG Y., DUBONOS S.V., GRIGORIEVA I.V., FIRSOV A.A., *Electric field effect in atomically thin carbonfilms*, Science 2004 306 666–9.

[7] TAPASZTO O., TAPASZTO L., MARKO M., KERN F., GADOW R., BALAZSI C., *Dispersion patterns of graphene and carbon nanotubes in ceramic matrix composites*, Chem. Phys. Lett., 2011, 511 (4–6) 340–343.
[8] WALKER L.S., MAROTTO V.R., RAFIEE M.A., KORATKAR N., CORRAL E.L., *Toughening in graphene ceramic composites*, ACS Nano 2011 5 (4) 3182–90.
[9] YEON Y., YUN J., KIM D., NA S., KIM S., *High-performance polimer solar cells with moderate reduced graphene oxide as an efficient hole transporting layer*, Solar Energy Materials & Solar Cells 2012 105 96-102.
[10] YU Y., KANG B., LEE Y., LEE S., JU B., *Effect of fluorine plasma treatment with chemically reduced graphene oxide thin films as hole transport layer in organic solar cells*, Applied Surface Science 2013 287 91-6.
[11] ZHANG Y.B., TAN Y.W., STORMER H.L., KIM P., *Experimental observation of the quantum Hall effect and Berry's phase in graphene*, Nature 2005 438 201–4.
[12] ZHU Y. et al., *Graphene and graphene oxide: synthesis, properties, and applications,* Adv. Mater. 2010, 22,3906–3924.