INFLUENCE OF PROCESS VARIABLES ON WEDM OF TUNGSTEN CARBIDE COBALT METAL MATRIX COMPOSITE

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Abstract

Wire electrical discharge machining (WEDM) is a successful advanced machining method in the field of hard and difficult to machine newer materials especially, metal matrix composites (MMC).Using WEDM technology, complicated profiles can be cut in electrically conductive component. The higher degree of precision, accuracy and fine surface quality obtained makes WEDM indispensible in modern manufacturing system. Tungsten Carbide Cobalt (WC-CO) metal matrix composite is widely used in the field of tool and die, auto, aeronautical and space applications. In this study WC-Co was cut by WEDM with the motive to identify the best input parameters that produces best output. Many works been done in WEDM modeling and optimization but yet, studies on influencing parameters, judicious selection of the machining conditions, their levels and analysis for a particular pattern of behavior is still not much ventured in. Experiments were conducted under different combinations of input variables such as percentage of cobalt in the composite, pulse ON time, delay time, wire feed, wire tension, ignition current, and dielectric pressure and the significant parameters and the causes are analyzed. This analysis offers insight into the wedm process, particularly, the machining of metal matrix composite WC-Co, the influential input parameters, their level play on the outputs such as material removal rate (mrr) and roughness (Ra), which are of critical importance in any machining operation. The results show careful selection of operating parameters for a particular (composite) material can enhance quality of machined component

Key words: Wire EDM, MMC, WC-Co composite, MRR, surface roughness

I. INTRODUCTION

Since the onset of CNC wire electrical discharge machines to the market in the 1970's, the continuous exploitation of machinery, CNC system, newer wire electrode and process technology have facilitated the wire-Edm as an apt and irreplaceable process in the tool and die making industry. Wire-EDM has also emerged in the fields of medicine, electronics, automotive and aerospace industries. It has the ability to produce precise intricate shapes and varying tapers in all electrically conductive materials [1] irrespective of their hardness.

Metal matrix composites and the newly developed advanced materials offer light weight, high stiffness, high specific strength, good wear strength and a low thermal expansion coefficient It finds extensive application in regular and specialized component industry. Availability of a viable machining method had been a problem which has limited the easy availability of mmc components. Greater hardness which is needed for wear-resistance and the reinforcements added to make material stronger, makes it difficult to machine mmc's using traditional techniques. This has impeded the rapid development of MMC'S. The use of traditional machinery to machine composite materials caused serious tool wear and roughness of surface (2) because of the presence and brittleness of reinforcements. On the other hand, WEDM has the ability to produce highly-complex shapes, independent of the mechanical properties of the material (especially, hardness, brittleness) with good surface finish (3). This, together with reasonable economy and excellent production rate make this process attractive. Even though nontraditional machining technique such as water jet machining and laser beam machining can be applied the drawback with these process are their costs and the limitation in the shape and dimension of the work piece and the productivity rates.

The principle of WEDM is electrical pulses, generated by the pulse generator unit which is applied between the work piece and the travelling wire electrode. (generally of 0.25 mm diameter). In the event of current across the wire electrode-work piece gap, a potential difference develops and once it reaches a critical value it ionizes the di-electric. An avalanche of electrons hit the workpiece with great momentum, instantly melting and vaporizing the material locally in the plasma channel. The energy content of a single discharge can be expressed as a product of Pulse ON Time × Peak current [4]. Energy contained in a tiny spark discharge removes a fraction of work piece material. Large number of such time spaced tiny discharges between the work piece and wire electrode causes the electro-erosion of the work piece material.

When high strength WC-Co MMCs are machined by WEDM, chances of electrolytic corrosion is high as the material is prone to electrolyzation. Irregular indents occur at places of porosity and soft matrix material caused by electrical sparks during the machining process. Due to its extensive industrial applicability it is imperative to study the wire electric discharge machining characteristics of WC-Co composites under varying input parameters for the optimal prediction of process output characteristics. Optimization of WEDM process variables were attempted by several researchers.

