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Properties of Al_2O_3 – hBN Composites

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Abstract**—**Alumina matrix composites with addition of hexagonal boron nitride (hBN), acting as solid lubricant, were produced. Main purpose of solid lubricants is to dispose the necessity of using cooling lubricants in machining process. Hot pressing was used as a consolidating process for Al_2O_3-x%wt.hBN (x=1/ 2,5/ 5 /7,5 /10) composites. Properties of sinters such as relative density, hardness, Young's modulus and fracture toughness were examined. Obtained samples characterize by high relative density. Hardness and fracture toughness values allow the use of alumina – hBN composites for machining steels even in hardened condition. However it was observed that high weight content of hBN can negatively influence the mechanical properties of composites.

Keywords**—**Alumina. Composites, Hexagonal boron nitride. Machining

I. Introduction

CONSTANTLY developing industry requires introduction of new technologies. Machining is one of the most important industry branch that needs to response to constant changes in automotive, aerospace and many other industries. Creating new materials, that characterize e.g. with improved hardness, reduced weight, higher fracture toughness, requires a way to machine them to desired shape. Cutting tools edges must have a specific properties in order to machine a chosen material. The main parameter is difference in hardness between cutting tool edge and machined material. Higher difference in favor of cutting tool edge can decrease wear of such tool in the machining process. In addition to hardness a cutting tool can't crack or chip in the process [1]-[3]. Machining process performed using that cutting tool edge must also be environmentally safe.

The vast majority of machining processes involves the use of cooling lubricants which are additional costs to the process. They are not friendly to environment and can even be hazardous for operating personnel. New concept that excludes the use of cooling lubricants involves a group of materials called solid lubricants. The solid lubricants are materials of structure very similar to graphite. Structure of used in this work hexagonal boron nitride is shown in Fig. 1. The atoms in planes are connected with strong chemical bonds and successive planes are connected with weak Van der Walls bonds. Such structure provides a possibility to slide successive planes with use of small strain even in room temperature [4]-[6].

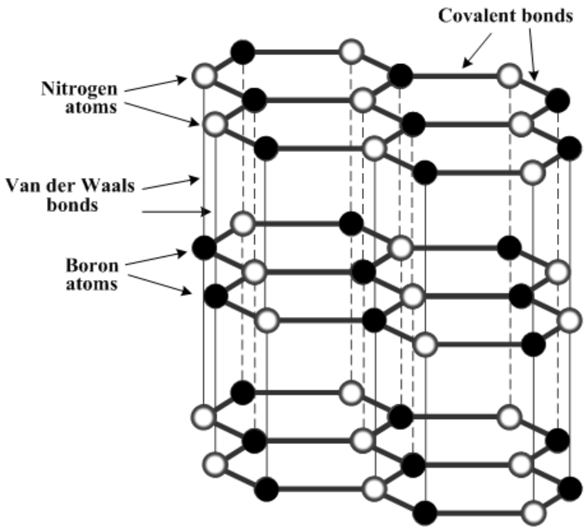

Fig. 1 Structure of hexagonal boron nitride (hBN)

Hexagonal boron nitride posses high melting point (~2800K) which is very important parameter for material used for cutting tool edge. Temperature at the contact area between tool and machined material can reach up to 1000ºC. It is very important that hBN stays in solid state in whole machining process.

II. Experiment

Powder substrates used in this work were: commercial one-phase α-Al_2O_3 powder (chemical purity of 99,99%) and commercial one-phase hBN powder (chemical purity of 99,8%). Alumina powder characterize with mean particles size of 135±35nm and irregular shape Fig. 2. Hexagonal boron nitride powder characterize with mean particles size of 5,63±3,36µm an flake shape Fig. 3. Powders substrates were wet blended in isopropyl alcohol suspencion for 24h in attritor type mill. Powders mixtures were dried for 24h at 50ºC and then hot pressed at 1350ºC for 1h under pressure of 20MPa in argon atmosphere. Sinters production process scheme is presented in Fig. 4. As the result of sintering Al_2O_3-x%wt.hBN composites were created, where x = 1 /2,5 /5 /7,5 /10.

