

S.K. Shather Metallurgy and Production
Engineering Department,
University of Technology,
Baghdad**A.F. Ibrahim**Metallurgy and Production
Engineering Department,
University of Technology,
Baghdad**N. Jammal**Metallurgy and Production
Engineering Department,
University of Technology,
BaghdadBaghdadiraq420@yahoo.com

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Influence of EDM Parameters on the Appearance of Recast Layer

Abstract- Electrical discharge machining (EDM) is one of non-traditional methods employed to produce complicated forms of electrical conductive materials. This process can be applied to materials difficult to machine with traditional methods. Thus, the study and analysis of EDM variables play an important role to improve the yield, and safety of a surface. This research aims at study and analyze influence of pulse current (I_p) (10, 16, 22) Amp, pulse on time (T_{on}) (50, 100, 150) μ s and pulse off time (T_{off}) (25, 50, 75) μ s, (keeping other parameters fixed) on a Recast Layer Thickness (RLT) for machining (AISI 1018 mild carbon steel) using Response Surface Methodology (RSM) within "Minitab 17" for designing of experiments. Optical microscopy and scanning electron microscopy (SEM) was used. Experiments proved that minimum RLT was 5.2 μ m at I_p , T_{on} and T_{off} at 10Amp, 50 μ s and 75 μ s, respectively. The results also indicated that RLT increased with the increased (I_p and T_{on}) and decreased in T_{off} .

Keywords: EDM, Recast Layer Thickness, SEM, Optical Microscope, 1018 Mild Carbon Steel.

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1. Introduction

Electro-discharge machining (EDM) or spark erosion is considered as one of the main non-traditional methods employed to produce complicated forms of conductive materials, whether brittle or hard. This process can be applied to materials difficult to machine with traditional methods. In addition, the most vastly used to cut difficult and complex shapes and to produce parts of high accuracy. Whatever the case, several materials are too hard to be machined by conventional machining techniques. When a hard material is machined by a conventional technique not only produce high roughness of the surface, tool life will be short. New machining techniques like non-conventional techniques are developed to overcome previous difficulties. Non-conventional techniques are based onto electro chemical, thermal and mechanical material removal operations. The non-conventional methods become more economical than conventional methods, in specific applications [1-3]. EDM technique can be successfully used to machine electrically conductive parts regardless of their hardness and toughness. While, in conventional machining techniques for material removal the tools must be higher than the workpiece. Non-conventional techniques do not need the tool to be harder than the workpiece. Electro discharge machining is used in aerospace parts with high accuracy, automotive and surgical parts [4-5]. At present day, an electrical discharge machining (EDM) has great

abilities to encompass the space industries and almost all fields of machining conductive materials. EDM is the only option to cut the alloy that requires high temperature resistance. EDM is now become the most important accepted technology in manufacturing industries using the tool electrode with the simple shape by which many complicated and 3D forms can be manufactured [6-8]. Pradhan [9] investigated the effect of EDM machining variables on RLT in EDM technique during RSM. The tests were conducted under varying I_p , T_{on} , V and duty factor (τ). In their work, design of testing was planned according to RSM to get 30 tests. ANOVA was use to study the performance features in the EDM technique of AISI D2 tool steel whereas Cu was used as a tool. It has been observed that I_p is the most dominating parameter followed by T_{on} for RLT, and RLT is directly proportional to I_p . Shabgard et al. [10] studies the effect of T_{on} and I_p on the recast layer thickness (RLT) when machining tool steel. These tests were performed by designing full factorial procedures. It was concluded that the (RLT) increased with the increasing in Li et al. [11] checked experimentally the influence of some machining variables on Ti-6Al-4V during EDM by Cu tool. Then the machining variables were I_p , T_{off} and T_{on} . The Central Composite Design (CCD) by (RSM) was used in planning for the experimental design. The results, of the ANOVA indicated that the EDM parameter of I_p and T_{on} were the most significant

factors for RLT. The discharge energy increasing led to the RLT increased. When the value of the Toff increased that led to reduce RLT.

