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Investigation into the Optimal Machining Conditions for Electrodischarge Machining of Conductive Ceramic

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Abstract

Among the various non-conventional machining processes, electrical discharge machining (EDM) is the most widely successfully applied processes for machining difficult - to - work materials such as steel, tungsten carbides and ceramics. In fact ,the EDM process is the best and sometimes the only canditate when all mechanical processes fail, providing that the material under consideration is sufficiently electrically conductive.

Machining of ceramics by the EDM process represents the state of the art technology, even though the entire production process is still in its infancy, and it is undergoing continuous refinement. In the present work, an attempt has been submitted to apply the EDM process on ceramic material (silicon-carbide) called REFEL SiC. The machining rate, tool wear and surface integrity have been studied under different machining parameters. The scanning electron microscope (SEM) has been used to investigate surface integrity to assess the optimum working conditions of the EDM process on the ceramic material.

Introduction

In modern technology there is a great demand for the use of harder, tougher and/or stronger workpiece materials, which in turn are more difficult to be machined with conventional methods [1-2]. Ceramics provide product designers with a number of interesting properties in the machine building and apparatus engineering field, mainly owing to the way in which technological limitations can be overcome by the use of these non-metallic materials [3]. Ceramic is an extremely hard, crystalline, and refractory material. They are employed on account of their special mechanical properties, their lightweight characteristics and their electrical, mechanical, optical, chemical and biological properties as compared with metals formerly used in the same applications [4].

Ultrasonic machining (USM), laser beem machining (LBM) and electrodischarge machining (EDM) are the most successful techniques used to deal with ceramics [5]. However, it has been found that EDM represents a wide range of opportunities to the design engineer more than the other techniques [5-7], especially for dies which have complex shapes.

Inspite of all the ceramics advantages in the modern industrial technology, very little information has been published about the machining of ceramics by the EDM process. Composite ceramics[8-10], Zicronia ceramic[11] and silicon carbide [12-15] were the main ceramic types which have been tested by EDM processes. However, the surface from a topographical point of view has not been emphasized. In the present work, an attempt has been made to outline the inter-relationships between ceramic and EDM processing, indicating the potential and the limitations of the process.

Experiments have been carried out on a silicon-carbide material called REFEL. This material is currently manufactured and marketed for a wide variety of engineering applications, especially where resistance to thermal stresses and oxidation at high temperature is of paramount need and where its high degree of hardness-typically twice that of tungsten carbide-and anti-wear characteristics can be fully exploited [16]. This material has been classified as a conductive material. This material is made by a proprietary reaction bonding technique, fine SiC and graphite powder is mixed with a plasticiser reaction bonding shapes by extrusion die or isostatic pressing. In the present work, experiments are conducted using copper electrodes which has been found to be the best electrode material and under a duty factor of 50% [9]. Stock removal rate (SRR), tool wear (v), surface finish (R_a) and side gap (Y_s) have been measured under the factors of peak current (i_p) and pulse durations (t_i).

Experimental work

The electrodischarge machine used in this investigation was AGIE-PULS 45 LMJP. Workpieces were flat 30 mm. x 10 mm. x 1.5 mm. REFEL SiC. Figure 1 shows a general shematic diagram of the used ED machine. Table 1 summarizes the various experimental conditions used in this investigation. The surface roughness measurements were conducted using Talysurf 10. Stock removal and tool wear were calculated by weight difference of the specimens before and after machining using a Sartorius 1712 MP8 precision scale with a readability of 0.1 mg. The side gap value (Y_s) was measured using an optical microscope (Carlzeiss Jena 5668) with an accuracy of 0.01 mm. . The side gap is estimated according to the following relationship:

$$(Y_s) = 0.5\ (d_{Hole} - d_{Tool})$$

The scanning electron microscope (JSM. T 100) was employed to study the surface topography, the surface and subsurface characteristics of the machined ceramic material.

