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# Black Layer Characterization in Electric Discharge Machining of Inconel 718

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***Abstract:*** *This paper discusses about the black layer characteristics during electric discharge machining of Inconel 718 by taking copper as tool material. Black layer is formed due to migration of iron (from work piece) and carbon (from die-electric fluid) to the tool surface. This work emphasises on the importance of black layer in respect of tool wear rate (TWR). The experiments have been conducted on die-sinking EDM based on L36 orthogonal array. Black layer formation was observed during machining. To ascertain the constituents of black layer, X-ray diffraction has been performed. By analysing the relation between TWR and black layer, it is observed that TWR decreases as black layer increases.*

***Keywords:*** *EDM, Inconel 718, MRR, TWR, black layer*

## 1. INTRODUCTION

Inconel 718, a nickel based super alloy, finds extensive use in high temperature applications like gas turbines, space vehicles and nuclear reactors. This material is categorised as difficult-to-cut material owing to some of its peculiar mechanical and metallurgical properties. Having found machining of this material on traditional machines difficult, shaping this material into complex parts with great accuracy and surface finish is popularly done by Electric Discharge Machine (EDM).EDM is a thermo-electric process wherein material removal takes place with the successive electric discharges (sparks) generated between tool (electrode) and work piece that are immersed in a dielectric fluid.

A temperature of the order of 8000˚C to 12000˚C is produced due to electric sparks that vapourises the material from tool and the work piece. The vapourised material is flushed away by dielectric fluid the moment spark is off. This process is repeated at a very faster rate and very small (micro level) amount of material is removed from work piece and tool in one spark. This results in low material removal rate (MRR), low tool wear rate (TWR) along with high dimensional accuracy and surface quality. The performance of EDM is normally measured in terms of MRR, TWR and Surface Roughness (SR).

Some researchers have shown that some materials are migrated from work piece and dielectric to the tool surface due to extremely high temperature produced during EDM process [1,2,3] but they did not discuss about the effect of this phenomenon on machining performance specifically TWR.These migrated materials are collected at the tool surface and the process is called black layer formation or carbon layer formation. This black layer is deposition of metal carbides on the tool surface. Mohri et al. [4] demonstrated how wear rate is affected by deposition of carbon at the tool surface which is migrated from hydrocarbon dielectric fluid. Marafona and Wykes [5] have shown that tool wear rate may be decreased by increasing the carbon layer on the tool surface. Patel et al. [6], after simulation of heat distribution, have shown that tool wear decreases with increase in pulse duration. Natsu et al. [7] have shown that carbon-layer formation acts as protective layer and thus reduces wear. Marafona [8], in his work, has established a relation between tool wear and carbon-layer deposition on tool. He concluded that wear rate reduces as carbon-layer increases. Murray et al. [9] have shown that debris deposition on tool electrode acts as a protective layer against wear. They also explained that this layer has an additional advantage of protecting the base electrode from secondary discharges. Maradia et al. [10] proposed a thermalmodel for the black layer formation. They presented the model on the basis of the melting point of workpiece and hydrocarbon vapourisation temperature of dielectric fluid.

This work focuses about black layer formation during electric discharge machining of Inconel 718 by taking copper as tool electrode. To ascertain the constituents of black layer, X-ray diffraction (XRD) has been performed and reported. On the basis of experimental results, the effect of black layer formation on TWR has been discussed.

## 2. EXPERIMENTATION

Experiments were carried out on Elecktra Plus S-50 ZNC die-sinking EDM in which the Z-axis is servo controlled and X and Y axis are manually controlled. Experiments were carried out by pulse arc discharges generated between tool (copper) and work piece (Inconel 718). Commercial graded standard oil has been taken as dielectric fluid.The working range of input parameters and the levels taken are shown in Table 1. The levels of the parameters were selected after conducting exploratory experiments.Experiments were designed as per Taguchi's L36 ($2^1 \times 3^6$). TWR (mm3/min) is calculated by measuring the amount of tool material eroded and the machining time by using following equation

$$TWR(mm^3/min) = \frac{\text{Reduction in weight of tool electrode (g)}}{\text{density of tool material} (g/mm^3) \times \text{machining time (min)}}$$

Initial and final weights of electrode were measured by electronic weighing balance having a resolution of 0.001 g.