2. Experimental Work

I. Workpiece material

AISI 1018 mild carbon steel was used as workpiece in this study. Before EDM, the workpiece was made in a rectangle specimen of (70×55×5) mm with a roughness Ra of 0.293 μm on the surface to be machined, as shown in Figure 1. Chemical composition was examined for workpiece material in organization for Standardization and Quality Control, Baghdad as shown in Table 1. The physical and mechanical properties of the workpiece material are given in the Table 2 and Table 3.

II. Tool material

The tool was made of 99.9% of Cu as a rod 30 mm long with diameter of 10 mm selected to carry out experiments. The electrode tool was of negative polarity, as shown in Figure 2. The chemical composition of the copper electrode is given in Table 4. Chemical composition was examined for copper electrode in organization for standardization and quality control, Baghdad.

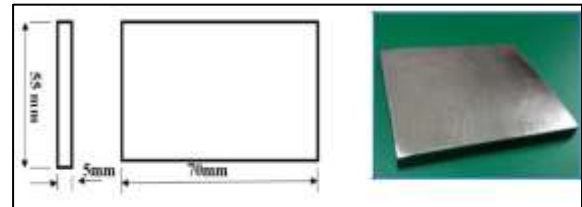


Figure 1: the workpiece before machining

Table 1: Chemical composition of AISI 1018 mild

| Material | C% | Si% | Mn% | P% | S% | Cr% | Ni% | AL% | CO% | Cu% | Fe% |
|----------|------|-------|-------|-------|-------|-------|-------|-------|-------|------|------|
| Weight % | 0.16 | 0.164 | 0.436 | 0.021 | 0.021 | 0.047 | 0.025 | 0.003 | 0.007 | 0.01 | Rem. |

Table 2: Physical properties of AISI 1018 mild carbon steel [12]

| Physical Properties | Melting Point | Modulus of elasticity(Gpa) | Thermal conductivity (W/mK) | Electrical Resistivity (Ω-cm) |
|---------------------|---------------|----------------------------|-----------------------------|-------------------------------|
| Description | 1350-1530°C | 205 | 51.9 | 0.0000159 |

Table 3: Mechanical properties of AISI 1018 mild carbon steel [12]

| Mechanical properties | Tensile Strength (MPa) | Hardness, Vickers | Elongation (in 50mm) |
|-----------------------|------------------------|-------------------|----------------------|
| Typical | 370 | 131 | 15.0% |

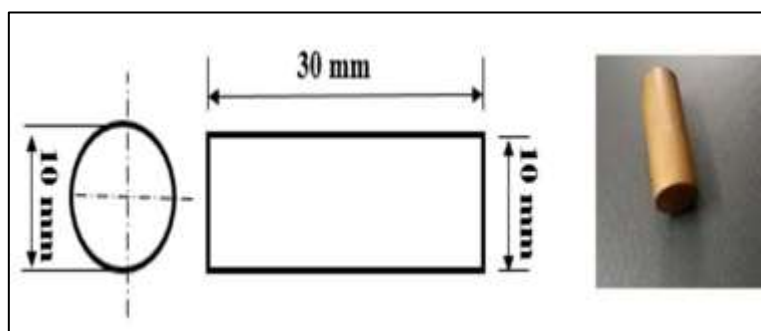


Figure 2: Copper electrode

Table 4: Chemical composition of copper electrode

| Material | Zn% | P b% | S n% | P% | Si% | S% | As% | Ag% |
|----------|-------|-------|------|---------|------|------|------|------|
| Weight% | 0.002 | | 0.00 | | 0.01 | 0.00 | 0.00 | 0.00 |
| Material | Bi% | Cd% | S b% | Se% | T e% | Au% | Cu% | |
| Weight% | 0.003 | 0.001 | 0.03 | <0.0001 | 5 | 5 | Rem. | |

III. Machine tool

In this study, experiments had been carried out via using an EDM sinking machine (CHMER model CM 323+50N) which is available at the Center of Training in University of Technology.

