Journal of International Scientific Publications:
Materials, Methods & Technologies, Volume 7, Part 1
ISSN 1313-2539, Published at: http://www.scientific-publications.net

AL_2O_3-NI COMPOSITES FOR CUTTING TOOLS

Kamil Broniszewski[a], Jarosław Woźniak[a], Marek Kostecki[a], Kazimierz Czechowski[b],
Lucyna Jaworska[b], Andrzej Olszyna[a]
[a] Faculty of Material Science and Engineering, Warsaw University of Technology. Warsaw,
Wołoska Str 141, 02-507, Poland
[b] The Institute of Advanced Manufacturing Technologies, ul. Wrocławska 37A, 30-011 Cracow

Abstract

The main disadvantage of ceramic cutting tools is their low fracture toughness that leads to a chipping and cracking of ceramic edges during machining process. It is believed that addition of metal particles would increase the K_{IC} parameter of ceramic matrix composites. In present work basic mechanical properties of Al_2O_3-x%wt.Ni composites were examined. A cutting tools life and surface roughness parameter were defined in dry machining of hardened steel tests. The possible reactions between cutting tool edge and machined material were also investigated as any chemical reaction can lead to increase of tools wear ratio.

Density and porosity of produced composites were measured with the use of Archimedes method. Phase analysis was carried out on an X-ray diffractometer. The microstructure observation was performed on an optic microscope. Fracture toughness was measured with the use of the Vickers indentation method.

Key words: *alumina, composites, cutting tools, nickel*

INTRODUTION

Machining is heavily dependant on cutting tools hardness parameter. It is one of the main criterion that characterize usefulness of the cutting tool for machining the chosen material. It is one of the reasons using alumina ceramic (α-Al_2O_3) as a matrix of composites in this work. Corundum is characterized with hardness in range of 16-18 GPa which allows machining steels even in hardened state [1-3]. Al_2O_3 cutting tools are used for machining grey cast iron, carbon and alloy steels below 38 HRC [4]. It also demonstrates high temperature stability of mechanical properties. High resistance to chemical wear is very important parameter which allows machining without any chemical interaction between cutting tool material and machining material (e.g. adhering, forming built-up edge) [5]. One of the main disadvantages of ceramic materials is the low resistance to brittle cracking [6]. As the cutting tool should wear uniform low value of fracture toughness can lead to cracking and chipping of cutting edge. That is why in this work it was decided to add the metallic phase into alumina ceramic matrix. Metallic phase can fulfill more than one role when added to ceramic matrix [7]. The main purpose of adding nickel phase in the present work was to increase the fracture toughness of the composite [8].

Nickel is not characterized with high chemical stability like corundum that is why it can lead to chemical interaction between cutting tool material and machined material. Such interaction is undesirable. In present work authors decided to examine if any new phases are created during machining C45 carbon steel with Al_2O_3-Ni composite cutting tool.

EXPERIMENT

Al_2O_3-x%wt.Ni (where x=1/ 2.5/ 5/ 7.5/ 10) composites were produced with the use of following powder substrates: commercial α-Al_2O_3 powder (average particles size of 135±35nm, chemical purity of 99.99%) and commercial Ni powder (chemical purity of 99.7%). After wet blending for 24h powder mixtures were dried and consolidated with the use of hot pressing method in argon atmosphere: T=1350ºC, t=1h, p=20MPa.

Sinters were then prepared for studies by grinding and polishing. Density of samples was examined with use of Archimedes method. Phase analysis was carried out on an X-ray diffractometer. Fracture toughness was measured with the use of indentation method under the load of 9.81N. The microstructure observation was performed on an optic microscope.

Produces sinters were manufactured into cross-section cutting tools (l=12.7mm, h=4.76mm). Corner radius of a cutting edge equals 1.2mm.

Dry machining tests were performed with use of the CNC machine with the following parameters: cutting speed V_c – 220 m/min., cutting feed f – 0.15 mm/rot., cutting depth a_p – 1.0 mm. Machined material was C45 carbon steel (hardness 167-179HB). The wear of tool was defined by a flank wear VB_C = 0.3 mm parameter (according to the PN-ISO 3685:1996 norm). Surface roughness parameter *Ra* of machined surface was measured with the use of profilometer.