Test results and examinations

The two important criteria for the economics of the EDM process are : (a) workpiece stock removal rate (SRR), and (b) wear of the electrode (v). Process improvements in EDM may yield higher machining speeds (Stock removal rate) and yet, remaining the same or even smaller electrode wear values. Tool wear is very important because tool-preparation can be quite expensive. For this reason, time tracking and evaluation of workpiece removal and tool wear may be essential for improving and controlling the process.

Figure 2-a shows the effect of pulse duration (t_i) on the stock removal rate (SRR). It has been found that as (t_i) increases, (SRR) increases. This result is due to the increase in the discharge energy at higher values of pulse durations [17]. The discharge energy is the product of mean discharge voltage, mean discharge current and discharge time. The experiments also revealed that pulse durations should not exceed 500 µs. due to the danger of crack formation. The effect of pulse durations has been tested at peak currents of 4 and 6 A. It has been observed that higher amperage removed more stock but produced rougher surface finishes.

Figure 2-b represents the R_a measurements under the different ED machining parameters of pulse duration and peak current (i_p). It has been observed that surface quality decreases at higher values of t_i and i_p. This result has been attributed to the increase of the spark energy which usually leads to more deeper craters on the workpiece surface [18].

The volume of electrode worn away as compared with the volume of workpiece ED Machined away is represented by :

$$\%\text{ volume wear } (v) = \frac{\text{Volume electrode wear}}{\text{Volume workpiece EDM'ed}} \times 100$$

Figure 2-c represents the effect of pulse duration (t_i) on the % volume wear ratio. The tool wear may vary between 1% and 10% as shown in the same illustration.

It was believed that the larger the discharge energy, the higher the relative tool wear, and the stock removal rate. Tool wear, however decreases for larger pulse duration because the material removal grows much faster than the tool removal when the pulse duration enlarges [19].

Figure 2-d shows the effect of t_i on the side gap value (Y_s). The increase in the side gap value has been observed at the higher values of pulse durations. This result is due to the increase in the energy of discharge as discussed before.

Surface integrity of the machined workpieces is of essential importance for the life endurance of these pieces [20]. The SEM has been used to study this criteria.

Figures 3 and 4, show the typical EDM'ed surfaces under coarse and fine machining conditions. The typical surface shows a distinct signature characteristic of the process condition. For coarse cutting, greater amount of the stock removal rate, a layer of well defined discontinuous patches of recast material and more extensive damage has been observed (Figs. 5 and 6). On the other hand, the surface was more uniformly cratered for fine machining conditions, this is usually achieved at low stock removal rate (Figs. 7 and 8). The SEM has revealed that SiC machined surfaces, at high energy power (i_p> 6 A. t_i>500 µs.) included a network of well defined cracks (Figs. 9 and 10). It should be mentioned that during the EDM process the workpiece material is melted and recasted by the cooling action of the dielectric. Furthermore, ceramic as a brittle material exhibits thermal-stress cracking more than others, because they are not good heat conductors. So, the tendency to crack formation is more possible than with other materials. The cracks usually tend to follow the pitting arrangement created in the surface by EDM'ing.

The effect of micro-cracking was more pronounced under rough machining conditions, whereas, it was minimum under fine machining conditions. The occurance of microcracks is a reasonable measure for the quality of the machined surface.

In order to improve machining performance, more studies including the analysis of the stock removal mechanism and the search for a machinability index for various ceramic materials are still needed. The present work has been achieved using a plunge electrode which is physically identical with the EDM wire process. It may be stated that any material which can be wire cut can also be machined by die-sinking and vice versa. So, the results obtained in this work are to emphasize that the EDM process can be also used to achieve the complex shaped products from ceramic materials.

Generally, the SEM technique showed that the increase in the discharge power, leads to an increase in the surface roughness. Therefore, the selection of slow process conditions are found to produce minimum damage (microcraking, recast layer) in the machining of SiC workpieces.

