Precise Manufacturing of Micro Structures by Spark Erosion in Electrically non-conductive Zirconia.

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1 Introduction

Electrically insulating ceramics like zirconia are increasingly used for high technological applications due to their extraordinary attributes. Especially high hardness, chemical inertia and thermal resistance serve engineering purposes. As a structuring in the pre-sintered state is nearly impossible, ceramics are commonly shaped in the sintered state. Post processing can be realised by grinding and polishing methods but those are limited in geometry and highly cost intensive.

Conductive materials can be structured by electrical discharge machining (EDM) as long as the conductivity is above 0.01 Scm^{-1} [1][2]. It is not only well-established in the field of mould inserts and tool making, it takes on a major role in high precision structuring. This shaping technique is contact free and hardly inserts any process forces into the work piece. Thermal energy converted from electric energy leads to material removal [3]. These aspects are very promising to achieve micro structures with particularly high aspect ratios.

An advancement of the spark erosion process to structure non-conductive materials is the usage of a conductive assisting electrode (AE) which is placed on top of the work piece [4]. For this reason we use a carbon compound based AE applied by screen printing [5]. During the process the AE is eroded and continuously recreated. The ceramic removal is a side effect due to the alternating thermal load (see Fig.1).

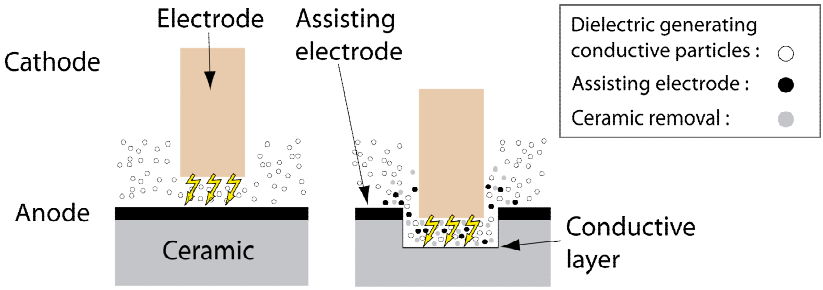

Figure 1: Principle of the spark erosion process using an assisting electrode

2 Outline

The intention of the following experiments is to analyse micro structures in zirconia samples with focus on wall thicknesses, heights and aspect ratios (AR). Further experiments are performed to characterise the influence of the heat treatment of the surfaces due to the spark erosion process. Therefor the characteristic Weibull bending strength σ_B and the Weibull modulus m [6] are determined in four-point bending tests.

2.1 Microstructured walls in zirconia with high aspect ratios

In order to analyse the spark erosive process regarding micro structuring, walls with variable dimensions are generated. Therefor a tool consisting of two copper electrodes and a distance plate with variable thickness of 25 µm up to 100 µm is used. Multiple trials are performed using different distance plate thicknesses and erosion depths between 0.25 and 1.5 mm. Afterwards micrographs are created to measure the wall thicknesses and heights and to calculate the resulting aspect ratios.

Table 1: Maximum aspect ratio depending on the thickness of the distance plate

Distance plate [µm]	Maximum aspect ratio	Wall thickness [µm]
100	30	47
75	34	27
50	47	28
25	83	12

Table 1 shows the maximum aspect ratios depending on the thickness of the distance plates and the corresponding wall thicknesses. Here the aspect ratios vary between 30 and 83, where the maximum value is reached with a wall of 12 µm thickness at a height of 990 µm. The thinnest achieved wall has a width of 8 µm and a height of 650 µm. Figure 2, left side shows a SEM picture of a wall with an AR of 25. To the right in Figure 2, a micrograph is presented of a wall with an AR of 83.

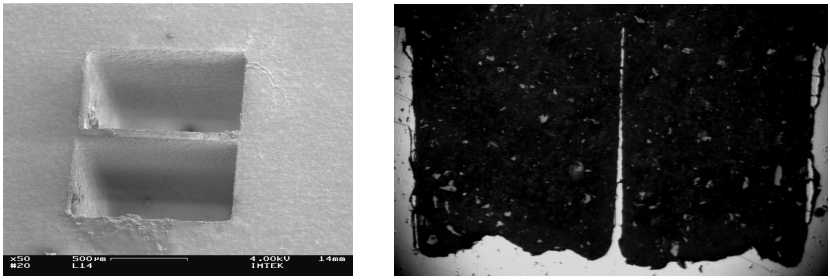

Figure 2: Wall with a height of 1.41 mm and a width of 57 µm (left), and micrograph of a wall with a height of 650 µm and a width of 8 µm (right)

2.2 Analytics of fracture behaviour

Experiments with distance plates of 25 µm thickness show that the process can lead to rupture of structures. Thus the fracture behaviour of two sample batches is analysed. The first batch consists of 33 unprocessed zirconia bars and the second one of 33 bars processed by spark erosion. The process parameters are held constant for all trials. The two batches are bent until breakage in a four-point bending setup that is designed according to DIN EN 843-1. The characteristic Weibull bending strength σ_B and the Weibull modulus m are determined for both batches according to DIN EN 843-5. Table 2 shows the results of the performed four-point bending tests.

Table 2: Resulting σ_B and m of unprocessed and processed bars of zirconia

Batch	σ_B [MPa]	m
Unprocessed	975.8	7.1
Processed	501.6	7.5

One can see that spark erosion influences the strength of structured ceramics significantly. The bending strength of unstructured zirconia matches the characteristic

value with 975.8 MPa. After processing with spark erosion the bending strength decreases about the half to 501.6 MPa in comparison to unstructured ceramics. In contrary the Weibull modulus is raised by about 6 % from 7.1 to 7.5.

3 Conclusion

The results show that it is possible to micro structure non-conductive ceramic material and to realise micro structures with high aspect ratios up to 83 and micro details below 10 µm. As expected the mechanical stability of zirconia is affected after a spark erosion process using an assisting electrode. The reason for a reduced bending strength σ_B can be found in the appearance of micro cracks and typical melt craters on the ceramic surface. But the fact that Weibull modulus *m* increases implies, that the generated surface defects during processing are introduced very homogeneously into the ceramic material regarding localisation and their appearance. In consequence of this a breakage of a ceramic part is more predictable as the width of the breakage distribution is narrower.

References:

[1] Schönbeck, J., 1993, Analyse des Drahterosionsprozesses, C.Hanser

[2] Siegel, R., 1994, Funkenerosives Feinstschneiden Verfahrenseinflüsse auf die Oberflächen-und Randzonenausbildung, Fortschritt-Berichte VDI

[3] Klocke, F., K. W., 2007, Fertigungsverfahren 3: Abtragen, Generieren und Lasermaterialbearbeitung. Springer

[4] Fukuzawa, Y., 1995, A New Machining Method for Insulating Ceramics with an Electrical Discharge Phenomenon, *Journal of the Ceramic Society of Japan, 103*, 987-992

[5] Hösel, T., M. C., R. H., 2009, Simple Techniques of Applying Lacquer Based Assisting Electrodes for Spark Erosive Structuring of Electrically Nonconductive Zirconia (ZrO2). Volker Saile, Kornel Ehmann, S.D. (Ed.), 4M/ICOMM 2009, The Global Conference on Micro Manufacturing

[6] Weibull, W., A Statistical Distribution of wide Applicability. ASME, *Journal of Applied Mechanics*, Transactions of the American Society of Mechanical Engineers, June 1952, 233-234