**TABLE 1: Machining parameters and their levels**

| Input parameters | Unit | Symbol | Range (as specified by machine manufacturer) | Levels and values | | |
|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 |
| Shape factor (SF) | - | A | - | Square | Circular | - |
| Pulse-on-time ($T_{on}$) | µs | B | 0.25-4000 | 50 | 100 | 150 |
| Discharge current ($I_d$) | A | C | 0.5-50 | 3 | 8 | 12 |
| Duty cycle (ζ) | % | D | 0-1 | 0.7 | 0.75 | 0.83 |
| Gap voltage ($V_g$) | V | E | 1-150 | 50 | 70 | 90 |
| Flushing pressure (P) | kg/cm$^2$ | F | 0-1 | 0.3 | 0.5 | 0.7 |
| Tool electrode lift time ($T_L$) | sec | G | 1-12 | 1 | 2 | 3 |

## 3. RESULTS AND DISCUSSION

The experimental results have been reported in table 2. Figure 1 shows the graph between TWR and pulse-on-time. TWR increases initially with increment in pulse-on-time but decreases with further increase in pulse-on-time. This isdue to black layer formation at the tool surface. The black layer consists of metal carbides migrated from work piece material and dielectric fluid. The black layer (also known as carbon layer) increases with increase in pulse duration. This layer acts as a protective layer at the tool surface and decreases the tool wear with further increase in pulse duration. This is in proximity with the research carried out in this area by various researchers. To ascertain the constituents of black layer in case of Inconel 718, XRD was performed and the results are reported in figure 2. The XRD pattern of copper indicates the formation of iron and copper carbides. The migrated materials are iron (from work piece) and carbon (from dielectric fluid).

## 4. CONCLUSIONS

In EDM, migration of material (from work piece and dielectric fluid) takes place at the surface of tool due to extremely high temperature. The migrated materials form a black layer at the surface of tool which prevents the tool wear with the increase in pulse duration. In the instant case, it was observed that iron and copper carbides formed at the tool surface which could be ascertained by XRD pattern. The experimental results also show that TWR decreases with the increase in pule-on-time.

**TABLE 2: Experimental results based on L 36($2^1 \times 3^6$) array**

| Exp No. | SF | $T_{on}$ | $I_d$ | Z | $V_g$ | P | $T_L$ | TWR |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 50 | 3 | 0.7 | 50 | 0.0.7 | 1 | 0.0299 |
| 2 | 1 | 100 | 8 | 0.75 | 70 | 0.5 | 2 | 0.6995 |
| 3 | 1 | 150 | 12 | 0.83 | 90 | 0.7 | 3 | 0.9407 |
| 4 | 1 | 50 | 3 | 0.7 | 50 | 0.5 | 2 | 0.1114 |
| 5 | 1 | 100 | 8 | 0.75 | 70 | 0.7 | 3 | 0.9235 |
| 6 | 1 | 150 | 12 | 0.83 | 90 | 0.3 | 1 | 0.3780 |
| 7 | 1 | 50 | 3 | 0.75 | 90 | 0.3 | 2 | 0.0741 |
| 8 | 1 | 100 | 8 | 0.83 | 50 | 0.5 | 3 | 0.3960 |
| 9 | 1 | 150 | 12 | 0.7 | 70 | 0.7 | 1 | 0.3010 |
| 10 | 1 | 50 | 3 | 0.83 | 70 | 0.3 | 3 | 0.0150 |
| 11 | 1 | 100 | 8 | 0.7 | 90 | 0.5 | 1 | 0.1029 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 12 | 1 | 150 | 12 | 0.75 | 50 | 0.7 | 2 | 0.1598 |
| 13 | 1 | 50 | 8 | 0.83 | 50 | 0.7 | 2 | 0.3109 |
| 14 | 1 | 100 | 12 | 0.7 | 70 | 0.3 | 3 | 0.2391 |
| 15 | 1 | 150 | 3 | 0.75 | 90 | 0.5 | 1 | 0.0075 |
| 16 | 1 | 50 | 8 | 0.83 | 70 | 0.3 | 1 | 0.1624 |
| 17 | 1 | 100 | 12 | 0.7 | 90 | 0.5 | 2 | 0.5226 |
| 18 | 1 | 150 | 3 | 0.75 | 50 | 0.7 | 3 | 0.0479 |
| 19 | 2 | 50 | 8 | 0.7 | 90 | 0.7 | 3 | 0.2283 |
| 20 | 2 | 100 | 12 | 0.75 | 50 | 0.3 | 1 | 0.5958 |
| 21 | 2 | 150 | 3 | 0.83 | 70 | 0.5 | 2 | 0.0215 |
| 22 | 2 | 50 | 8 | 0.75 | 90 | 0.7 | 1 | 0.1750 |
| 23 | 2 | 100 | 12 | 0.83 | 50 | 0.3 | 2 | 0.3855 |
| 24 | 2 | 150 | 3 | 0.7 | 70 | 0.5 | 3 | 0.0156 |
| 25 | 2 | 50 | 18 | 0.75 | 50 | 0.5 | 3 | 0.7231 |
| 26 | 2 | 100 | 3 | 0.83 | 70 | 0.7 | 1 | 0.0599 |
| 27 | 2 | 150 | 2 | 0.7 | 90 | 0.3 | 2 | 0.0202 |
| 28 | 2 | 50 | 18 | 0.75 | 70 | 0.5 | 1 | 0.2196 |
| 29 | 2 | 100 | 3 | 0.83 | 90 | 0.7 | 2 | 0.0300 |
| 30 | 2 | 150 | 2 | 0.7 | 50 | 0.3 | 3 | 0.0874 |
| 31 | 2 | 50 | 18 | 0.83 | 90 | 0.5 | 3 | 0.2781 |
| 32 | 2 | 100 | 3 | 0.7 | 50 | 0.7 | 1 | 0.0653 |
| 33 | 2 | 150 | 2 | 0.75 | 70 | 0.3 | 2 | 0.0694 |
| 34 | 2 | 50 | 18 | 0.7 | 70 | 0.7 | 2 | 0.4013 |
| 35 | 2 | 100 | 3 | 0.75 | 90 | 0.3 | 3 | 0.0150 |
| 36 | 2 | 150 | 8 | 0.83 | 50 | 0.5 | 1 | 0.3037 |

