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# ANALYSIS OF ELECTRICAL DISCHARGE MACHINING (EDM) CUT OF CERAMIC LAYERS OBTAIN THROUGH ATMOSPHERIC PLASMA SPRAYING (APS) ON STEEL SUBSTRATE

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***Abstract:*** *Atmospheric plasma spraying (APS) of ceramic powders was used to obtain complex* $Al_2O_3$*-*$ZrO_2$ *layers on steel substrates for industrial applications. The ceramic layers were obtained after five-time passing's using a robotic arm with ceramic plasma on the metallic surface. The ceramic layers were investigated before and after mechanical grinding (2000 grit). Ceramic layers' surface and thickness were analyzed using scanning electron microscopy (SEM) and optical microscopy (MO) on the cutting line area. The appearance of micro-pores or micro-cracks was analyzed on the surface for grinded state samples. The thickness and the continuity of the ceramic layers were analyzed along the cutting line.*
***Key words:*** *ceramic layers, APS, SEM, AFM.*

## 1. INTRODUCTION

Ceramic materials are used in numerous engineering applications for various manufacturing industries. This is primarily due to their excellent mechanical properties at high temperatures, good oxidation stability and high hardness. However, their inherent fragility characteristics have led to difficulties in providing correct shape through machining (dimensional realization) and precision that greatly limits the number of their applications [1].

Ceramics have become an important industrial material and are widely used in various fields to overcome the limitations introduced by metallic materials. Ceramic materials are generally crystalline inorganic substances (glass being an exception) that are composed of metals and non-metals connected by ionic or covalent bonds [2].

Based on the chemical composition, industrial ceramics are classified into oxide and non-oxide (carbides, nitrites, borides, silicates and glasses). Compared to metals and polymers, the ability of ceramics to withstand very high operating temperatures makes them viable solutions in many engineering applications. Their stiffness and strength characteristics are close to those of metals and they are generally chemically inert.

Most ceramic materials are heat and electricity insulators and very resistant to the action of various environments [3].

Most of the ceramic materials have the characteristics of high electrical and thermal resistance, high chemical stability, high corrosion and electro-corrosion resistance, superior wear resistance, high temperature stable properties and high hardness.

Some applications of ceramic materials are silicon carbide, tungsten carbide and aluminum oxide are used as abrasive elements in grinding equipment. Fireclay (mainly composed of alumina ($Al_2O_3$) and silicon dioxide ($SiO_2$)), alumina, zirconia or magnesia, etc. are used in obtaining refractory bricks.

Zirconium diboride, is a ceramic with a very high application temperature (UHTC: ultra-high-temperature-ceramic), and boron nitride, are used to make crucibles and other elements that involve very high temperatures of use (at which most metals and alloys are in the molten state). Silicon carbide (SiC) and silicon nitride (SiN) have high wear and stress resistance properties, so they are used for applications where a wear-resistant surface is required, bearings, turbocharger rotors, etc. Uranium oxide ($UO_2$) is used in nuclear reactors as a fuel material. The titanium carbide (TiC) is used as a thermal barrier material for aerospace vehicles. In engine and turbine parts, high-performance ceramic materials such as Sialon ($Si_3N_4$) are used. Numerous applications have been identified for piezoelectric ceramic materials such as lead titanate, barium titanate and lead zirconate titanate (PZT) in ultrasonic testing, manometers and MEM (micro-electro-mechanical) devices.

Ceramic materials are also accepted in the making of cutting tool and die elements, fuel systems and valves for space vehicles, automotive engines, weapons systems for the military, nuclear industry, biological industry, heat exchangers and substrates for electronic devices in microwave equipment [4,5].

There have always been problems in the cutting/processing of industrial ceramic materials due to the extreme characteristics that influence their applications. Moreover, due to their high hardness and brittleness, these materials are more susceptible to fracture. Figure 1 shows different methods of cutting industrial ceramics.

Conventional cutting methods generally present cuts with high material loss, cutting marks with deviations that will normally reduce the mechanical strength of these materials but will also influence their other properties. Since in the case of ceramic materials a considerable cutting force is required, this will induce micro-cracks on the surface of the material and especially at cutting edges [6] or near the cutting channel.

Alternative cutting techniques, such as wire discharge machining, LASER beam machining, abrasive water jet machining, or hybrid machining processes have been used by various researchers worldwide for cutting ceramic materials [7 -9]. Only some of these techniques manage to produce high-quality and high-precision surfaces without degrading the base material, and this is achieved ~~by~~ using customized parameters. These modern methods can overcome the barriers in manufacturing engineering components made of ceramic materials.

In this paper the effects of EDM cutting process applied on metal-ceramic systems were analyzed using microstructural investigation equipment's.