Conclusions

Summarizing the main observations of the present work on the EDM'ing of ceramic, the following conclusions may be drawn.

- The EDM process appears to be a promising method to deal with the conductive ceramic irrespective of its hardness and toughness.

- The realistic stock removal rate has been observed for pulse durations from 200 to 500 µs. and under peak currents from 4 to 6 A. and a duty factor of 50%.

- The most efficient combination of machined parameters, from the point of view of crack minimization, as studied by the SEM technique is: peak voltage 60 V, discharge current 4 A and pulse durations (t_i) from 100 to 200 µs. or discharge current 6 A. and pulse durations (t_i) from 20-100 µs.

- Finally, it is therefore hoped that these results will be helpful for industrial engineers towards further applications of electrodischarge wire cutting (EDWC) on the ceramic products.

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Table 1. Experimental working conditions

Type of pulse voltage	Rectangular pulse
Electrode feed	Automatic
Pulse voltage (V)	60-80 V
Dielectric	$^2/_3$ Kerosene + $^1/_3$ Petroleum oil
Duty factor (τ)	50%
Peak current (i_p)	2-6 A.
Pulse durations (t_i)	20-1000 μs.
Pulse frequency (f)	0.55 - 55 KHz
Workpiece	Silicon carbide (SiC)-Refel
Workpiece density	3.1 gm./cm^3.
Workpiece polarity	Negative
Workpiece hardness (HV)	2500 Kg./mm.^{2}
Elastic modulus	410 G Pa
Electrical conductivity of Refel	10 mho/cm. at 500^{o}C
Thermal conductivity of Refel	180 Wm^{-1}K^{-1}
Tool polarity	Positive
Tool material	Copper (φ = 3.2 mm.)

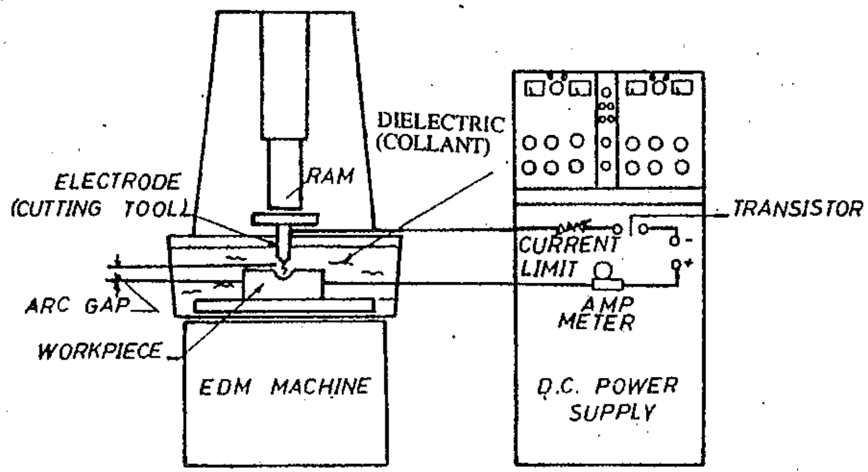

Figure 1. Schematic diagram of an EDM system.