A mathematical model was developed by Liao et al [5] and process parameters were optimized by feasible direction method. Response surface methodology and artificial neural network model was attempted by spedding et.al [6] with outputs of cutting speed, material removal rate and surface roughness. Probir saha et.al [7] compared multi-variable regression model and a feed-forward back-propagation neural network model to correlate the input process parameters and concluded, that the multivariable regression model yields an overall mean prediction error of 6.02%. Neural network architectures, 4-11-2 can predict cutting speed and surface roughness with 3.29% overall mean prediction error. Ramakrishnan et.al [8] was using WEDM for machining super-alloy inconel 718 and optimized by multi response using robust design. The output and optimization results indicated a marked improvement. Muthuraman et.al [9] studied the influence of microstructure on the characterization of WEDM-ed WC-Co and recommended lower pulse on time and medium pulse off time to obtain better surface characteristics. Yet the influence of process variables on machining process and on outputs like material removal rate and surface roughness of WC-Co is not thoroughly probed. WEDM is a complex, stochastic thermo electric process, higher number of input variables with contrasting requirements.Hence to utilize the full potential of the process, in-depth understanding is necessary and hence this study.

II. EXPERIMENTAL PROCEDURE

A. Wire EDM operating Conditions

Tungsten carbide-cobalt metal matrix composites with two different cobalt binder phase percentages (10% and 20%) were cut into cross sections of 5 × 5 mm using SODICK AQ 327L WEDM machine. Table 1 shows the range of parameters used in the experiments. This was prepared in consultation with industrial technicians, literature survey and sodick manufacturer's [10]-catalogue. Three trials were conducted for each experiment planned and the mean was taken as the final result. Figure 1; show the scheme of wire EDM process with wire electrode, ceramic rollers are employed to reduce friction and enable high speed machining.

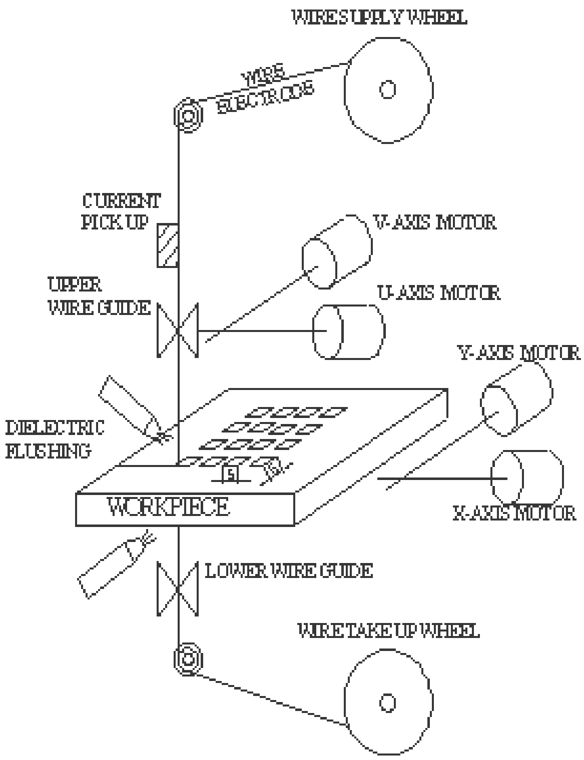

Fig. 1. Scheme of Wire EDM Process

B. Material properties

The chemical composition consists of 80% WC and 20% Co. and 90% WC with 10% Co.The average mechanical properties of the work specimen are presented in Table 1. The grain size is 0.8 microns and young's modulus 570 GPA. Table 2 represents the operating conditions.

Table 1. Typical property of WC-Co

Density gm/cm^3	14.5
Transverse Rupture Strength N/mm^2	4100
Compressive Strength N/mm^2	775
Hardness HRA	91
Coefficient of Thermal Expansion 10^{-6} K^{-1}	5.4
Thermal Conductivity Wm^{-1} K^{-1}	85
Electrical Resistivity 10^{-8} Ω m	19

Table 2. Wire EDM operating Conditions

Control Factors	Description
Wire material	Cu-Zn
Pulse ON	6-15 μ sec
Pulse OFF	10-25 μ sec
Wire tension	6-12 N
Wire feed	70-100 mm/min
Ignition current	8-20
Flow rate	30-45

The output - 1, material removal rate was calculated using the formula given below

Material removal rate (MRR) = (Vc/T) mm^3/min (1)

Where, 'Vc' is the volume of the machined cubical Work-piece and 'T' is the time taken in minutes.

