Marcin Podsiadło[1], Barbara Smuk[2], Lucyna Jaworska[3], Bogna Królicka[4]

Al_2O_3 CUTTING PROPERTIES IMPROVEMENT

ABSTRACT

Alumina base ceramic tools have mainly been used as environmentally-friendly cutting tools, because they have particularly high temperature limit and allow dry cutting without or with limited quantity of coolant. The main negative aspects of alumina ceramic inserts are their brittleness, poor resistance to thermal shocks. However, actually there are new technological possibilities improving the ceramic cutting materials properties. The presented results of studies showed the significant influence of alumina based compacts composition on its properties improvement. Selected properties were investigated for alumina compacts with MgO, ZrO_2, TiC, TiN or Ti(C, N) addition.

KEYWORDS: *alumina, cutting tools, free sintering, modifying additives, properties*

1. INTRODUCTION

Ceramic cutting tools have been in use for approximately 90 years. Ceramics represents different class of cutting tool materials with unique chemical and mechanical properties.
Major ceramic cutting materials are:

- Alumina – is the basic ceramic tool material,
- Alumina-silicon carbide whisker composites. The addition of SiC_w increases the fracture toughness of alumina,
- 70%Al_2O_3 – 30% TiC. This material has exellent thermal stability and is capable of cutting dry or with a water base cutting fluid,
- Si_3N_4 is shock resistant, with a high thermal conductivity and a moderate thermal expansion. Silicon nitride is widely used for machining cast iron where the material's abrasion resistance is exellent,
- Titanium carbide/titanium nitride materials are identified as cermets having good abrasion resistance,
- SiAlONs are solid solutions principally between silicon nitride and alumina.. The presence of alumina provides improved resistance to oxidation,
- Polycrystalline diamond (PCD) has excellent abrasion resistance and is used for cutting non ferrous metals, glass and ceramics,
- Cubic boron nitride (cBN) continues to be used as a cutting tool insert, especially for hard turning,

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[1] Marcin Podsiadło, the Institute of Advanced Manufacturing Technology
[2] Mgr inż. Barbara Smuk, the Institute of Advanced Manufacturing Technology
[3] Prof. AP, dr hab. inż. Lucyna Jaworska, Pedagogical University of Cracow, Institute of Technology; the Institute of Advanced Manufacturing Technology
[4] Mgr inz. Bogna Królicka, the Institute of Advanced Manufacturing Technology

- Cemented carbide is actually a cermet where the WC part is the ceramic constituent. It is incredibly strong, resistant to thermal shock, has a toughness up to 15 $MPam^{-1/2}$, and at lower cutting speeds is very wear resistant,
- Coatings deposited on tools are made of oxide, nitride and superhard ceramics can be beneficial especially for hard turning.

Over the past three decades in the Institute of Advanced Manufacturing Technology (IZTW, Instytut Zaawansowanych Technologii Wytwarzania) has been realized researches for ceramic cutting materials. Studies are realized in six groups:

- Alumina and alumina as composite matrix with ZrO_2 stabilized Y_2O_3, with TiC and Ti(C,N),
- Si_3N_4 with additives,
- Cermets,
- Diamond composite (PCD),
- Cubic boron nitride composites,
- Ceramic inserts with PVD coatings.

All of these materials obtaining in the IZTW are used for machining by cutting. Ceramics materials are characterized by high hardness and abrasive wear resistance but they have relatively low fracture toughness and susceptibility to thermal shock. These ceramic tool materials exhibits differentiation of properties such as: thermal and electrical conductivities, high hardness, abrasive wear resistance and corrosion resistance, resistance to temperature change and chemical inertness towards the workpiece materials, all of which determine applications of these materials [1].

Alumina based ceramics was introduced in early 1950s and continues to be used as cutting tool inserts. Alumina and alumina with various additive tools, are manufactured using cold pressed aluminium oxide, or the hot pressing process and free sintering in air, vacuum or protective gasous There are appear novel concepts for the realization of innovate properties and cutting possibilities of this material:

- New types of reinforcing materials in ceramic composites – whisker or nanometer size particles,
- New compositions of compacts – new properties,
- Functionally Graded Materials,
- Nanomaterials.

Al_2O_3 has a very low solubility in iron and a third group with intermediate solubility, containing borides, nitrides and carbides of Ti and Zr. The chemically stable materials like alumina and zirconia are actually constituent phases of successful cutting tool materials for high speed turning of steel [2].

This paper presents an up-date state on recent studies which are realized in IZTW in aim to improving of Al_2O_3 ceramic cutting materials properties.

