Surface Characterization of Electric Discharge Machined Surface of High Speed Steel

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\begin{abstract}
A comprehensive study of the Surface Characterization of Electric Discharge Machined surface of High Speed Steel work piece was investigated in this Project. EDM tests on High Speed Steel work piece were conducted on a Minor model Modern Machine Tools make Electric Discharge Machine with a transistorized pulse generator having a maximum output of 85 V and 20 A. The test conditions used were Copper electrode with negative polarity, kerosene as dielectric, side flushing, Pulse Current settings of 2, 5, 10, 15 and 20 A, Pulse on-times of 50, 200, 400, 800 and 1600 μs with duty factor of 0.5, and 85V open voltage. The Electric Discharge Machined surface morphology was examined with a Metallurgical Microscope and Scanning Electron Microscope (SEM-Leo-440 model) with EDX analysis. It was observed that at low pulse current and low pulse on-time, the craters were shallow and the density of global appendages and pockmarks were low, whereas at higher pulse current and pulse on time, the craters were deeper and global appendages were most evident. These global appendages were molten metals, which were expelled randomly during the discharge and later solidified on the work piece surfaces. It is also observed that the EDM conditions have no effect on the microstructure of the bulk material work piece, and the damage caused by the EDM surface is limited to certain depth only. These changes will depend on the variation of pulse current and pulse on-time.
\end{abstract}

Introduction

The development of new, advanced engineering materials and the need for precise and flexible prototypes and low-volume component production have made Electric Discharge Machining an important manufacturing process to meet such a demand. Electric Discharge Machining (EDM) is a thermo electric process that erodes work piece material by a series of discrete electrical sparks between the work piece and an electrode flushed by or immersed in a dielectric fluid. Unlike traditional cutting and grinding processes, which rely on the force generated by a harder tool or abrasive material to remove the softer work material, the EDM process utilizes electrical sparks or thermal energy to erode the unwanted material and generate the desired shape. The hardness and strength of the difficult to machine work material are no longer the dominating factors that affected the tool wear and hinder the machining process. This makes the EDM process particularly suitable for machining hard, difficult to machine material. The EDM process has the ability to machine precise, complex and irregular shapes with a CNC control system. In addition, the cutting force in EDM process is small, which makes it ideal for fabricating parts with miniature features.

Several theories were proposed by early investigators to account for the erosion mechanism of the EDM process. It has been accepted generally that the metal removal phenomenon is predominantly thermal in nature \cite{1}. The best explanation of EDM phenomena has been established by extensive experimental studies \cite{2, 3}.

Three stages can be distinguished:

1. Ionization and arc formation, at a localized area between the electrodes, following the application of a voltage exceeding the breakdown voltage.

2. The occurrence of the main discharge as an electron avalanche striking the anode, with low electrical resistance in the discharge channel. The cathode is struck by ions and is heated less rapidly than the anode.
3. Local melting and evaporation follow, and some material is removed from the site of the discharge by explosion occurring after the cessation of electrical discharge. The current density decreases with increasing discharge duration, the discharge tending to become an arc.

For a commercial EDM machine, the manufacturer provides a database of setup parameters for commonly used work and electrode materials under typical operating conditions. Such a database cannot meet the growing new EDM applications, including machining new advanced materials and miniature features. Wang and Yan, et al.[4], investigated the Blind hole drilling of Al2O3/6061 Aluminum composite using rotary electrode discharge machining. Lin and Lin, et al. [5], optimized the EDM process parameters based on the orthogonal array with fuzzy logic and grey relation analysis method. Lin and Lin, et al.[6], studied the use of the orthogonal array with grey relation analysis to optimize the electrical discharge machining process with multiple performance characteristics i.e. the effect of current, polarity, voltage, and spark on-time on the EDM process by using the Taguchi method. Uno, et al. [7], studied the high efficiency fine boring of mono crystalline silicon ingot by electrical discharge machining and showed the relationships between the material removal rate and spark on-time in EDM of silicon and mild steel. Hocheng, et al. [8], studied the material removal in electrical discharge machining of SiC/Al. Hocheng, et al. investigated the correlation of current and spark on-time and the crater size produced by a single spark of SiC/Al work material.