Output - 2, surface roughness (Ra) was measured using Surf coder SE-1200. Since this value varies slightly due to surface waviness, average is taken. The estimated values are presented in graphical format for easy identification of trend in the analysis.

III. RESULTS AND DISCUSSION

The influence of process parameters are discussed below. The parameter, pulse on time, pulse off time which indicate supply current's duration on to the work surface in micro seconds, for four levels and the corresponding outputs are presented.

A. Influence of Pulse ON Time

The graph in figure 2 shows that as the Pulse ON Time increases, the amount of material removed also increases but only to a certain level. It decreased in the middle and at the end there was a rise. The initial increase occurred because when the pulse current produces a stronger spark, which in turn produces high temperature while machining and thereby equal amount of material tends to melt and erode from the work piece. The material removal rate decreases in the middle; this could be because of the arcing which decreases discharge and machining efficiency (11). Also continuously letting it spark leads to erratic spark, initially higher and later with charge decreasing, become less intense and short. This gives poorer result reduces mrr which is undesirable. The uneven distribution of reinforcement could also play a role here. When the reinforcement is greater, stronger bonds with base metal makes more energy expenditure to separate particles.

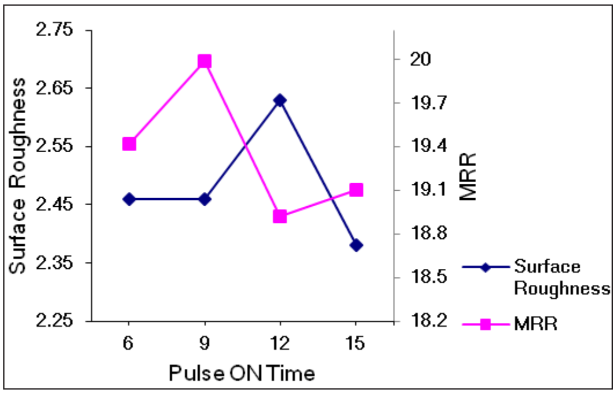

Fig. 2. Output response on varying PULSE ON TIME

The roughness does not add a significant influence with Pulse ON Time initially but there was a considerable increase as it progresses and then it decreases. Electrical sparks being more intense, crater can form on the surface of the work piece which could have shown waviness. As spark intensity reduces the depth of material removed and hence surface roughness decreased at the end. It is clear that difference in reinforcement or cobalt binder percentage did not have a major direct effect on the surface roughness value. This result is as anticipated, since WEDM process is not influenced by small variations in mechanical property like hardness etc., by nature of the process itself.

B. Influence of Pulse OFF Time

The graph in figure 3 shows the responses for rise in Pulse OFF Time and the corresponding output responses material removal rate and roughness. It is clear that as the Pulse OFF Time increased the material removal rate, decreased steadily and this result is same as that observed by Puri A., et.al (12) at the initial stage to a certain limit. When the delay time is more, lesser is the number of sparks issued and lesser is the material removal rate, and non uniform machining along the surface which had led to poor finish in the middle. Further rise in pulse-off times has set off higher mrr and better finish. This is desirable. It suggests at 25 micron seconds, with more charge time, the spark issued during on-time removes more material with less roughness. This result indicates the importance of right parameter selection to obtain best output response. The distribution of reinforcement in the base metal matrix if not uniform, could also cause erratic rise and fall of outputs locally.