2. ALUMINA PROPERTIES IMPROVING

Historically, alumina has been the first ceramic material used for cutting tool inserts. First alumina compacts consists a glassy phase derived from additions of talc or clay. The problem with glass-bonded alumina was the glassy phase softeness at cutting temperatures. The addition of MgO as a sintering aid eliminates the glassy phase and improves the strength of material and limites the grain growth [1]. High speed cutting tools can encounter temperatures of 1270 K or higher, so a key property for an efficient cutting tool is hot hardness. Alumina retain a higher hardness at temperatures between 870 – 1270 K then either tool steels or cobalt bonded WC cermets.

Its low thermal conductivity and fracture toughness could be improved by addition of 10-40vol % of Ti(C,N) or TiC secondary phase providing a tool without catastrophic failure on impact. The dispersion of hard particles increases the harness for temperatures up to 1070 K [3].

Alumina with ZrO_2 contains up to 10% of zirconia's dioxide. Toughness of this materials could be improved via matrinsitic transformation [4].

Singlecrystal whiskers deflect cracs in the alumina matrix and thereby improve fracture toughness of the tool. For alumina ceramics the addition of silicon carbide whiskers offers increased productivity in the machining of Inconel and similar high strength, high temperature alloys in the aerospace industry [1].

3. EXPERIMENTAL PROCEDURE

For the mixtures the 0.50 μm powders of Al_2O_3 (Alcoa product) and up to 0.5 wt% of MgO were used (resulted as TA type of compact); The addition of ZrO_2 to alumina powders resulted as TA–Z compacts. Yttria stabilised zirconia solid solution and the content of Y_2O_3 was 5.3 wt % (UNITEC Ceramics product). For the "black" ceramics, powders of alumina and TiC, TiN or $Ti(C, N)_{30/70}$ (Stark products) were used. The average size of carbide and nitride particles was 1 – 1.5 μm (TW, TZC, TACN, TW-N types), contents of initial powder mixtures are presented in the table 1.

Mixtures of powders are milled in the alumina rotary mill with alcohol and lubricant, next the mixtures was granulated. Samples are formed by single action pressing at pressure of 110 MPa and cold isostatically pressed inside a latex tube with applied pressure of 250 MPa. These ceramic precursors were treated in air to 510 K, for the lubricant removing. Samples were free sintered, depend on the type of material, in air for TA and TAZ samples or in vacuum or in protective argon or nitride atmosphere presence, for TW, TW-N. They were heated at a rate of 2 - 5°/min and held for 1h at 1880 - 1970 K using the GERO HTK 8/22G furnace.

Samples for microstructure analysis were thermal etched at 1820 K during 40 minutes. Microstructure of materials were assessed by scanning electron microscopy. Apparent density was measured by Archimedes method.

Vickers identation technique was used to measure microharness (HV0.5), hardness (HV30) and fracture toughness HVG (load of $30x10^3$ N).

Abrasive wear tests were performed using the own made apparatus. The rate of the wear material on the SiC80 was measured under constant loading of $3x10^3$N during 2 minutes.

In the figure 1a microstructure of Al_2O_3 compact with 0.5 wt % MgO addition (TA type) is presented. The microstructure of compact with yttria stabilised zirconia solid solution is shown in the figure 1b (TA–Z compact). Microstructures of compacts with TiC addition (TW type) and TiC and TiN addition are presented in figures 1c and 1d (TW and TW–N compacts).