As the reference sample a commercial ceramic cutting tools was used. Dry machining test parameters were the same as for produces composites.

In order to investigate the possible reactions between cutting tool material and machined material a new powder mixture was manufactured. It consists of fifty weight percent of Al_2O_3-10%wt.Ni and fifty weight percent of C45 carbon steel powder. Powder mixture was wet milled, compacted and annealed at 1000ºC in air and in vacuum. Because time of contact between cutting tool edge and machined material is extremely short it is believed that possible chemical reaction could happens without participation of oxygen (vacuum conditions). After annealing compacts were subjected to an X-ray analysis in order to determine if any new phases were created. Creation of new phases could means possible reactions between cutting tool material and machined material.

RESULT

Produced Al_2O_3-x%wt.Ni composites are characterized with near theoretical density (Fig 1.). There are very slightly differences between obtained samples. The lowest relative density examined was for Al_2O_3-1%wt.Ni composite and equals 98%. Al_2O_3 sinter without addition of molybdenum is characterized with relative density over 99%. X-ray analysis reveals that produced sinters contain two phases: α-Al_2O_3 and Ni. The diffractogram of Al_2O_3-5%wt.Ni composite is shown in Fig. 2.

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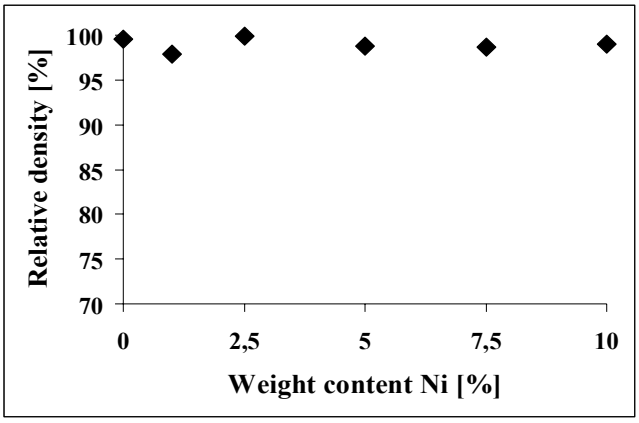


Fig. 1 Relative density of Al_2O_3-x%wt.Ni composites

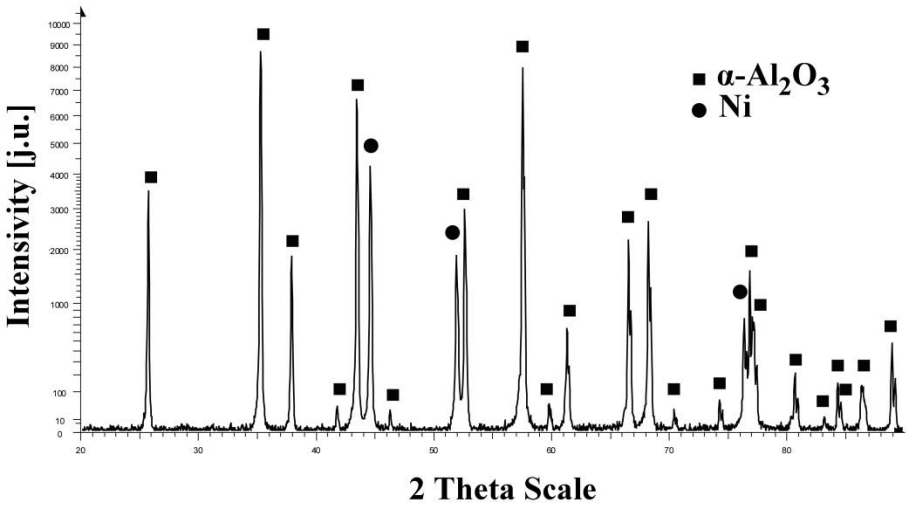


Fig. 2 The diffractogram of Al_2O_3-5%wt.Ni

The microstructure of Al_2O_3-5%wt.Ni is shown in Fig.3.

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Fig. 3 The microstucture of Al_2O_3-5%wt.Ni

Produced composites are characterized with uniform nickel particles distribution in alumina matrix.