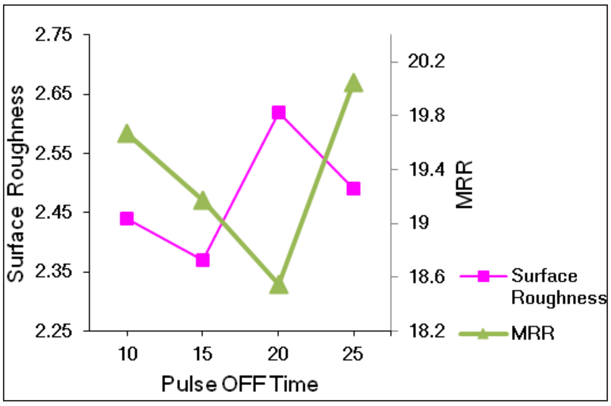

Fig. 3. Output response on varying PULSE OFF TIME

C. Influence of wire feed

Wire feed is machine's mechanical parameter like wire tension. From the graph in figure 4 it is clear that as the wire feed scales up roughness values also increased drastically and linearly up to a certain limit and at the end it reduced by a small value. This could be because the spark erosion occurs during the travel of the wire. When the wire feed is increased more fresh wire is exposed to the work piece. For a given wire tension, more the wire feed, more will be the wire-vibration which initially increases the mrr at the cost of surface smoothness. With further rise in wire feed sparking will not be uniform as it becomes random. With more fresh wire available the electrode gap too changes, Hence mrr drops and so does smoothness. Also excess wire feed leads to poor utilization and unsparked electrode.

Overall, the material removal rate had increased with rise in wire feed. This is in accordance with observation of yoshiyuki uno (13). With reference to mrr, as the electrode travel is lowered the spark occurrence is lower. The wire feed is greater; wire introduced for the spark is greater. When new wire supplied is greater the conductance is more and larger is the spark, there by resulting in greater material removal rate. The drawback with increased wire feed is, it is not economical, as the amount of wire wastage is more. The increase in material removal rate could also depend on the wire material used. Better conductance of wire can yield better cutting rate.

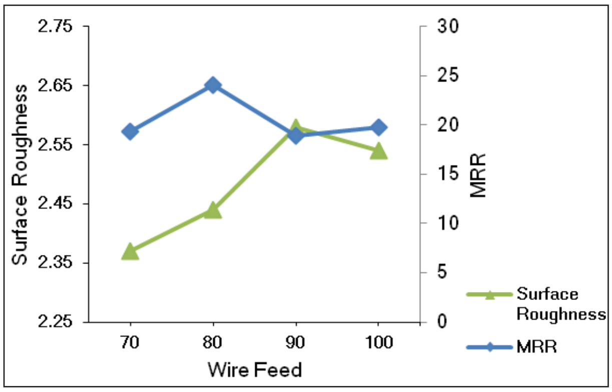

Fig. 4. Output response on varying Wire Feed

D. Influence of wire tension

From the graph in figure 5, the value of 6 N was found most suitable for machining WC-Co, as further away the performance deteriorates for both mrr and roughness. The roughness has increased to a high value as the tension was increased but then at the end it drastically decreased. Generally the increase in vibration of the wire is caused by the reduction in wire tension. As vibration increases a very slight amount of surface unevenness can occur. The material removal rate did increase as was the observation by Shome S.N (14) and decrease with a considerable differences in between as the wire tension increased. The effect could be due of transversal wire vibration leading to limitation of geometric precision, but though this vibration could improve machining efficiency through homogenous spark location and distribution on the work-piece.

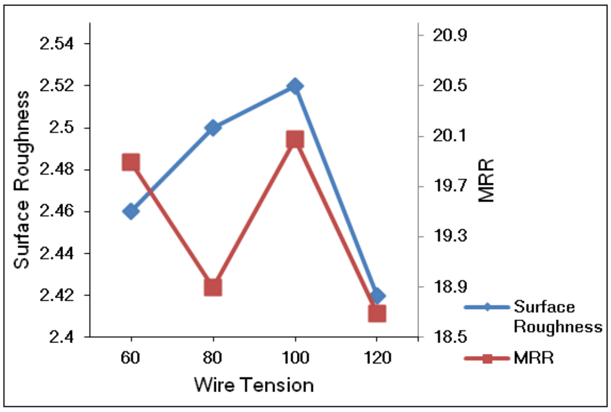

Fig. 5. Output response on varying Wire Tension

For a given feed rate, as the wire tension increases, feed rate decreses. As feed reduces drastically, it affects sparking, sparking takes place between two peaks, a well rounded wire sparks better whereas spent wire sparks poorly as each and every spark removes not only work material but a tiny chunk of wire electrode. as well [15], with ensuing poor spark, mrr falls and hence the roughness reduces.