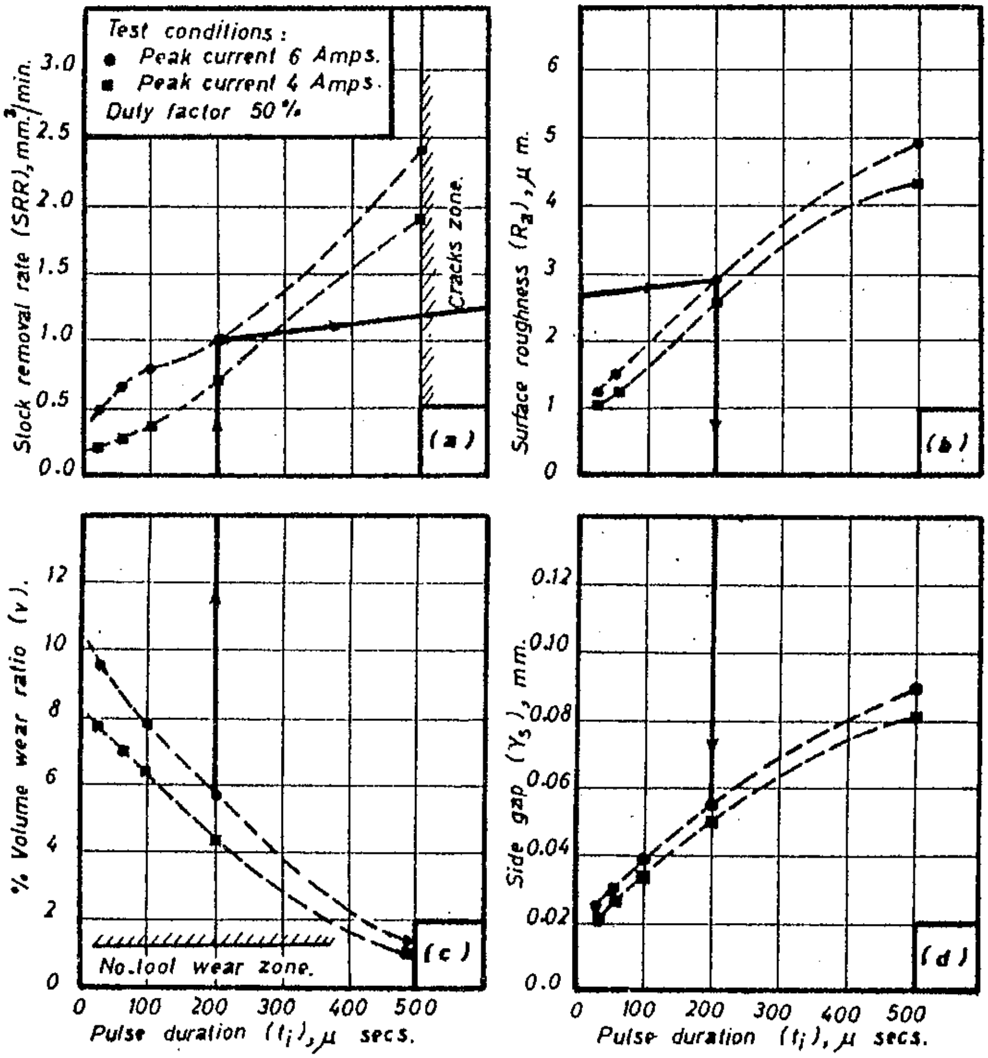

Figure 2. Stock removal rate, wear ratio, surface roughness and side gap versus pulse duration.