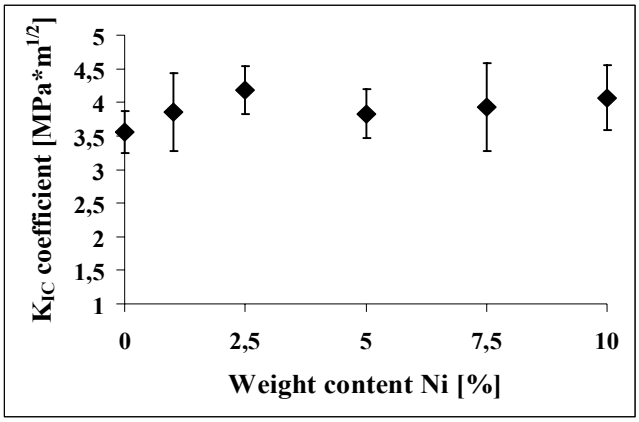


Fig. 4 Fracture toughness results of Al_2O_3-x%wt.Ni composites

There is slightly increase in K_{IC} coefficient of Al_2O_3-x%wt.Ni composites compared to Al_2O_3 sinter. Increase of K_{IC} coefficient after metallic phase addition agrees with common knowledge. Nevertheless high value of standard deviation must be taken into account.

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The composite with one weight percent of nickel is characterized with highest average tool life of 44.3 min. The machining test results are shown in Fig.5. The average surface roughness parameter *Ra* of C45 carbon steel after machining with Al_2O_3-1%wt.Ni composite tool equals 1.25±0.25 µm (Fig.6).

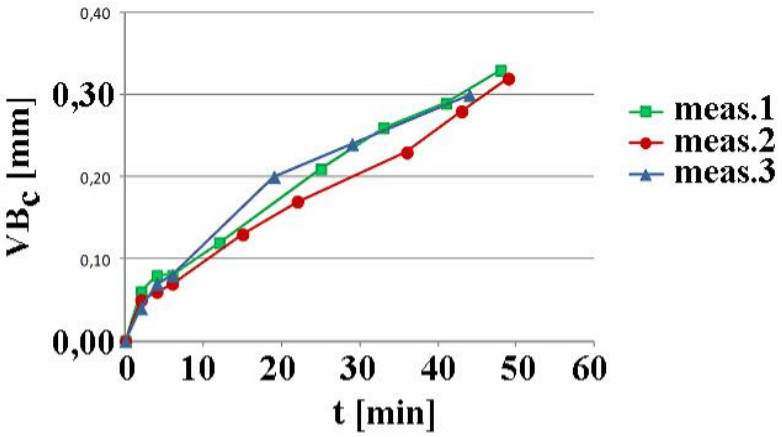


Fig. 5 Machining tests results for Al_2O_3-1%wt.Ni composite tool

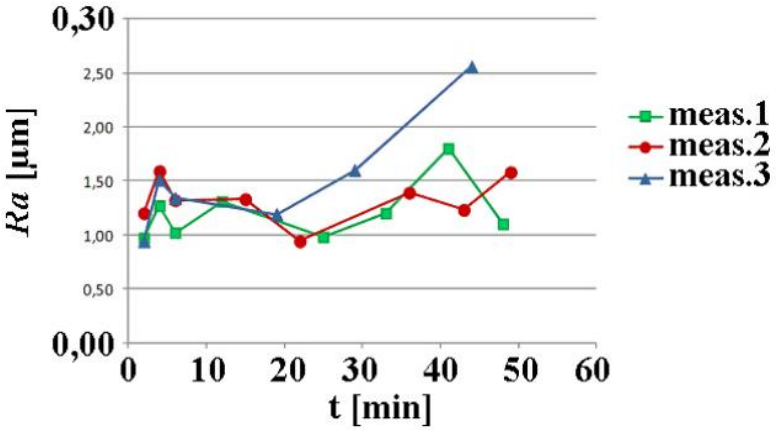


Fig. 6 Surface roughness of C45 steel results after machining using Al_2O_3-1%wt.Ni composite tool