E. Influence of ignition current

Ignition current is an electrical parameter, that determines mrr, roughness and the productivity of process. Figure 6 presents the response. Surface roughness value has increased progressively as the ignition current increased and at the end there was significant drop in the value. But at the highest value of ignition current, roughness value was the lowest. This result is presented in graph of figure 6. Generally when the ignition current is increased the electric field becomes stronger and spark discharge occurrence takes place more easily under the same gap and a coarse surface obtained.

Further rise in ignition current, reduced the mrr and increased roughness. This is in expected lines as some of the dislodged heavier particles can block the electrode gap causing the effect. At the end mrr improves and roughness value has decreased this could be because of the stronger reinforcement bond with the base metal. The material removal rate has increased as ignition current increased, discharge energy increases and cutting rate increases. A slight decrease happened in between. This is because of the arcing, causing micro cracks and decreases the discharge and the machine efficiency and also, the optimal levels of the factors for mrr and Ra differ widely [15]. Generally rise in ignition current increases mrr.

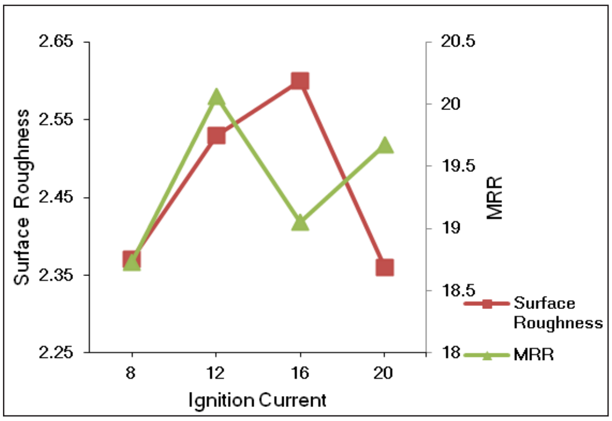

Fig. 6. Output response on ignition current

F. Influence of dielectric pressure

The graph in figure 7 shows the effect of dielectric pressure. The surface roughness values have actually decreased and increased alternatively. This effect could be because greater dielectric pressure on the work-piece surface, prevent the debris from adhering to the surface and debris formed pass through narrow gap effectively, with the increased the cooling effect, less heat is evolved and surface finish improves.

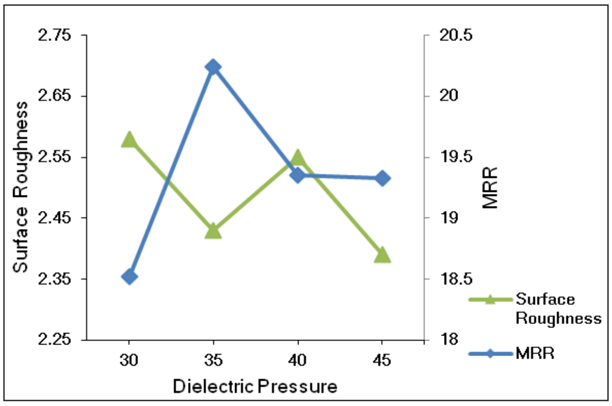

Fig.7. Output response on varying Dielectric pressure

Material removal with respect to dielectric pressure has increased steadily initially. As mrr increased the debris formed and flushed away should match. Without which mrr drops, when flushing does not keep pace with rise in mrr the amount of particles in the gap becomes too large and can form electrically conducting paths between the tool electrode and the workpiece, causing unwanted discharges, that damage the electrode surfaces (tool and workpiece).