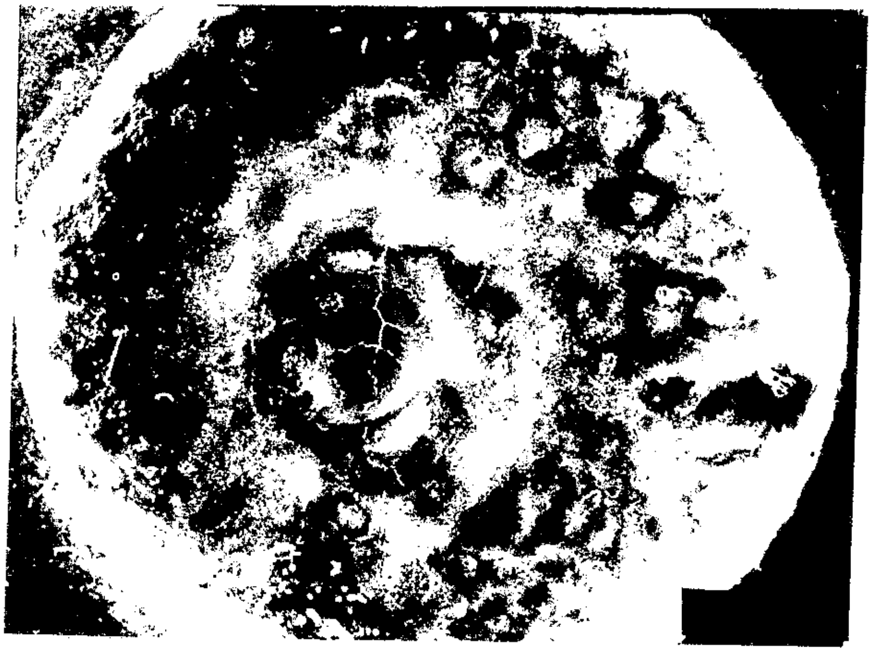

Figure.3. Typical EDM surface at coarse machining conditions. Test conditions : ($V = 80$ V, $i_p = 6$ A., $t_i = 200$ μs., and $f = 2.75$ KHz)

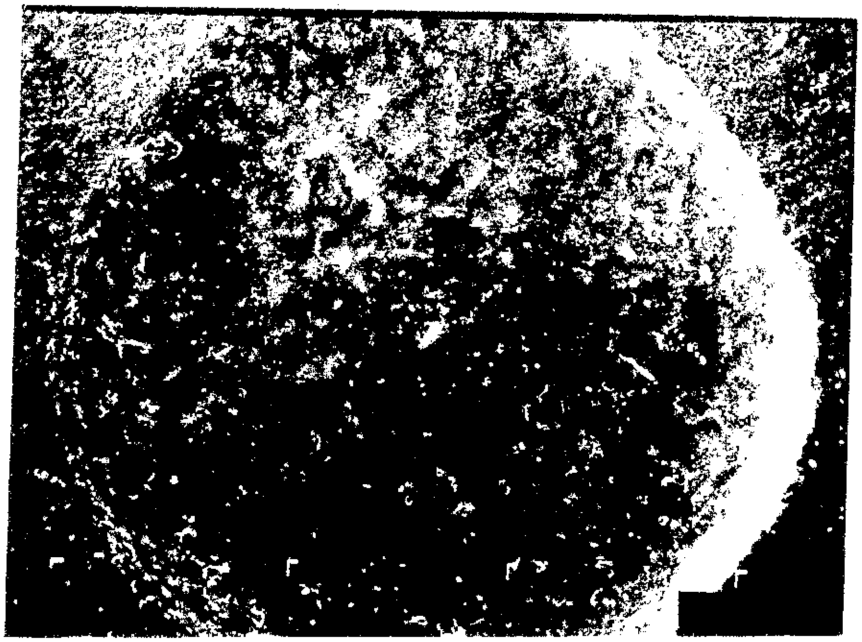

Figure 4. Typical EDM surface at fine machining conditions. Test conditions : ($V = 60$ V, $i_p = 4$ A., $t_i = 20$ μs., $f = 21.4$ KHz)

Figure 5. SEM photograph of EDM'ed surface shows a view of a crater formed by a single electrical discharge Test conditions : ($V = 70$ V, $i_p = 6$ A., $t_i = 500$ µs., $f = 1.1$ KHz) - (X 1000 1 cm = 10 µm.)

Figure 6. SEM photograph of EDM'ed surface at coarse machining conditions including : Bubbles, deposited material and white layer.
Test conditions : ($V = 70$ V, $i_p = 6$ A, $t_i = 500$ µs, $f = 1.1$ KHz) - (X 1000 1 cm = 10 µm.)