The structural changes of electric discharge machined surface have been studied extensively [1]. Rebelo, et al. [9] investigated the influence of EDM pulse energy on the surface integrity of martensitic steels. SooHong Lee, et al. [10] studied the surface integrity of the machined work piece in the EDM of tungsten carbide. Hwa-Teng Lee, et al. [11] studied the surface integrity using the small area EDM process with copper-tungsten electrode. Ghanem, et al. [12] studied the influence of steel type on EDM surface integrity. Lim and Lee, et al. [13] has reported that only 15% of the molten work piece material is flushed away by the dielectric. The remaining material re-solidifies on the EDM surface due to the fast cooling rate generated by the dielectric. This recast layer is referred as the 'white layer' since it is very difficult to etch and because its appearance when observed through an optical microscope is white. For HSS, it has been shown that the top most surface layer is uneven, non-etchable layer called as 'white layer'. Immediately beneath the white layer there is an intermediate layer called as 'heat affected layer', where the heat is not enough to cause melting the work piece material but it is sufficient to induce micro structural changes in the work piece material [1,3,14-15].

Surface Integrity of the machined components dominates the physical and mechanical properties of the work piece material. Surface Integrity includes work hardness, surface roughness, surface structure, residual stresses, metallurgical transformations and micro structural changes which causes or affect the operational behavior of the work piece material. Thus the surface integrity plays a vital role in promoting the physical and mechanical properties of the work piece material. The present study is aimed at investigating the effect of two EDM process parameters on Surface characterization of High Speed Steel material.

**Experimental set up**

A Minor model modern machine tools make electric discharge machine with a p-25 transistorized pulse generator having a maximum output of 85 V and 20 A was used to machine High speed steel specimens in this investigation. Copper electrode with diameter of 8.35 mm, Kerosene as dielectric fluid with side flushing was used in this investigation. Surface topography observed with Neophot (GDR Make) Metallurgical Microscope with magnification of X100. The EDMed surfaces were cleaned with soft brush and etched with 2% Nital reagents after polishing with 200, 400, 800 and zero grade polishing papers. Metallurgical transformations were measured with Leo 440 model Scanning Electron Microscope (SEM) with magnification of X500 to a depth of 100µm.

**Results and discussions**

**Surface topography**

In electric discharge machining process for each discharge, a crater is formed on the work piece and a smaller crater is formed on the tool electrode. From the molten material produced by the discharge, only 15% or less is carried away by the dielectric. The remaining material re-solidifies on the electric discharge machined surface due to the fast cooling rate generated by the dielectric. The surface observed after magnification appears to have matt appearance covered with overlapping craters, globules of debris, and pockmarks or chimneys, formed by entrapped gases escaping from the re-deposited material. Thus the surface texture becomes rougher, as the pulse on-time or the pulse current was increased, as shown in Fig. 1.1 to 1.9.

It was observed that at low pulse current and low pulse on-time, the craters were shallow and the density of global appendages and pockmarks was low, as shown in Fig. 1.1, whereas at higher pulse current and pulse on-time, the craters were deeper and global appendages were most evident, as shown in Fig. 1.9. These global appendages were molten metals, which were expelled randomly during the discharge and later solidified on the work piece surfaces.

![Figure 1.1 Metallurgical micrograph of EDMed surface at Current I=2A, and T=50 μs.](image-url)
Fig 1.2 Metallurgical micrograph of EDMed surface at Current I=2A, and $T_{on}=200 \, \mu s$.

Fig 1.3 Metallurgical micrograph of EDMed surface at I=2A, and $T_{on}=800 \, \mu s$.

Fig 1.4 Metallurgical micrograph of EDMed surface at I=10A, and $T_{on}=50 \, \mu s$.

Fig 1.5 Metallurgical micrograph of EDMed surface at I=10A, and $T_{on}=200 \, \mu s$.

Fig 1.6 Metallurgical micrograph of EDMed surface at I=10A, and $T_{on}=800 \, \mu s$.