But as the pressure increased it did reduce mrr without much significant variation. This is because dielectric fluid flushed the spark gap to remove gaseous and solid debris during machining and to maintain the dielectric temperature by acting as coolant. There was almost no change in material removal rate when cut was made at the higher percentage cobalt reinforcement metal matrix composites.

G. Scanning Electron Microscopic Images (SEM)

Figure 8 (a-c) shows the SEM images for the best mrr and smoothness of WC-Co composite.

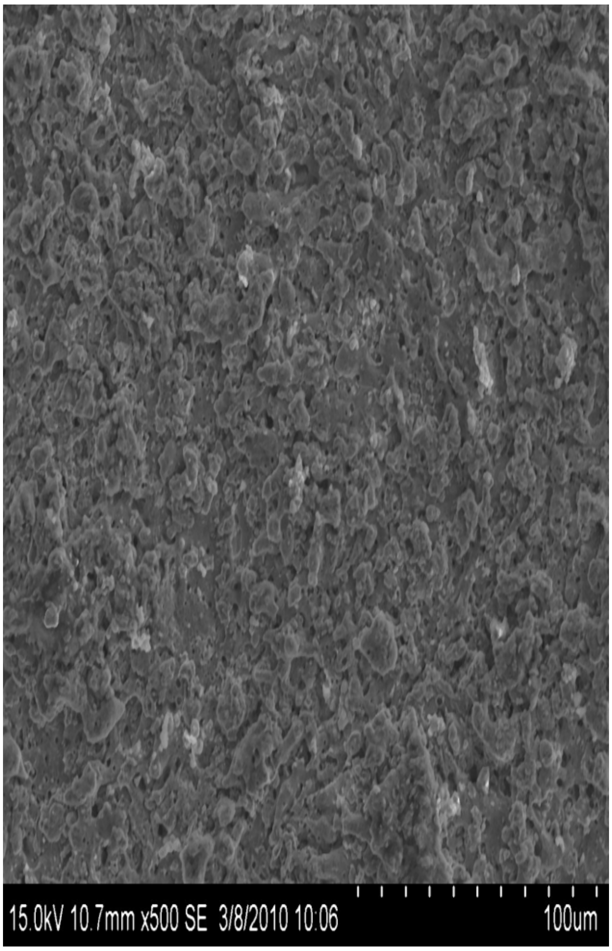

Fig. 8. (a) Best Surface smoothness

Figure 8 (a) displays more uniform distribution of particles with less, refined voids, regular hills and valleys, and overall, good mosaic of tungsten carbide cobalt network seen.