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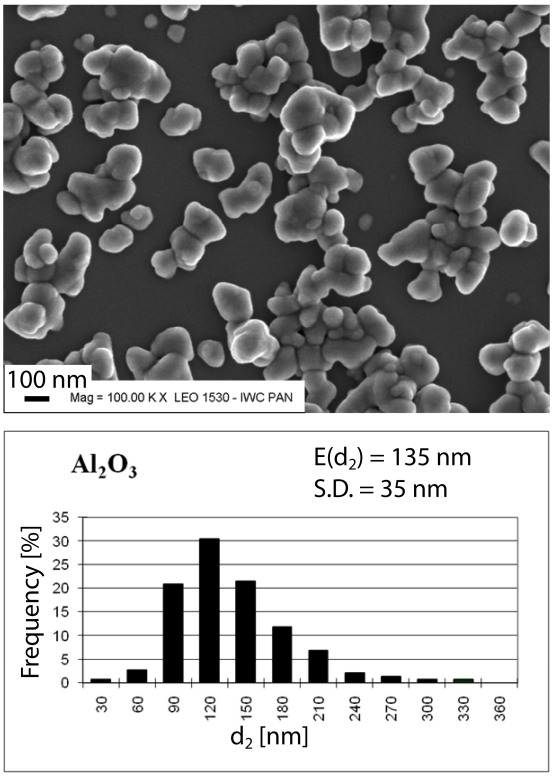

Fig. 2 Morphology and average particles size of alumina powder

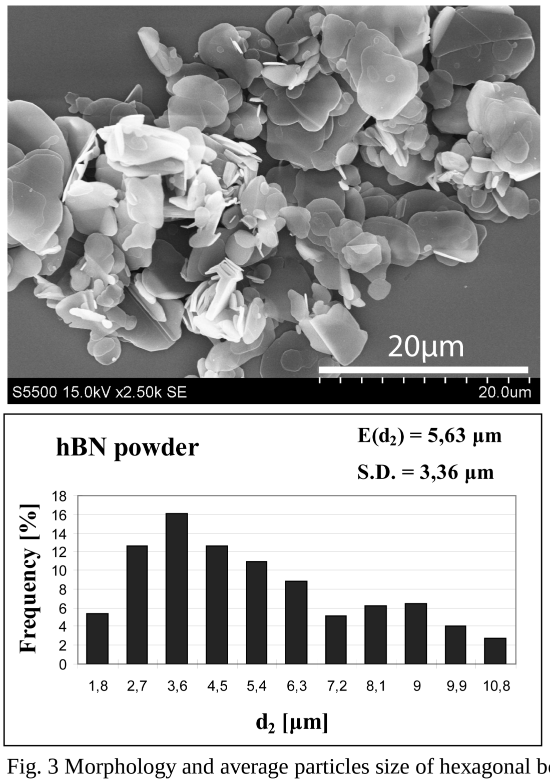

Fig. 3 Morphology and average particles size of hexagonal boron nitride powder

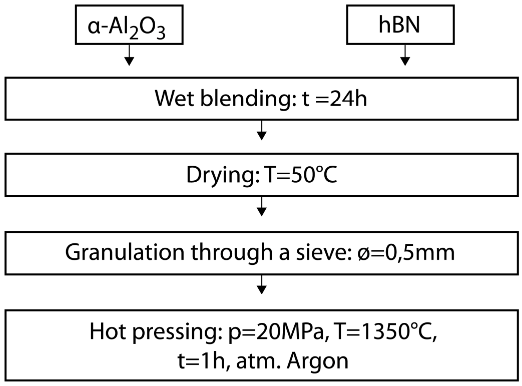

Fig. 4 Al_2O_3-hBN composites production scheme

Sinters have been subjected to grinding and polishing. Final polishing was performed on 1µm diamond suspension. Density and porosity of specimens were examined by Archimedes‘s method and additionally with use of helium pycnometer. Hardness and fracture toughness were measured with use of indentation method under 98,1N load. Young modulus of composites was measured with use of ultrasonic method.

