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The effect of Wire -EDM processing on the flexural strength of large scale ZrO_2-TiN

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Abstract

Technical ceramics are generally used in high demanding applications, e.g.: Zirconia (ZrO_2) has an excellent fracture toughness but it is difficult to machine into complex shapes. Electrical Discharge Machining (EDM) is a valid option for hard materials, though this requires an electro-conductive work piece. In the presented work a large scale ZrO_2 blank with a conductive secondary TiN phase is processed by Wire -EDM with different finishing regimes. 4 Point bending tests are conducted to check the final flexural strength as a consequence of the EDM process, and the integrity of the surface and subsurface is analyzed and discussed.

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Keywords: Wire EDM; Ceramic composites; ZrO_2; Spark Plasma Sintering; Large scale ceramics

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1. Introduction

Demanding applications within the industry and biomedical field which require: high wear resistance, fracture toughness, Young's modulus, operation at high temperature or in chemical aggressive environments often rely on technical ceramics (e.g.: Al_2O_3, Si_3N_4, B_4C,. SiC, etc.). Nonetheless, the mechanical performance of technical ceramic components is directly related to the surface integrity of the finished part. Surface defects can have a major impact on the mechanical behavior because of the brittle nature of these materials. For example, small cracks on the surface can propagate quickly throughout the material and foreseen strength or durability is not achieved by the final product, while material properties prove to be adequate.

Yet another issue that needs to be considered is finding a cost effective manner for shaping ceramics accurately into the final shape. Because of the hard and brittle nature of ceramics it is difficult to machine them by conventional cutting operations (e.g.: turning, milling, drilling, etc.). Alternatively, electro chemical processes can be used, since hardness of the workpiece does not need to be considered for these operations. One of these processes which is well established (especially for machining hard metals) is electrical discharge machining (EDM). A volumetric electric conductivity of at least 100 Ωcm of the workpiece is required, in order to allow machining by standard EDM operations [1]. Although alternative strategies such as electrode assisted EDM [2] allow processing of non-conductive materials, these are rarely used in industry. Low electrical conductivity poses a problem for some oxide based ceramics such as: Al_2O_3, BaO and ZrO_2. The latter, zirconium dioxide (ZrO_2) is known to the general public for its use in dental applications. From an engineering point of view, it is especially interesting because of its high resistance to crack propagation, good fracture toughness and high thermal expansion (10.5 10^{-6}/K) which makes it possible to use it jointly with steel.

Processing ZrO_2 by conventional EDM operations is possible by embedding a secondary conductive phase into the material, thus creating a ceramic composite. Past studies have focused on determining the percolation point at which an adequate secondary phase is present allowing EDM processing [3,4,5]. Other studies have reported on the material removal mechanisms (MRM) [6] and effect of EDM on mechanical performance [7] of ceramic composites.

In this study, ZrO_2 ceramic blanks with 40% volumetric composition of TiN as secondary phase [8] are processed by Wire EDM (W-EDM). This process uses a wire as electrode to

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cut a specific contour from a rough block of material. For manufacturing accurate shapes with a high surface quality, a number of finishing steps are required. The initial cut is used to create the rough shape. The second and third cuts are used to accurately create the shape and all following finishing steps are used to assure a certain surface quality (surface roughness). Past studies on W-EDM processing of ZrO_2-TiN reach R_a roughness values of 2.7 µm for roughing and show melting and evaporation as the material removal mechanism [6]. In this work, the effect of different finishing steps on flexural strength is analyzed.

Fig. 1. 250 mm Diameter ZrO2-TiN blank shown next to smaller 150 mm and 40 mm blank.

For this study, a large scale blank with a diameter of 250 mm and a height of 16 mm produced by hybrid spark plasma sintering (SPS) is used. Fig. 1 shows the large scale blank next to smaller 150 mm and 40 mm diameter blanks. Conventional SPS sends a current through a cylindrical pressing die (consisting of graphite) and compacted powder, creating heat by means of the Joule effect [10,11]. Hybrid SPS has an extra coil around the outer die, which can heat the die and compacted powder by means of inductive heating [12]. The combination of Joule and inductive heating generates a better heat distribution, allowing larger blanks to be produced.

2. Experimental setup

The large scale blank contains 59.3 vol.% ZrO_2 and 39.6 vol.% TiN. An extra 1.1 vol.% Al_2O_3 and 0.1 vol.% Y_2O_3 is used as stabilizer and sintering aid. Ball milling (turbula mixer) was used to mix the sintering powder in an ethanol environment in batches of 500 grams with 2.5 kg ZrO_2 balls (diameter 3 mm). The mixture is dried and sieved with a 400 µm mesh, before being placed into the SPS oven. From this blank, samples are cut and ground to check material properties. A Vickers hardness of 1360 kg/mm^2 and an average 4 point flexural strength of 1104 MPa were measured.

To determine the flexural strength samples of 3 x 4 x 45 mm are tested in a 4 point bending setup on an Instron® 4467 test bench. The surfaces of the W-EDM samples are processed by W-EDM, except for the faces parallel to the compression load which are ground (as indicated by Fig. 2).

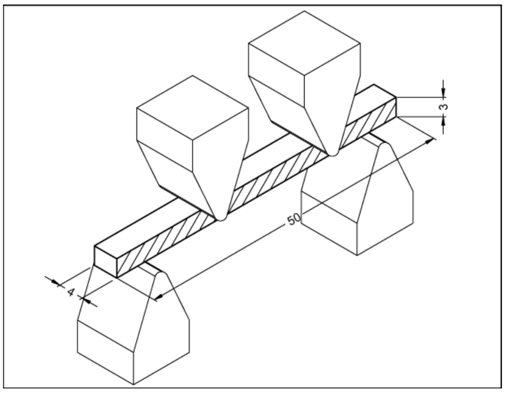

Fig. 2. Setup of the 4 point bending test.

Samples are machined on a Charmilles ROBOFIL® 240CC W-EDM, by firstly cutting 3 x 50 mm rectangles from the 16 mm high blank. Next, these shapes were cut into 3 x 4.5 x 45 mm beams and finally grinded down to 3 x 4 x 45 mm bending samples. Demineralized water was used as EDM dielectric (11 µS/cm) and a 0.25 mm diameter AC Brass wire with a tensile strength of 900 N/mm^2 is utilized as cutting electrode.

Table 1. Most important generator settings for the “isopulse” controlled cuts.

Cut	Pulse on time [μs]	Pulse off time [μs]	Current [A]	Open gap volt. [V]	Discharge volt. [V]
1	0.50	11.0	10	80	52.0
2	0.05	5.0	10	120	90.3
3	0.05	20.5	4	60	42.3

Generator, wire and flushing settings are based on commercial hard metal settings. In section 3.3, surface roughness for each finishing cut is also compared to the surface roughness of hard metals expected by the W-EDM machine manufacturer. The 3 initial cuts are performed in isopulse mode, while the final finishing cuts are performed in isofrequency mode. The most important settings are shown in Tables 1 & 2 for each mode.

Table 2. Most important generator settings for “isofrequency” controlled cuts.

Cut	Pulse on time (μs)	Pulse off time (μs)	Curr. (A)	Open gap volt. (V)	Speed. (mm/s)
4	0.4	3.0	10	120	8.93
5	0.4	3.0	5	120	9.37
6	0.4	1.6	6	240	5.06

3. Experimental results

3.1. Flexural strength

To assess the effect of the W-EDM process on the flexural strength, Weibull statistics are used. For each finishing