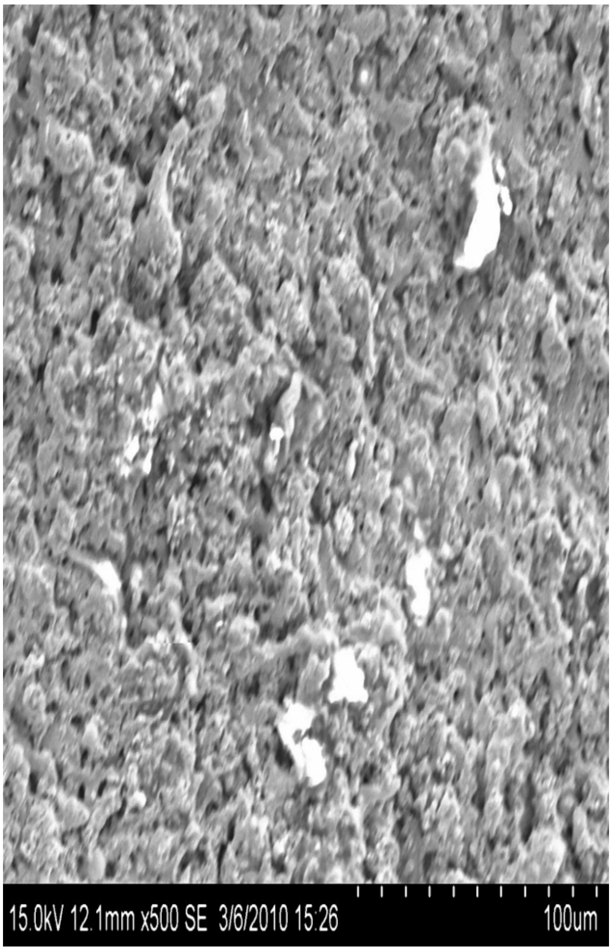

Fig. 8. (b) Best MRR

Figure 8 (b) represents the image corresponding to best MRR, for the same magnification. It shows, an irregular surface profile with more hills and valleys, uneven reinforcement pull outs, dislodged tungsten carbide particles leaving behind the voids due to evaporation of cobalt, and smeared copper zinc wire electrode particles on work surface are observed.

Figure 8 (c) is for the same conditions as in figure 8 (b) but at a higher magnification. Here the thermal spalling cracks are visible. It has been found that crack formation is caused by the stress induced by the WEDM process. This cracking occurs when the degree of induced stress exceeds the maximum tensile strength of the material.

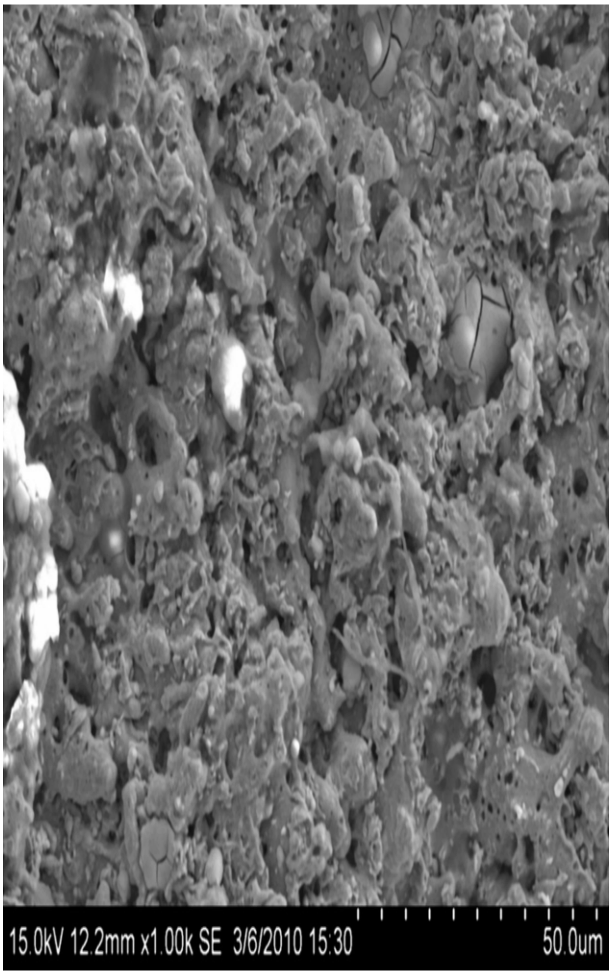

Fig. 8. (c) Best MRR (magnified)

IV. CONCLUSION

- As the Pulse ON Time increased, the material removal rate also increased but the increase was not steady. The surface roughness had also decreased at the end but the decrease was not linear. Pulse on time is a significant parameter in raising mrr and roughness due to larger melting and re-solidification of work-material.
- As the Pulse OFF Time increased the material removal rate increased and the surface roughness values did vary with higher and lower values.
- As the wire feed increased the surface roughness value also increased over all to a certain point and decreased at the end. The material removal rate kept on increasing in small incremental values.
- As the wire tension increased the material removal rate decreased and increased and so there was an uneven change in the cutting rate. The roughness value increased steadily to a highest point and decreased to a lowest value.
- Ignition current has same significance as pulse on. With increase in input current, material removal rate increased linearly and the surface roughness value increased due to the higher energy content of a single spark discharge and roughness decreased at the end due to uniformity of spark.
- As the dielectric pressure increases the material removal rate also increased and decreased at the end and the surface roughness value did decrease overall as the dielectric pressure increased.

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