III. Results

Obtained sinters characterize by the presence of 2 phases: α-Al_2O_3 and hexagonal boron nitride as shows the exemplary diffractogram Fig. 5 Produced Al_2O_3-x%wt.hBN composites possess high relative density Fig. 6. Increase of hBN addition in alumina matrix increases density of obtained composites. Composites with 7,5%/10% hBN have near theoretical density.

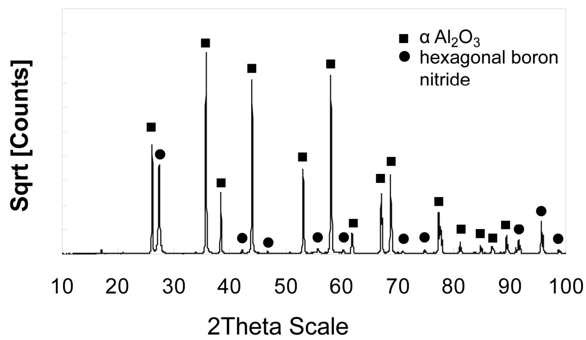

Fig. 5 Exemplary diffractogram of Al_2O_3-5%wt.hBN

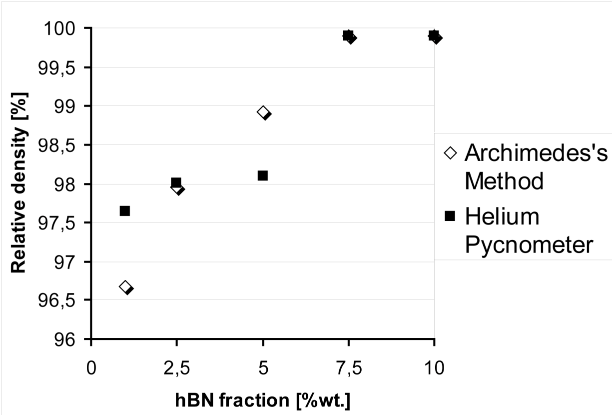

Fig. 6 Relative density of produced Al_2O_3-x%wt.hBN examined by Archimedes method and with use of helium pycnometer

Hexagonal boron nitride is homogenously distributed in alumina matrix in all produced composites. Exemplary microstructure of Al_2O_3-7,5%wt.hBN is shown in Fig. 7.

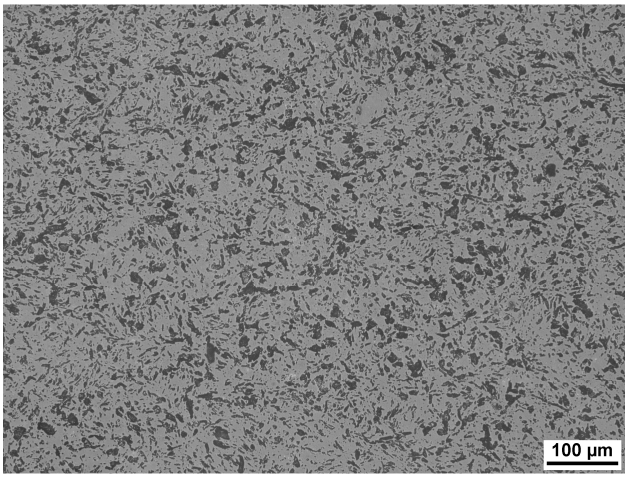

Fig. 7 Exemplary microstructure of Al_2O_3-7,5%wt.hBN

Hardness of obtained sinters is below 1100HV10 value. As expected, addition of low hardness hexagonal boron nitride in alumina matrix causes reduction of Al_2O_3-x%wt.hBN composites hardness (Fig. 8). Hardness decreases with increase of hBN content to value of 534±74 HV10 for specimen containing 10%wt.hBN. It must be noted that sinter with 1%wt.hBN, which possess lower density than other sinters, can have his hardness undervalued compared to fully compacted sample. It was observed, that under a indenter load surface of sinters containing 7,5%wt. and 10%wt. hBN is cracking/chipping around indenter. It interferes with accurate evaluation of indentation edges. Such occurrence was observed also for Al_2O_3-5%wt.hBN but at a lower degree.