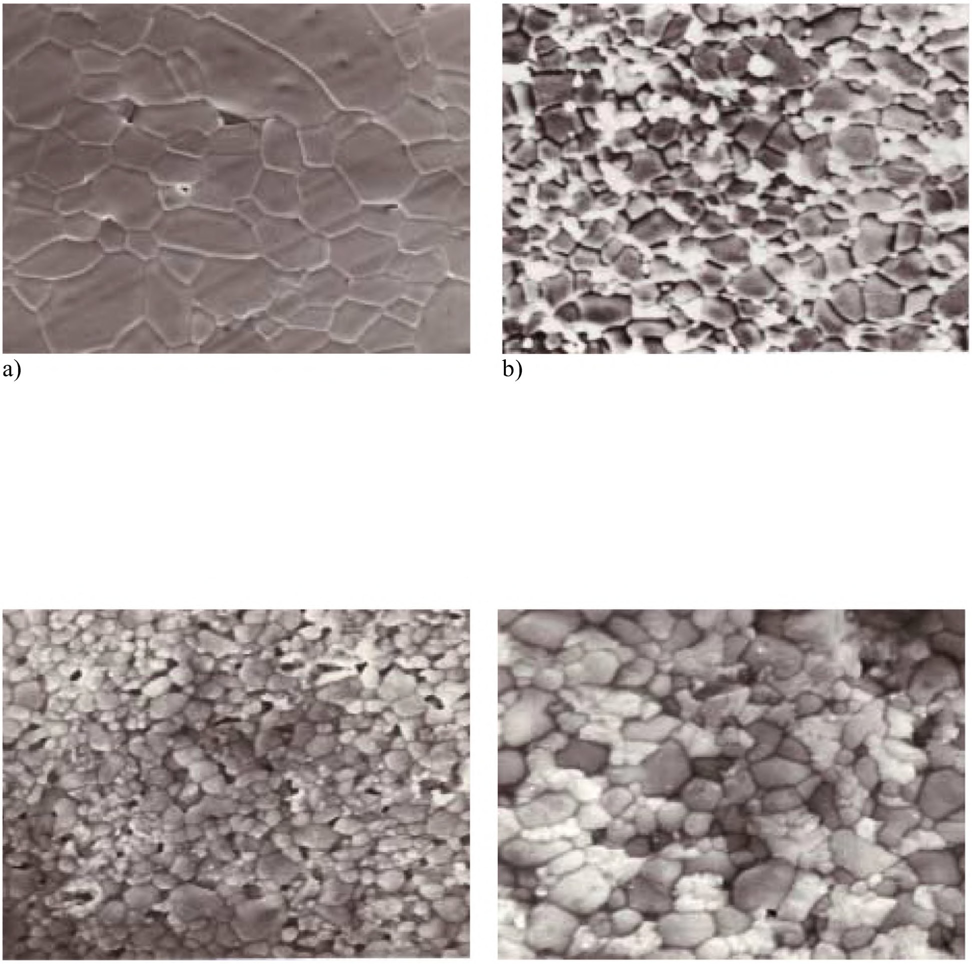
The study showed the significant influence of alumina composition on its properties, table1. The increase is not only in fracture toughness but in hardness and wear resistance, also.

The yttria stabilised ZrO_2 addition improve the thermal shock resistance and the fracture toughness of alumina compacts (TAZ, TAZ-1). Machining recommendation of this material is for turning carbon steels and cast irons with hardness up to 350 HB. Alumina with TiC (TW type of ceramic)is used for machining carbon alloy, tool steels, and stainless steel.

Alumina with the titanium phases addition (TWN, TACN type of ceramic) are particularly effective in the turning and milling hardened steels with hardness up to 62 HRC. These materials are particularly abrasion resistant.

Table 1. Same selected properties of Al_2O_3 materials.

Mat. type	Phases content wt%	Temp. and duration of sintering K/h	Apparent density g/cm^3	HV30 GPa	HV0.5 GPa	HVG MPa·m$^{1/2}$	Average grains size µm	$v_n \cdot 10^3$ µm/h
TA	Al_2O_3 +MgO	Air 1920 K 1h	3.91	17.0	18.00	2.6	<3	9.0
TA-Z	(Al_2O_3 +MgO)+ 20% ZrO_2 stab. Y_2O_3	Air 1920 K 1h	4.22	16.10	17.60	3.0	1.5	6.5
TAZ1	(Al_2O_3 +MgO)+ 9% ZrO_2 +5% ZrO_2 stab.Y_2O_3	Argon 1940 K 1h	3.88	12.40	14.00	2.3	2.9	15.0
		Vacuum 1920 K 1h	3.94	12.50	14.20	2.9	2.5	8.5
		Air 1920 K 1h	4.13	16.10	16.80	3.4	2.0	5.4
TW	Al_2O_3+10% TiC	Vacuum 1970 1h	4.1	-	19.00	-	<2.5	7.0
TZC	(Al_2O_3 +MgO)+ 10% ZrO_2+5%TiC	Vacuum 1970 1h	4.16	17.70	18.50	3.0	2	6
TACN	(Al_2O_3 + ZrO_2)+ 30%Ti(C,N)	Vacuum 1970 1h	4.22	17.80	18.80	3.4	-	5.0
TW-N	(Al_2O_3 +10%TiC)+ 20%TiN	Vacuum 1970 1h	4.24	16.90	18.50	3.7	<2	6
		Nitride 1960 1h	4.125	17.50	18.30	3.2	<2	10



a) b) c) d)

Fig.1. Microstructures of alumina compacts; a) TA type: Al_2O_3 +MgO; b) TA-Z type: (Al_2O_3+MgO)+20% ZrO_2 stab.Y_2O_3; c) TW type: Al_2O_3+10% TiC; d) TW-N type: (Al_2O_3 +10%TiC)+20%TiN.

CONCLUSION

Actually there are new technological possibilities for improving the ceramic cutting materials properties such as nanopowders sintering, whiskers addition, or new chemical compositions. It is possible to design and to manufacture materials with high hardness and improved fracture toughness, while ceramic materials could become the main group of cutting materials.

Ceramic inserts are generally more costly than carbides but their metal removal rates are ~3 to 4 times greater. Ceramic inserts also demonstrates reduced wear rates.

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