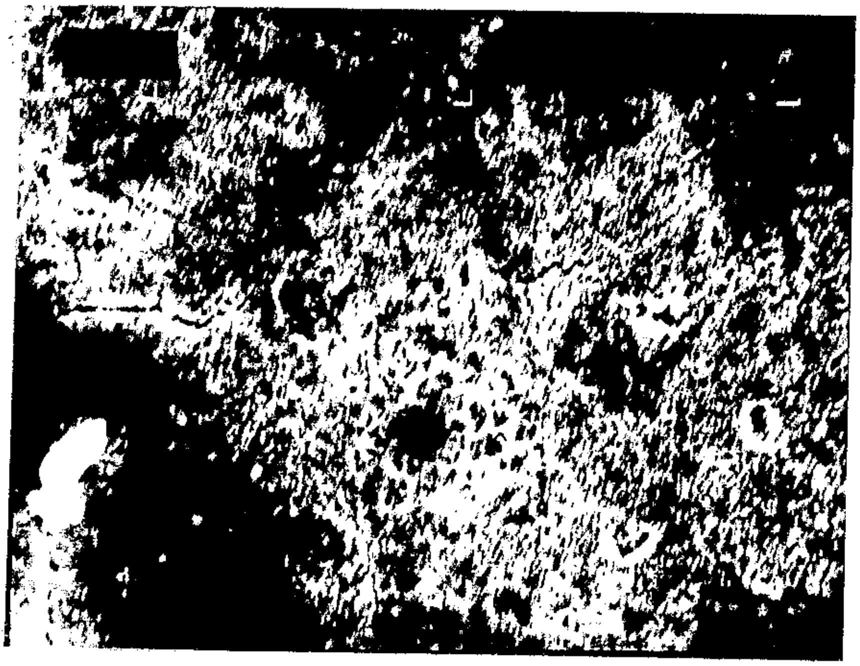

Figure 7. SEM photograph of EDM'ed surface of ceramic at fine working conditions.
Test conditions : ($V = 60$ V, $i_p = 4$ A., $t_i = 20$ µs., $f = 21.4$ KHz) - (X 1000 1 cm = 10 µm.)

Figure 8. SEM photograph of EDM'ed surface of ceramic at fine working conditions.
Test conditions : ($V = 70$ V, $i_p = 4$ A., $t_i = 50$ µs., $f = 9.8$ KHz) - (X 1000 1 cm = 10 µm.).

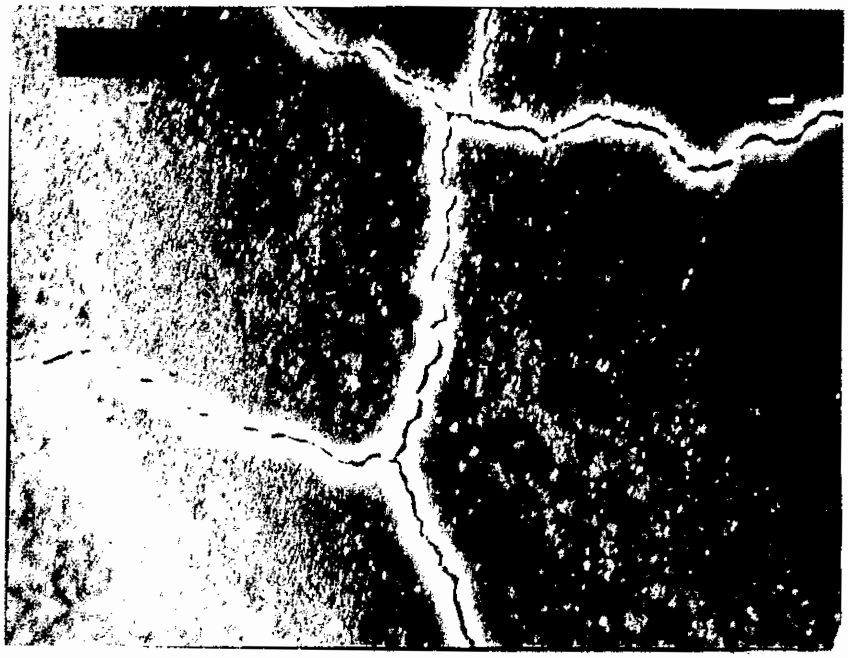

Figure 9. SEM photograph of cracks network at EDM'ed ceramic surface.
Test conditions : (V = 60 V, i_p = 8 A., t_i = 1000 μs., f = 0.55 KHz) - (X 1000 1 cm = 10 μm.).