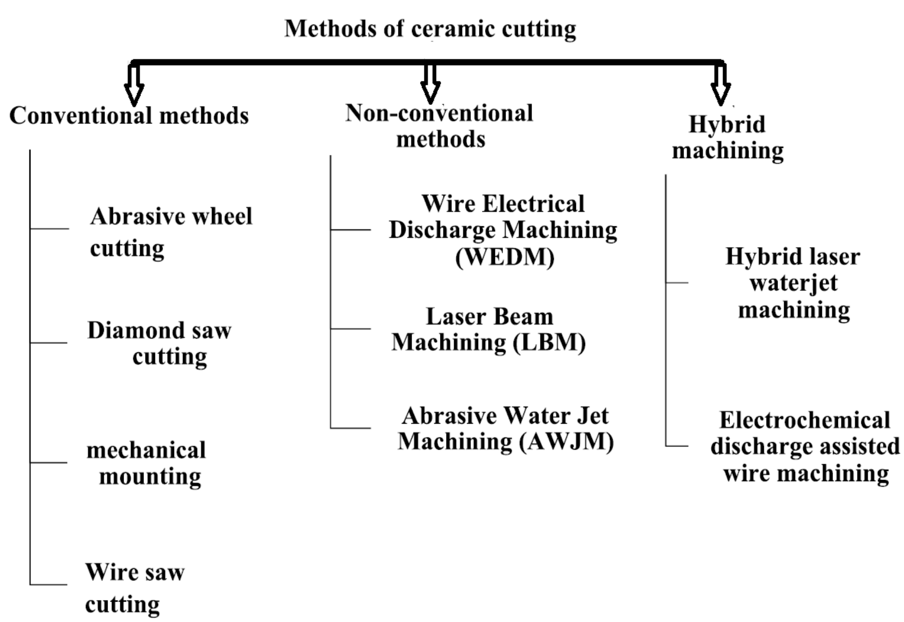



**Fig. 1.** Cutting methods of ceramic materials (bulk and layers) [1].

## 2. MATERIALS AND METHODS

Ceramic layers were obtained through Atmospheric Plasma Spraying (APS) technique. As a substrate was used a commercial steel substrate (weight percentages: Fe: 86,1%, C: 1,38%, Si: 1,98%, Mn :2,4%, Cr: 0,35%, Mo: 0,16%, Ni: 4,6% and Al: 0,16%) [10]. The ceramic layers were obtained from Metco powders $Al_2O_3$ and $ZrO_2$ (75/25; 50/50 and 25/75 percentages) [11].

The ceramic layer surface was analyzed after polish through scanning electron microscopy (SEM – VegaTescan LMH II, SE detector, 30kV electron gun supply) and atomic force microscopy (AFM – Easy Scan II, nanosurf, non-contact mode, CTR10 tip).

The metal-ceramic systems were cut using a wire electro-erosion equipment DEM 320A with the following characteristics: cutting wire: 0.18 mm of CrMo, cooling liquid: machining rate of 200 mm$^2$/min and precision of ≤ 0.01 mm. The cut part present usually a roughness smaller than 1 µm. The software used for programming the cut was WXPCNC & CAD/CAM (CAXA) [12]. The ceramic layers were firstly polished to 2000x with SiC metallographic papers.

## 3. EXPERIMENTAL RESULTS

The wire EDM cutting technique is a very promising technology that can produce complex shapes. The introduction of CNC and wire in the EDM technique to control various movements in the plane (and later in space) increased its capability for 2D contour cutting.