Examined values of Young's modulus for produced alumina – hBN composites are close to their theoretical values received from rule of mixtures. The exception is sample with 1%wt.hBN in which case examined value is definitely lower than expected.

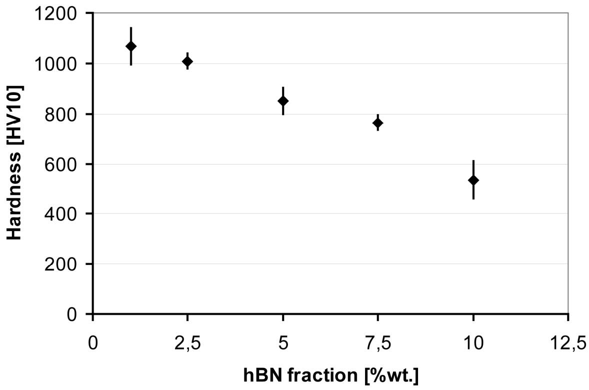

Fig. 8 Vicker's hardness HV10 for Al_2O_3-x%wt.hBN composites

It is believed that lower density causes the decrease of Young's modulus for this sample. It can be seen that Al_2O_3-2,5%wt.hBN and Al_2O_3-5%wt.hBN composites characterize by high standard deviation. Obtained in ultrasonic methods peaks for these composites showed tendency to overlap each other, which causes large difference in obtained Young modulus values. The cause of this phenomenon needs further examination.

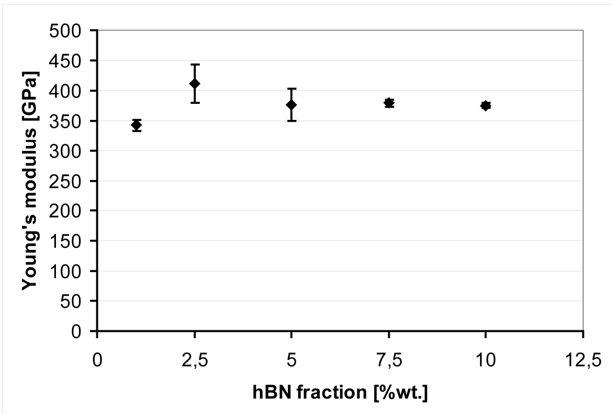

Fig. 9 Young modulus for Al_2O_3-x%wt.hBN composites

Fracture toughness for produced composites was also examinated. Results of obtained K_{IC} coefficient is shown in Fig. 10. Fracture toughness values of samples decrease with increasing fraction of hexagonal boron nitride in alumina matrix. Because of low K_{IC} coefficient of hBN such tendency is expected. Al_2O_3-2,5%wt.hBN composite characterize by very high standard deviation and therefore real fracture toughness of this sample is uncertain. It is very likely that this K_{IC} value match a previous mentioned tendency. In calculation of K_{IC} values, a Niihara, Morena and Hasselman equation was used [7].

Table I summarizes results of density, hardness, Young's modulus and fracture toughness for all produced samples.