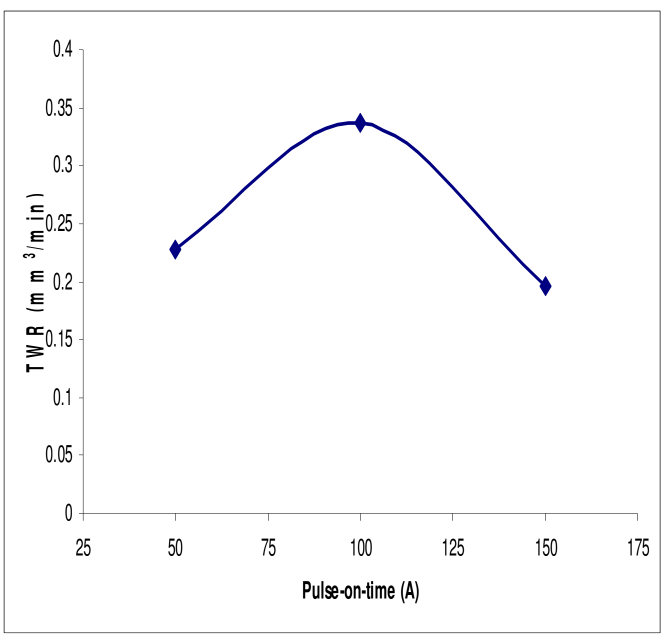


**Fig. 1. Relationship between TWR and pulse-on-time**

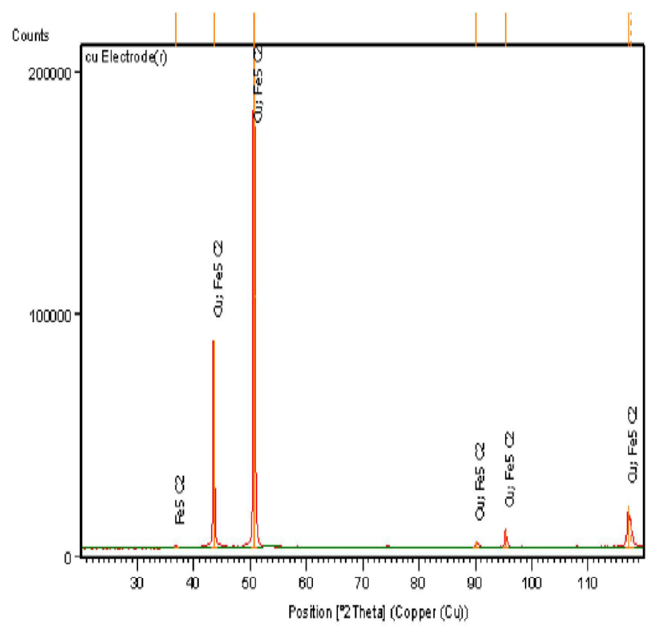


**Fig. 2. X-Ray diffraction profiles of copper**

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