3. Design of Experiment

Response Surface Methodology (RSM) is an effective technique used in modeling and analysis of experimental parameters and their responses [13]. The machining parameters were 3-factors and three levels of 20 samples made of AISI 1018 mild steel, the machining variables and their levels are given in Table 6. Whereas, the fixed input parameters are given in Table 5. The design of experiments was based on Central Composite Design (CCD) contained from technology RSM as given in Table 7.

4. Measurements the Thickness of Recast Layer (RLT)

Before beginning to measure the Recast Layer Thickness (RLT) each specimen was cut off in sections at the end of EDM process by a Wire Electro-Discharge Machining (WEDM), as shown in Figure 3.

- In the first step, the samples were cut in to sections using wire cut EDM machine. After machining, they must be polished successively with

silicon carbide papers of grit sizes 120, 320, 500, 1000, and 1200. While in wire cut-EDM, the microstructural area of samples may change, during the sample cutting processes. Therefore, the included samples were left for relatively more time to remove the Recast Layer Thickness (RLT) and the Heat Affected Zone (HAZ) caused by the wire cut processes, (grinding process).

- The second step is polishing with a slurry of alumina (Al₂O₃) until they become like mirror. Finally, they were treated with a chemical nitric acid (NITAL) to distinguish between the interfaces of the samples under the optical microscope.

Table 5: Machining Parameters and Levels

| Parameters | Units | Levels /blade | | |
|-----------------------|-------|---------------|-----|-----|
| | | -1 | 0 | 1 |
| Pulse current (Ip) | Amp | 1 | 16 | 22 |
| | | 0 | | |
| Pulse on time (Ton) | µsec | 5 | 100 | 150 |
| | | 0 | | |
| Pulse off time (Toff) | µsec | 2 | 50 | 75 |
| | | 5 | | |

Table 6: Fixed input parameters

| Machining parameters | Gap voltage | Polarity | Voltage of discharge (V) | Type of dielectric | Depth of cut | S code | SVO | WT | J.T |
|----------------------|-------------|------------------------|--------------------------|--------------------|--------------|--------|-----|---------|-------|
| Fixed value | 1 | Straight (EDM process) | 140 | oil | 1mm | 999 | 75% | 1.6 sec | 1.2mm |

Table 7: Observed values for machining condition

| Run Order | Ip Am | Ton µsec | Toff µsec | Machining Time (sec) | WLT µm |
|-----------|-------|----------|-----------|----------------------|--------|
| 1 | 22 | 50 | 25 | 91.2 | 18.7 |
| 2 | 16 | 100 | 50 | 144.6 | 11.8 |
| 3 | 10 | 50 | 75 | 683.4 | 5.2 |
| 4 | 10 | 150 | 25 | 318.6 | 8.16 |
| 5 | 16 | 100 | 50 | 148.2 | 10.9 |
| 6 | 22 | 150 | 75 | 124.8 | 22.0 |
| 7 | 10 | 100 | 50 | 309 | 9 |
| 8 | 16 | 100 | 50 | 147.6 | 11.4 |
| 9 | 16 | 100 | 25 | 141 | 13.7 |
| 10 | 16 | 50 | 50 | 210 | 8.98 |
| 11 | 22 | 100 | 50 | 121.2 | 20.8 |
| 12 | 16 | 100 | 50 | 145.8 | 11.8 |
| 13 | 16 | 100 | 75 | 152.4 | 11.7 |
| 14 | 16 | 150 | 50 | 152.4 | 11.5 |
| 15 | 22 | 50 | 75 | 138.6 | 14 |
| 16 | 16 | 100 | 50 | 146.4 | 11.7 |

| | | | | | |
|----|----|-----|----|-------|------|
| 17 | 10 | 150 | 75 | 384.6 | 8.4 |
| 18 | 10 | 50 | 25 | 390 | 7.11 |
| 19 | 16 | 100 | 50 | 149.4 | 10.7 |
| | | | | | 2 |
| 20 | 22 | 150 | 25 | 125.4 | 20.1 |
| | | | | | 1 |

