Nozzles from Alumina Ceramics with Submicron Structure Fabricated by Radial Pulsed Compaction

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Abstract

By means of magnetic pulsed compaction and sintering of weakly aggregated alumina based nanopowders the jet forming nozzle samples for the hydroabrasive cutting were fabricated. The ceramics was obtained from pure alumina, as well as from alumina, doped by TiO_2, MgO and AlMg. It was shown that the samples sintered from AlMg doped Al_2O_3 powder have the best mechanical properties and structural characteristics: relative density ~0.97, channel microhardness – 18-20 GPa, channel surface roughness ~0.7 µm, average crystallite size ~1 µm.

Keywords : alumina, pulsed compaction,submicron ceramics, micro hardness

1. Introduction

Due to combination of high hardness, heat resistance, chemical inertia on one hand and accessibility on the other hand alumina appears to be a perspective material for a wide range of structural applications with energy tense service conditions. A tube-shaped jet-forming nozzle for hydroabrasive cutting can be of a good example. However the applications of conventional coarse-grained Al_2O_3 ceramics are limited due to their low hardness, toughness and wear resistance.

It was shown earlier [1] that ceramics with homogeneous fine structure has substantially higher mechanical properties. That is why fabrication of critical parts from such ceramics is an actual problem. The authors develop the magnetic pulsed compaction method of the powders, which allows them to obtain homogeneous compacts from nanopowders with high relative density suitable for high-dense ceramics sintering [2].

In present work the possibility of fabrication of nozzle samples with high channel hardness from fine-grained ceramics by compaction and sintering of alumina based nanopowders is investigated.

2. Experimental and Results

The main characteristics of the starting powders, used in this work, are presented in Table 1. Here: d – average powder particle size, T_s and t – sintering temperature and holding time, correspondingly.

All the powders except A-IAM were obtained at the Institute of Electrophysics UD RAS (Russia) by electrical explosion of the wires method. The metallic powder AlMg and the oxide powders (TiO_2, Al_2O_3) were synthesized in inert gas and oxygen content atmospheres, correspondingly. The commercial 99.8% pure alumina powder A-IAM (Inframat Advanced Materials LLC, USA) and AlMg alloy were used to produce powders 1 and 2. Powders 2 and 3 were obtained by mechanical mixing of Al_2O_3 with AlMg and TiO_2 in isopropanol, correspondingly. Powder 4 was obtained by electrical explosion of Al+1.3 wt% Mg alloy with 1 hour post heating at 1300°C.

Table 1. Main characteristics of the starting powders

#	Powder type	Chemical composition	d, [nm]
1	A-IAM	α-Al_2O_3	200
2	A-IAM + 15Al	α-Al_2O_3 + 15 wt% AlMg	Al_2O_3: 200 AlMg: 30
3	AT 1-5	(γ+δ)-Al_2O_3 + 1 wt% TiO_2	Al_2O_3: 20 TiO_2: 30
4	AAM 1-13	α-Al_2O_3 + 4 wt% $MgAl_2O_4$	Al_2O_3: 90

The powders were compacted into homogeneous thick-wall tubes ($\rho_{rel\ green}$ ~0.55-0.6) with the external diameter of ~12-14 mm and with central channel of ~2-3 mm in diameter. The compaction was realized by radial magnetic pulsed press [3] with the pressure pulses of up to 0.3 GPa in amplitude and the duration of ~100 µsec. Also a series of the samples from pure A-IAM and 15, 30 wt% AlMg doped A-IAM was produced by uniaxial magnetic pulsed press. The compacts were 15x1 mm disc-shaped bodies with relative density of 0.56-0.85. The green bodies were sintered in resistive furnace in air at temperatures of up to 1550°C with up to 300 min holding time.

Ceramics microhardness was studied by indentation method (Nanotest 600) at mean load of 2 N. It's structure was investigated by AFM (Solver 47p). The channel surface roughness, R_a, was determined by NewView-5000 device. The samples density was measured by Archimedes method.