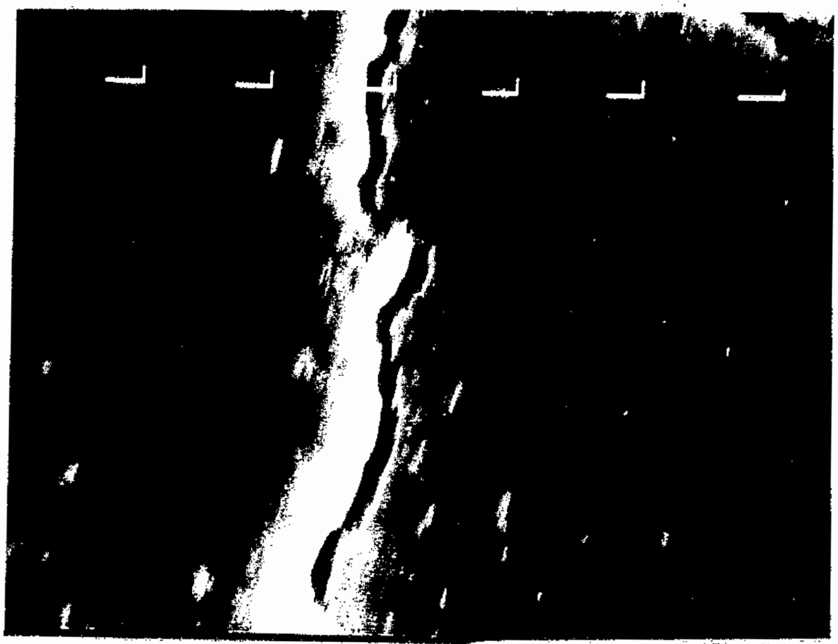

Figure 10. SEM photograph of EDM cracks at higher magnification.
Test conditions : (V = 60 V, i_p = 8 A., t_i = 1000 μs., f = 0.55 KHz) - (X 4000 1 cm = 2.5 μm.).

فحص على أمثل ظروف تشغيل بالشرر الكهربى
للسيراميك الموصل كهربيا

الملخص:

يقدم البحث امكانيه وتصور جديد للتشغيل بالشرر الكهربى لمادة السيراميك ذو قابلية التوصيل الكهربى وذو الاستخدامات العديدة فى المجال الصناعى خاصة فى مجال صناعة الاسطمبات والمفاعلات النووية ويلخص البحث أهم براميترات التشغيل (زمن النبضة - التردد- التيار الكهربى - الجهد الكهربى) وانعكاسات هذه العوامل على (معدل المادة المزالة - خشونة السطح - معدل التآكل فى أداة القطع - الثغرة الجانبية المتولدة أثناء التشغيل بين أداة القطع والشغلة).

كذلك يقدم البحث دراسة للسطح الناتج من خلال استخدام الميكروسكوب الالكترونى لبيان كافة ظروف التشغيل الحادثة من فجوات وتشدخات وطبقات متراكمة على السطح وذلك حتى يمكن اختيار افضل الظروف التشغيلية من وجهة نظر الحفاظ على جودة وتكاملية السطح وذلك تحت كافة عوامل التشغيل بالشرر الكهربى.

وأخيرا فإن استمرارية البحث فى هذا المجال يفتح آفاقا جديدا لعملية التشغيل بالشرر الكهربى على المواد ذات الطبيعة الخاصة مثل السيراميك.