Composite tools with addition of nickel phase exceeding one weight percent shows greatly inferior machining properties comparing to Al_2O_3-1%wt.Ni. composite tool. As opposed to Al_2O_3-1%wt.Ni. composite tool where cutting edges wear uniform increasing weight content of nickel leads to chipping and/or cracking of cutting edges. The cutting tools with 2.5/ 5/ 7.5/ 10 weight content of nickel chipped before reaching flank wear value of 0.3 mm. The exemplary machining test results for Al_2O_3-2.5%wt.Ni. composite tool are shown in Fig.7. The Al_2O_3-2.5%wt.Ni. composite tool is characterized with highest average tool life of 6.8 min. among previously mentioned composites. The surface roughness parameter Ra obtained for Al_2O_3-2.5%wt.Ni. composite tool is lower than 1.5 µm (Fig.8). In case of second measurement suddenly increase of roughness parameter is due to the chipping in the last stage of machining test.

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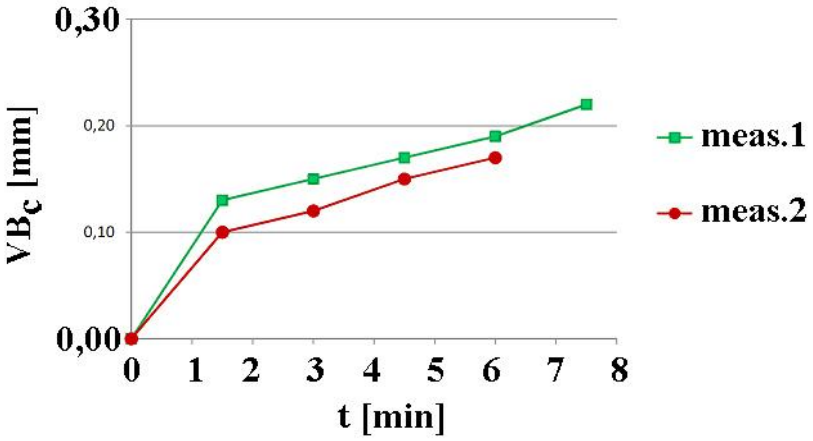


Fig. 7 Machining tests results for Al_2O_3-2.5%wt.Ni composite tool

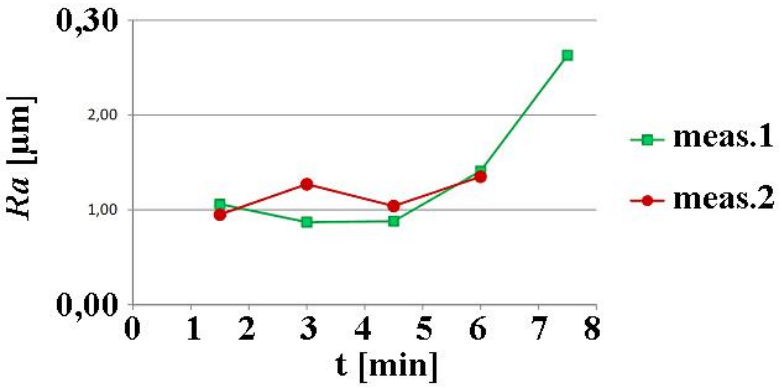


Fig. 8 Surface roughness of C45 steel results after machining using Al_2O_3-2.5%wt.Ni composite tool

The machining test results for reference commercial ceramic cutting tool are shown in Fig.9. It is characterized with average tool life of 13,8 min. The commercial cutting tool wear uniform without cracking or chipping. The average surface roughness parameter *Ra* of C45 carbon steel after machining is in range of 1.0-2.0 µm (Fig.10).

The reason why produced Al_2O_3-1%wt.Ni composite shows so much higher average tool life than the composites with higher nickel content needs further examination. Nonetheless the Al_2O_3-1%wt.Ni cutting tool is characterized with over three times higher average tool life than reference commercial cutting tool. Produced cutting tools with higher nickel content are in the best case (Al_2O_3-2.5%wt.Ni) characterized with two times lower average tool life than reference cutting tool.