Table 2. Main characteristics of sintered ceramics

#	T_s, [°C]/ t, [min]	ρ_{rel}	$H_{V, ch}$, [GPa]	$H_{V, bulk}$, [GPa]	d_{cer}, [μm]	R_a, [μm]
1	1550/ 60	0.97-0.98	18.9-19.4	16.6±0.2	0.9	0.75
2	1550/ 60	0.96-0.97	18.8-19.8	17.3±0.6	0.98	0.68
3	1450/ 300	0.93-0.96	6.7-1 7.7	17.0±0.9	1.03	1.14
4	1450/ 6	0.88-0.91	18.1-19.7	13.38±0. 7	0.32	1.09
5	-		20.9±1.5		single crystal	

Here: ρ_{rel} – ceramics relative density, $H_{V, ch}$ and $H_{V, bulk}$ – channel and bulk microhardness, correspondingly, d_{cer} – average ceramics crystalline size, R_a – channel surface roughness, #5 is a leuco sapphire single crystal.

It is seen from Table 2 that ceramics 1 and 2, obtained from commercial A-IAM alumina based powder have the highest densities. The investigation that was held on discs from pure A-IAM and A-IAM doped with different amount of AlMg showed that metal aluminum being lubricant facilitates for more dense and uniform particle packing during compaction. However ceramics, obtained from the

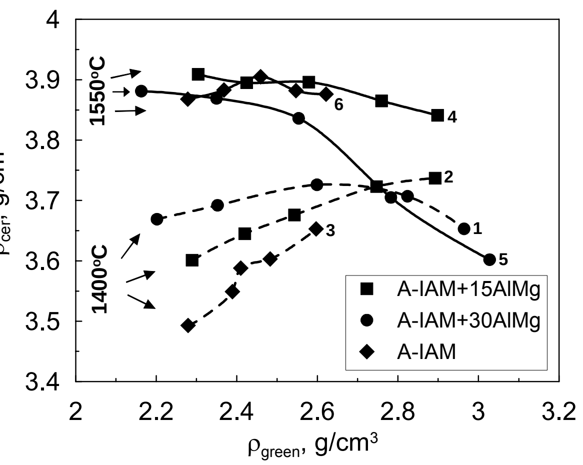

Fig. 1. The dependence of density of sintered ceramics from the green bodies density.

powder with smaller amount of metal, turns denser upon sintering at 1550°C in the whole analyzed range of green bodies densities (compare curves 4 and 5 on fig. 1). Thus, 15AlMg doped alumina powder appears to be the most perspective material for the fabrication of homogeneous compacts and high-dense ceramics.

Table 2 shows that the highest channel as well as bulk microhardness is reached in A-IAM and A-IAM+15Al ceramics. Lower values of bulk hardness as compared to the channel one can be explained by the influence of the surface mechanical grinding of the investigated section before the bulk hardness measurements. It should be mentioned that these ceramics are comparable to α-Al_2O_3 single crystal in terms of microhardness. It was also shown that microhardness is distributed uniformly along cross-section radius of the nozzle, obtained from A-IAM powder.

The fracture analysis of two types of ceramics based on A-IAM with and without AlMg alloy additive showed that they have a similar morphology in the center of the nozzle and in peripheral. But near the channel the crystals in ceramics from pure Al_2O_3 were not shaped completely. It can take place due to lower density of the material near the channel as a result of inhomogeneouty of the green body in this region. The introduction of metal addition led to close grain packing – the crystallites were completely shaped and the fracture was generated mainly though their volume. Also some small crystals (50-200 nm) were observed at intercrystalline boundaries in A-IAM+15AlMg ceramics. Probably they were formed in the result of micro explosions of AlMg alloy particles upon their burning during sintering.

3. Summary

By means of radial magnetic pulsed compaction and sintering of weakly aggregated alumina based nanopowders the jet forming nozzle samples for the hydroabrasive cutting were fabricated. From investigated compositions homogeneous ceramics sintered from 15 wt% AlMg doped Al_2O_3 powder has the best mechanical properties and structural characteristics. The relative density of this ceramics is ~0.97, channel microhardness – 18-20 GPa, channel surface roughness ~0.7 μm, crystalline size ~1 μm.

4. References

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