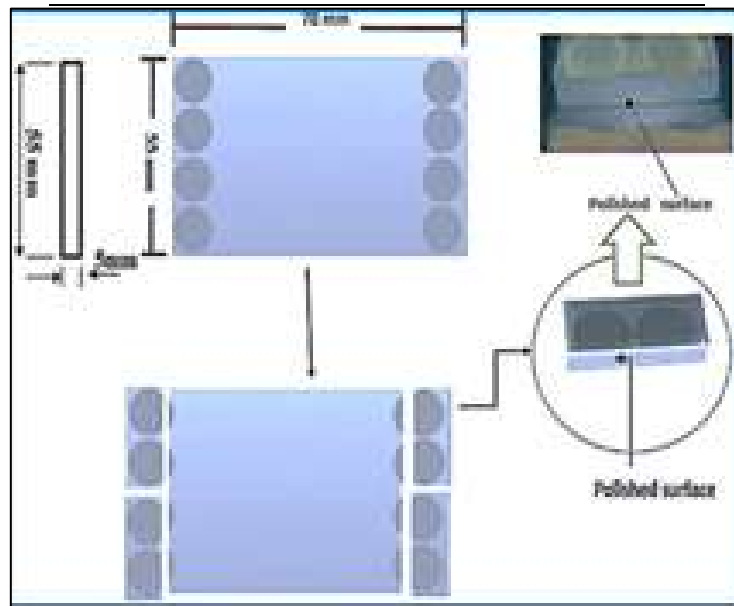


Figure 3: Cut section of workpiece after machining

5. Results and Discussion

A central composite design (CCD) having eight as corner point, six as axial points and six as central points, totally, 20 experiments in three blocks and the experimental results are shown in table (7) about Recast Layer Thickness (RLT). The machining time change in every experiment has been obtained from a reading device at the end of each experiment.

I. Analysis the effect of machining variable on RLT

Recast Layer Thickness (RLT) is one of the important factors in EDM machining due to a significant impact on the surface integrity. Figures 4, 5 and 6 show the effect of machining variables on RLT, where, Figure 4, those can be used to graphically assess the effects of the factors on the response. It indicates that I_p , T_{on} and T_{off} have significant effect on RLT. This figure shows that I_p is the most influencing parameter showing a sharp increase of (3.83 μm) and (7.7 μm) in the mean of RLT when I_p increases from (10Amp to 16Amp) and (16Amp to 22Amp), respectively. As well, Figure 5 scheme display RLT is directly proportional to T_{on} , the increase of RLT is rapid (1.5 μm) when T_{on} increases from 50 μs to 100 μs and (1.6 μm) when T_{on} increases from 100 to 150 μs . Figure 6 scheme display the RLT decreases by (1.7 μm) with the increase in T_{off} from (25 μs) to (50 μs), but its main effect is slight increase by (0.4 μm) when T_{off} increases from (50 to 75) μs .

RLT rises with rising discharging energy and T_{on} and I_p lead to, increase the discharging energy that was responsible for producing sparks at the interface between tool and workpiece. Increases of the I_p from low to high level, where I_p and T_{on} constructed the spark responsible for size and depth of the craters. Also, the reduction of I_p , T_{on} and, supply power produce small spark. Therefore, the formation of craters will be smaller, and will reduce RLT with less heat. Selecting higher T_{off} lead to lower RLT, because there is plenty of time for cooling of workpiece and tool. A white layer thickness (RLT) depends on thermal, transmission to the workpiece and the microstructure alteration going through workpiece by EDM machining. Thermal, transportation is a function of the quantity of heat provided via discharging, energy.