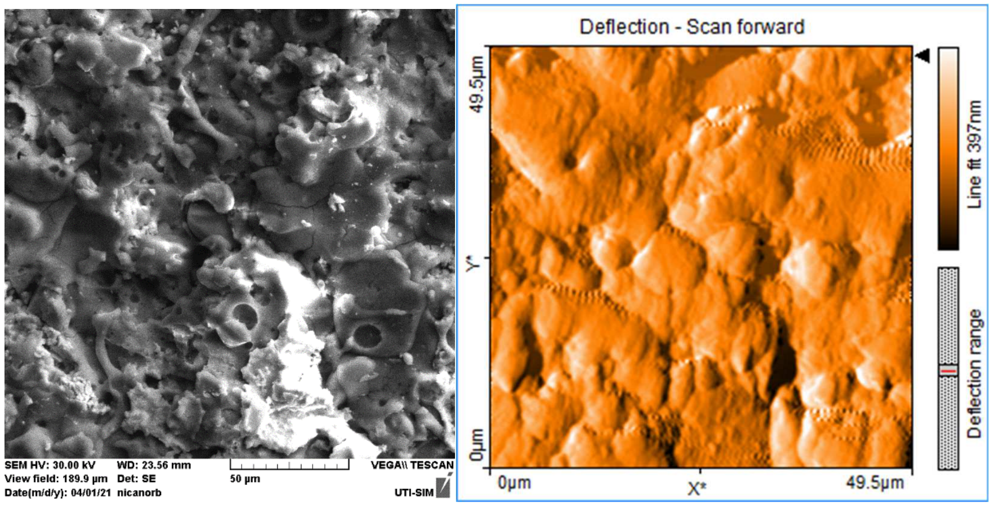
During the process, a series of electrical sparks are generated between the wire electrode and the part being melted and part of the material is vaporized and the other is removed with the help of coolant and cleaning liquid. The continuous flow of dielectric fluid (it also acts as a coolant) is coaxial with the cutting wire and is maintained throughout the cutting process for efficient removal of molten material in the form of debris from the spark zone. A pulsating voltage is used to create a spark between the electrodes. When the supplied voltage reaches a critical value, a plasma channel is generated and a spark is initiated. This leads to a sharp increase in temperature at one point, as a result, the material to be cut at that point melts and vaporizes.

In figure 2, a) we present the state of the ceramic layer obtained on the steel substrate through APS. Using an optical microscope, in figure 2 b), the cutting line presented for all three experimental samples is in the left part of the sample. The material has 10 mm thickness of steel as substrate and 25-50 µm thickness of the ceramic layer as coating. Using the EDM technique, the risk is of interrupting the process and breaking the wire because of the non-conductive nature of the ceramic layer. The cutting line is straight and no macro exfoliation or removal of the material was observed at this scale.

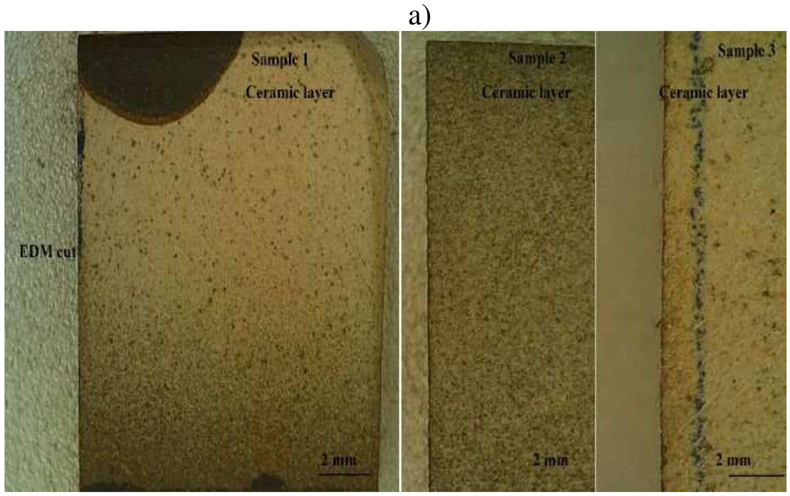
The plasma flow is interrupted when the pulsed energy supply is turned off, due to which the temperature begins to drop suddenly. This allows the dielectric to remove debris from the machined surface [13,14]. The live wire is fed continuously without any contact with the work-piece. A distance of 0.025–0.05 mm is automatically maintained between the work-piece and the wire based on the machining parameters.

It has been observed that during the wire EDM cutting process, the vibration in the wire reduces the accuracy of the cut and increases the slot width. This process can be reduced using smaller diameter wires than those currently applied or by improving the anti-vibration system of the cutting equipment [15,16]. Ceramic materials are also accepted in the making of cutting tool and die elements, fuel systems and valves for space vehicles, automotive engines, weapons systems for the military, nuclear industry, biological industry, heat exchangers and substrates for electronic devices in microwave equipment [5].

In figure 3, using scanning electron microscopy, few microscopic aspects are given after the EDM cutting process of the metallic-ceramic system near the cut line.




a)




**b)**

**Fig. 2**. a) SEM and AFM images of the ceramic layer and b)Optical images of the EDM with wire process cut of a metal-ceramic system.

At the microscopic level, the cut presents some small defects and their influence on the ceramic layer stability and properties must be evaluated in a following paper.