TABLE I
SUMMARY OF PRODUCED AL_2O_3-X%WT.HBN COMPOSITES PROPERTIES

Sample ID	Relative density – Archimedes [%]	Relative density – Pycnometer [%]	Hardness [HV10]	Young modulus [GPa]	K_{IC} [MPa*m$^{1/2}$]
Al_2O_3-1%wt.hBN	96,7	97,6	1067±73	342±10	5,15±0,34
Al_2O_3-2,5%wt.hBN	97,9	98,0	1009±31	411±32	3,87±0,89
Al_2O_3-5%wt.hBN	98,9	98,1	852±52	376±27	4,31±0,19
Al_2O_3-7,5%wt.hBN	99,9	99,9	764±30	379±6	4,07±0,37
Al_2O_3-10%wt.hBN	99,9	99,9	534±74	375±4	3,51±0,27

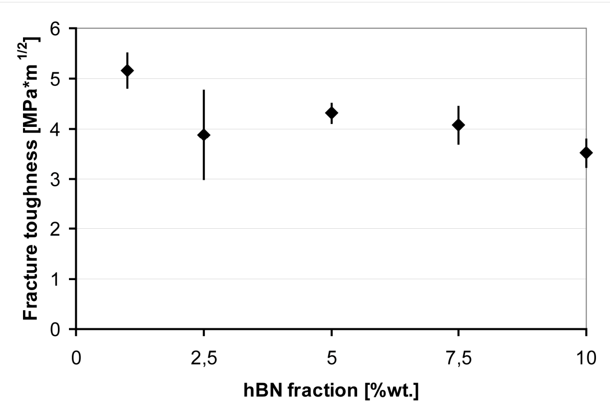

Fig. 10 Fracture toughness of produced Al_2O_3-x%wt.hBN composites

IV. CONCLUSION

Produced Al_2O_3-x%wt.hBN composites characterize by high relative density (96,7%-99,9%) that raises with increase of hBN fraction. Sinters are two-phased and consist of α-Al_2O_3 and hBN phases. Hexagonal boron nitride is homogenously distributed in alumina matrix. As it was expected, increase of hBN phase content leads to reduction in hardness of obtained composites. Hardness achieves the lowest value (534±74HV10) for composite with 10%wt.hBN. Examined Young modulus values are very close to theoretical. High weight fraction (>2,5%) of hBN in alumina matrix leads to chipping and cracking of surface near indentation. It is highly possible that these composites posses very low K_{IC} coefficient.

Produced composites with low weight content of hexagonal boron nitride (1% and 2,5%) are promising materials, containing solid lubricants, for cutting tool edges. With hardness value over 1000HV10 and fracture toughness accordingly 5,15±0,34 and 3,87±0,89MPa*m$^{1/2}$ for sinters with 1%wt.hBN and 2,5%wt.hBN, these composites may have use in machining steels even in hardened condition (~62HRC what equals ~750HV). Composites with higher content of hBN (more than 2,5%wt.) may have application in machining steels after normalizing process.

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REFERENCES

[1] J. Dmochowski, "*Podstawy obróbki skrawaniem*," Państwowe Wydawnictwo Naukowe, Warszawa 1981
[2] W. Grzesik, "*Podstawy skrawania materiałów konstrukcyjnych*," Wydawnictwo Naukowo – Techniczne, Warszawa 2010
[3] G. Górny, L. Sobierski, P. Rutkowski, A. Metryka, M. Rączka, "*Właściwości mechaniczne i użytkowe tworzyw Al_2O_3 modyfikowanych heksagonalnym azotkiem boru*," Spiekane materiały narzędziowe przeznaczone na ostrza narzędzi do obróbki z wysokimi prędkościami skrawania, 80-91, 2010
[4] T. Uğurlu, M. Turkoğlu, "*Hexagonal boron nitride as a tablet lubricant and a comparison with conventional lubricants*, "International Journal of Pharmaceutics 353 (2008) 45-51
[5] M. Hubáček, M. Ueki, T. Sato, and V. Brožek, "*High-Temperature behaviour of hexagonal boron nitride*, " Thermochimica Acta 282/283 (1996) 359-366
[6] Y. Kimura, T. Wakabayashi, K. Okada, T. Wada, H. Nishikawa , "*Boron nitride as lubricant additive*," Wear 232 (1999) 199-206
[7] C.B. Ponton, R.D. Rawlings, "*Vickers indentation fracture toughness test Part 1. Review of literature and formulation of standardized indentation toughness equations*," Materials Science and Technology vol.5 1989