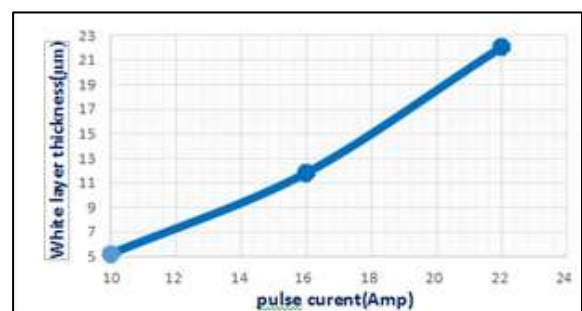


Figure 4: The impact of pulse -current on RLT

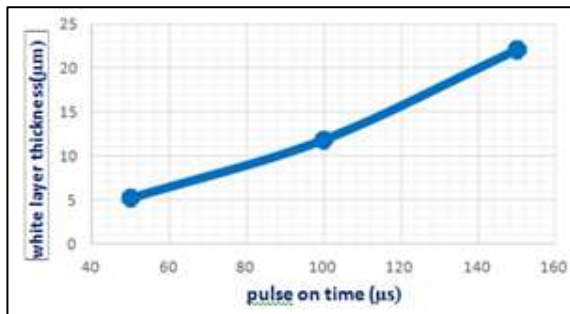


Figure 5: The impact of pulse- on –time on RLT

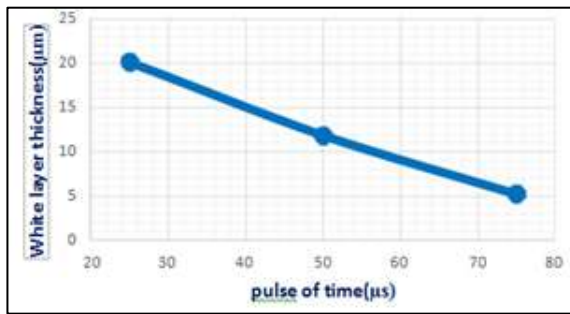


Figure 6: The impact of pulse- off–time on RLT

II. Optical microscope images for RLT and topography

The cross-section micrographs of the workpiece samples EDM machined surface were with magnification of (400X). Recast layer forms because of melt and solidification without ejection or removal during flushing by a dielectric on the surface for an EDM workpiece. The recast layer appeared is shown in Figures 7 to 10. Figure 7 is for lower I_p (10Amp), lower T_{on} (50 μs) with higher T_{off} (75 μs). Lowest RLT was achieved RLT = 5.2 μm . From Figure 8 the RLT increases clearly from (5.2 to 11.5) μm with increases in I_p from (10 to 16) Amp and, increases in T_{on} from (50 to 150) μs and decrease in T_{off} from (75 to 50) μs . Similarly, with increasing I_p from (16 to 22) Amp, and decreases in T_{off} from (50 to 25) μs the RLT increased and thus thicker RL is formed as shown in Figure 9. To study the effect of EDM parameters under different parametric combinations on, surface, roughness and also, crater, forming through EDM can be clearly seen through microscopy. Where, after EDM surface machining some microscopic cracks may appear and these are caused by the large thermal power heating the workpiece surface, which is immediately and rapidly cooled by dielectric fluid.

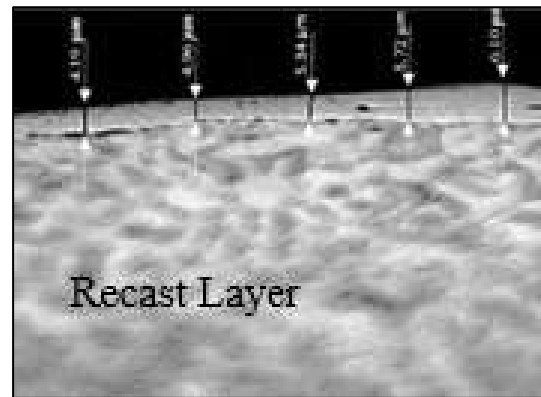


Figure 7:cross-section

| |
|-------------------------------------|
| micrograph RLT at condition: |
| 1. $I_p=10$ Amp |
| 2. $T_{on}=50$ μsec |
| 3. $T_{off}=75$ μsec |
| RLT= 5.2 μm. |