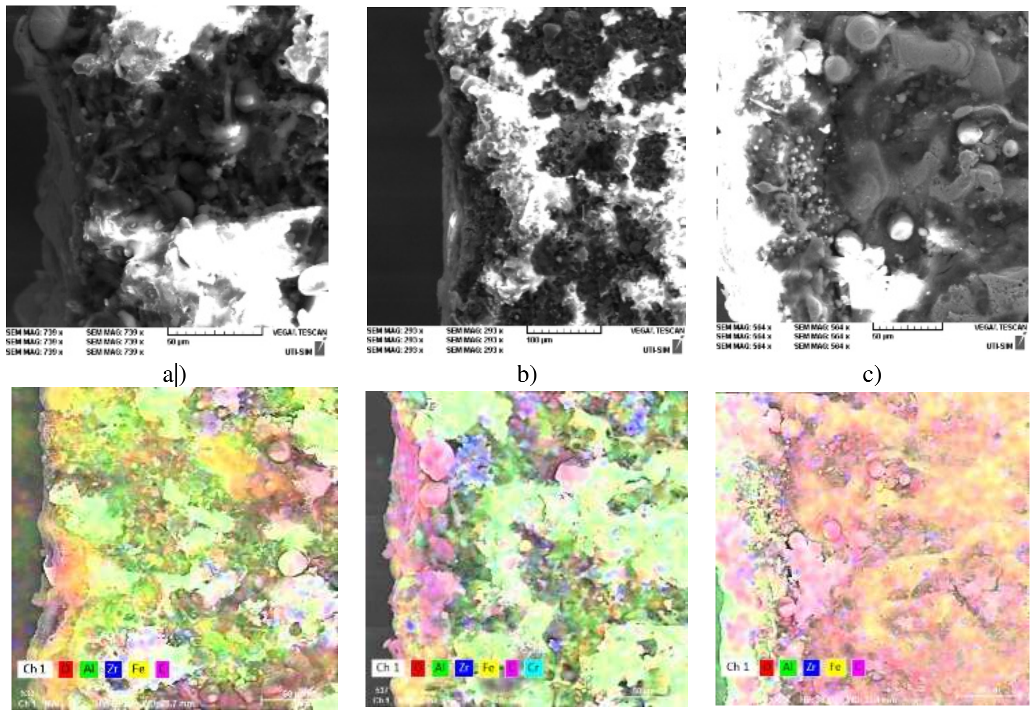
All three layers' present small interruptions, figure 3 a) and b), which can be assigned to small local discharges of the current between the cutting wire and the experimental system sample.

The ceramic layer is affected in a reduced proportion (50-100 µm) in the form of small pinches (less than 50 µm in depth), figure 3 d) and e), and mostly from the ceramic layer with an unaffected metallic substrate (the electric discharge occur between the wire and metallic substrate and if sparks appear the non-conductive ceramic material can be affected).

## 4. CONCLUSIONS

Main conclusion of the study is that EDM cutting can be a solution for mechanical processing of metal-ceramic systems, the process seems dependent of ceramic layer thickness and the cutting rate. From the cutting experiments, we observed a clean cut of the material with no major spalling of the ceramic layer at macroscale and only few pinching at micro-scale. It has been observed that during the wire EDM cutting process, the vibration in the wire reduces the accuracy of the cut and increases the slot width.

This process can be reduced using wires with a smaller diameter than those applied at this moment or by improving the anti-vibration system of the cutting equipment and in this way, the precision of the cut and its quality will be increased. After 20 cuts with a length of 50 mm the wire broke, probably the flow was interrupt by the ceramic layer or the wire presented a fabrication defect, and after we replaced it, we finished our set of 30 cuts.



a) b) c)

d) e) f)

**Fig. 3.** SEM Images of the EDM cut a) sample 1 – from the top of the ceramic coating, b) sample 2 – from the top of the ceramic coating and c) sample 3 – transversal image and EDS mapping of the elements d) sample 1, e) sample 2 and f) sample 3.

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## ANALIZA TĂIERII PRIN ELECTROEROZIUNE (EDM) A STRATURILOR CERAMICE OBȚINUTE PRIN PULVERIZARE CU PLASMĂ ATMOSFERICĂ (APS) PE SUBSTRAT DE OȚEL

*Pulverizarea cu plasmă atmosferică (APS) a pulberilor ceramice a fost utilizată pentru a obține straturi complexe de* $Al_2O_3$-$ZrO_2$ *pe substrat de oțel pentru aplicații industriale. Straturile ceramice au fost obținute după cinci treceri cu ajutorul unui braț robotizat cu plasmă ceramică pe suprafața metalică. Straturile ceramice au fost analizate înainte și după șlefuirea mecanică (granulație 2000). Suprafața și grosimea straturilor ceramice au fost analizate cu ajutorul microscopiei electronice de scanare (SEM) și microscopiei optice (MO) pe zona liniei de tăiere. Aspectul microporilor sau microfisurilor a fost analizat pe suprafața pentru probele de stare șlefuită. Grosimea și continuitatea straturilor ceramice au fost analizate de-a lungul liniei de tăiere.*

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