The series of an X-ray analysis performed on Al_2O_3-10%wt.Ni-C45 samples (annealed in air and vacuum conditions) shows no sign of additionally phases. It may indicates that no reaction between cutting tool material and machined material occurs. Nonetheless as the X-ray diffraction gather information from very small area it is still possible that during series of measurements information was not gathered from an area in which chemical reaction occurs.

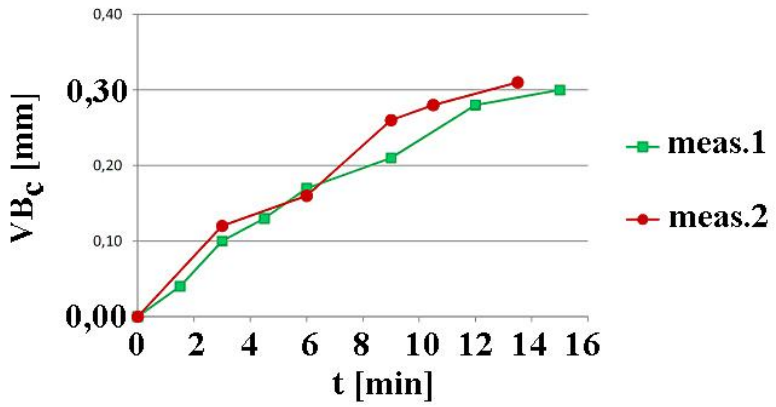


Fig. 9. Machining tests results for commercial composite tool

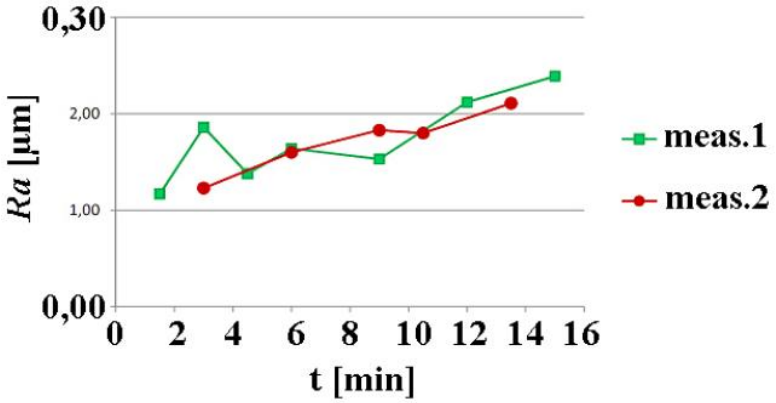


Fig. 10 Surface roughness of C45 steel results after machining using commercial composite tool

SUMMARY

Produced Al_2O_3-x%wt.Ni composites are characterized with near theoretical relative density (>97.9%). Sinters consists of two phases: α-Al_2O_3 and Ni. Produced composites are characterized with uniform nickel particles distribution in alumina matrix. K_{IC} coefficient of alumina ceramic – nickel composites increases slightly comparing with Al_2O_3 sinter (3.56±0.31 MPa*$m^{1/2}$). Al_2O_3-2.5%wt.Ni composite is characterized with the highest K_{IC} coefficient value of 4.18±0.36 MPa*$m^{1/2}$. The composite with nickel weight content of 5% is characterized with lowest K_{IC} coefficient value of 3.83±0.36 MPa*$m^{1/2}$. Conducted machining tests show that Al_2O_3-1%wt.Ni cutting tool is characterized with highest average tool life (44.3 min.). The tool wears uniformly without cracking or chipping. Surface roughness parameter *Ra* of C45 carbon steel after machining with Al_2O_3-1wt.%Ni composite tool equals 1.25±0.25 µm. The cutting tools with higher content of nickel show a tendency to chipping before achieving defined flank wear of 0.3 mm. Al_2O_3-2.5wt.%Ni composite tool is characterized with highest average tool life among composite tools with nickel content higher than 1wt.% (6.8 min.). The surface roughness parameter *Ra* measured after machining with Al_2O_3-2.5wt.%Ni composite tool is lower than 1.5 µm. The conducted experiment shows that no additional phases were created in the simulated conditions of machining process.

Acknowledgement

Scientific research supported by European Regional Development Fund Program - Innovative Economy (Grant No. UDAPOIG.01.03.01-12-024/08)

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