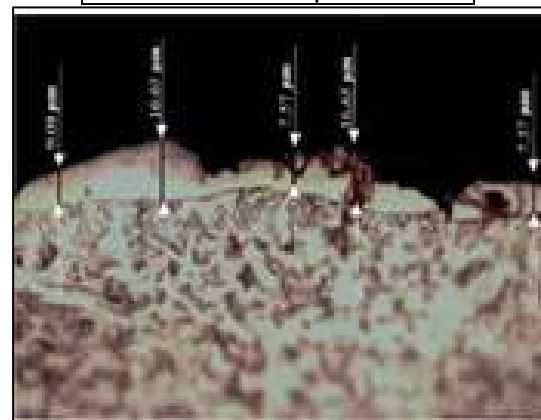


Figure 8:cross-section

| |
|-------------------------------------|
| micrograph RLT at condition: |
| 1. $I_p=16$ Amp |
| 2. $T_{on}=150$ μsec |
| 3. $T_{off}=50$ μsec |
| RLT= 11.5 μm |

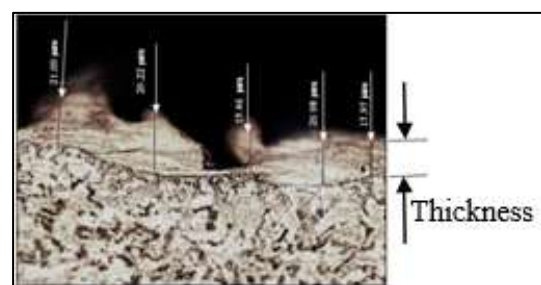


Figure 9:cross-section

| |
|--------------------------------------|
| micrograph RLT at condition: |
| 1. $I_p=22$ Amp |
| 2. $T_{on}=150$ μsec |
| 3. $T_{off}=25$ μsec |
| RLT=20.11 μm. |

III. Scanning Electron Microscopy (SEM)

In this study, SEM is used to generate high-resolution images of shapes of surfaces. Figures 10 and 11 depict the scanning electron micrographs (SEM) of AISI 1018 mild carbon steel taken with the

parametric set of ($I_p = 10\text{Amp}$, $T_{on}=50\ \mu\text{s}$ and $T_{off} = 75\ \mu\text{s}$) and ($I_p = 22\text{Amp}$, $T_{on}=150\ \mu\text{s}$ and $T_{off} = 25\ \mu\text{s}$), respectively. It notes that the size of the crater and the amount of molten material produced during the sparking it relies heavily dependent of the I_p . The heat-affected layer will form due to melting and solidification on the surface of an EDMed workpiece without being ejected nor removed by flushing. A structure of this layer is quite different from the parent material and it is usually very fine grained and hard. The top surface contains globules, cracks, and micro cracks, whose density depends on the operation circumstances. This structure of the surface led to higher roughness and strongly dependent on I_p . The impact of EDM factors on crater and rough surface formed during EDM can clearly to note from

the (SEM) micrographs under different parametric combinations. Investigation of (SEM) illustrates that the surfaces have complex appearance and shallow craters, spherical particles, melted drops, globules of debris, pockmarks and gaps because high thermal energy issued by discharges and later quenching. The spherical molecules are molten materials, which are expelled wildly through discharge and then solidifies and attached to the surface. There is a marked increase in the size of the crater in the specimens for 10Amp and 22Amp as shown in Figure 10 and 11 respectively. This is because spark energy increment with pulse currents led to deeper and wider craters on surface. In addition, the crater diameter is also influenced through (T_{on}) and increases with it.

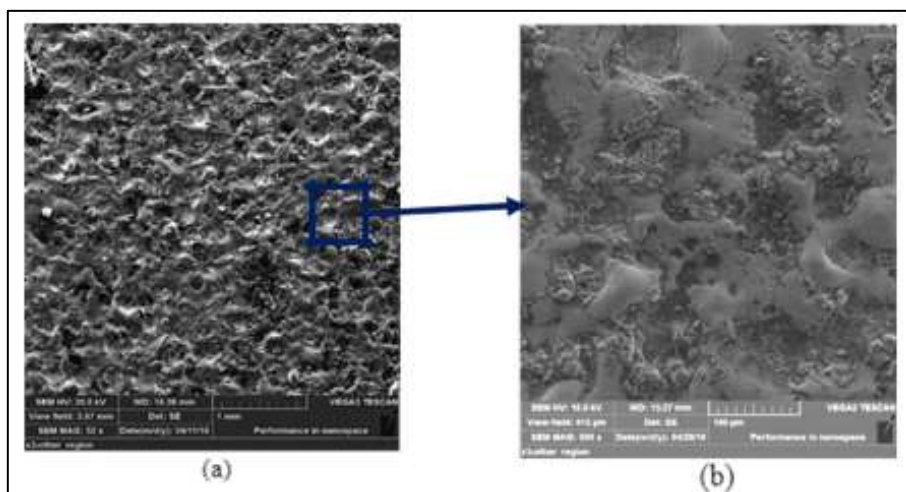


Figure 10: SEM images of surface machined by EDM of AISI 1018 mild carbon steel at conditions $T_{on}=50\ \mu\text{s}$, $I_p=10\text{Amp}$ and $T_{off}=75\ \mu\text{s}$. At low white layer thickness, (a) low magnification 52X and (b) high magnification 1000x

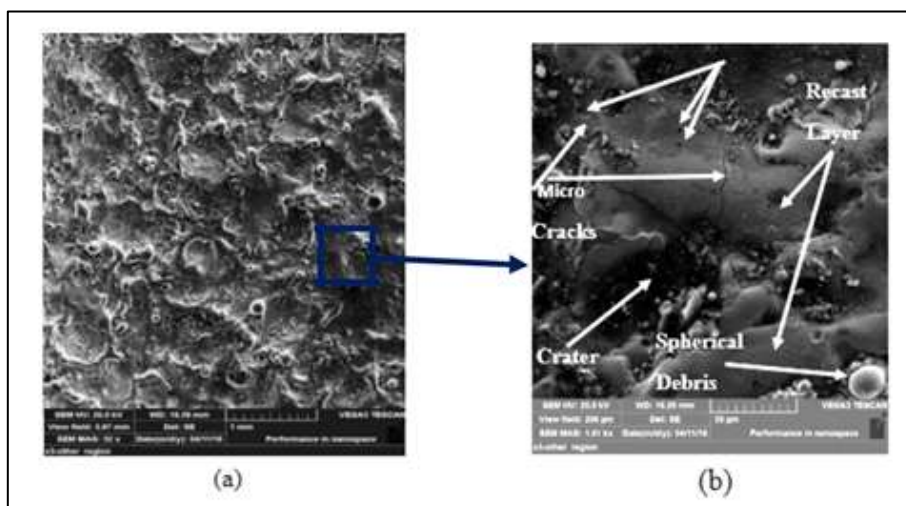


Figure 11: SEM images of surface machined by EDM of AISI 1018 mild carbon steel at conditions $T_{on}=150\ \mu\text{s}$, $I_p=22\text{Amp}$ and $T_{off}=25\ \mu\text{s}$. At high white layer thickness, (a) low magnification 52X and (b) high magnification

6. Conclusions

1. Concluded by analysis of surface topography images after EDM surface machining (RLT) and crater depth was increased clearly with the rise of I_p also T_{on} and reduce in T_{off} .
2. The machining time has a reverse tendency with the RLT where increase it cause to decrease in RLT.
3. Pulse current (I_p) is the most controlling parameter influencing the RLT, the result reveals that in order to minimize the recast layer thickness the pulse current should be kept at their low level.
4. With the increases in I_p that Lead to a rise in spark energy, which lead to in wider and deeper, craters on machined surface.
5. The crater depth is increased with increasing I_p from (10 to 16) and, increases in T_{on} From (50 to 150) and decrease in T_{off} From (75 to 50).
6. Providing the heat for long duration, due to rising I_p and T_{on} and therefore, it is causing in the production of more molten material is produced with craters, deeper and large globules as well as rise in RLT.

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