Fig 1.7 Metallurgical micrograph of EDMed surface at I=20A, and $T_{on}=50 \, \mu s$.

Fig 1.8 Metallurgical micrograph of EDMed surface at I=20A, and $T_{on}=200 \, \mu s$.

Fig 1.9 Metallurgical micrograph of EDMed surface at Current I=20A, and $T_{on}=800 \, \mu s$. 

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Micro structural changes

The EDM conditions are seen to have no significant effect on the microstructures of the bulk work piece material. This means that EDM causing damages on the EDMed surface is limited to a surface layer within a certain depth. It was observed that the depth of the damaged layer and the average length, width and number of micro-cracks increases with the peak current and pulse duration, and the increase was more pronounced for peak current. The damaged layer and micro-cracks seem to disappear when the peak current and pulse duration were set at very low values. In the case of High speed steel, the metallurgical transformation results in the creation of three different layers, as shown in Fig. 1.10.

- A white layer, situated at the surface, corresponding to a dendritic phase. It is due to the melting and rapid cooling of the molten metal by the forced circulation of the dielectric fluid during the EDM process. Its average thickness is about 8 \( \mu \text{m} \) for weaker current (2A) and 50 \( \mu \text{m} \) for stronger current (20A).

- A quenched or heat affected layer, located directly under the white layer. This layer has a martensitic quenched structure. Its average thickness is about 50 \( \mu \text{m} \) for weaker current (2A) and 400 \( \mu \text{m} \) for stronger current (20A). It depends on the type and hardenability of the steel and also on the machining conditions.

- A transition layer, situated at the end of the heat affected layer. This layer can reach a thickness of up to a few microns for higher currents and it is not visible for lower currents.

It can be seen from the scanning electron micrographs that in the case of higher EDM conditions i.e. at higher pulse current and pulse on-time there was a clear damaged layer on the work piece distinguished by the amount of micro cracks and rough surface, as shown in Fig. 2.12.

Electric discharge machined surface was observed to have an abundance of cracks, especially at high pulse current and pulse on-time. The crack formation was associated with the development of high thermal stresses exceeding the fracture strength of the material, as well as with plastic deformation. These cracks were formed as a result of the exceedingly high thermal stresses usually at the insert surface as the latter was cooled at a fast rate after the discharge.

Furthermore, the results indicate that obvious cracks are always evident in thicker white layers. A smaller pulse current tends to increase the surface crack density, while extended pulse on-time widens the opening degree of the surface crack, thereby reducing the surface crack density. In general, the density of cracks increases as the pulse current and pulse on-time was increased.

The scanning electron micrographs at various electric discharge machined conditions are as shown in Figs.2.1 to 2.12.
Fig. 2.5 Scanning Electron Micrograph of EDMed Surface at I = 10A and $T_{on} = 50 \mu s$

Fig. 2.6 Scanning Electron Micrograph of EDMed Surface at I = 10A and $T_{on} = 400 \mu s$

Fig. 2.7 Scanning Electron Micrograph of EDMed Surface at I = 10A and $T_{on} = 800 \mu s$

Fig. 2.8 Scanning Electron Micrograph of EDMed Surface at I = 10A and $T_{on} = 1600 \mu s$

Fig. 2.9 Scanning Electron Micrograph of EDMed Surface at I = 20A and $T_{on} = 50 \mu s$

Fig. 2.10 Scanning Electron Micrograph of EDMed Surface at I = 20A and $T_{on} = 400 \mu s$

Fig. 2.11 Scanning Electron Micrograph of EDMed Surface at I = 20A and $T_{on} = 800 \mu s$

Fig. 2.12 Scanning Electron Micrograph of EDMed Surface at I = 20A and $T_{on} = 1600 \mu s$
Carbon content in the EDMed surface

The compositions of the electric discharge machined surfaces were examined by using energy dispersive x-ray (EDX) analysis. There is higher amount of carbon in the craters of the EDMed surfaces. The carbon could possibly come from dielectric fluid due to pyrolysis process. An EDX analysis result reveals that the percentage carbon in the electric discharge machined surfaces is high at low pulse current and high pulse on-time i.e. at 2A and 1600 μs, as shown in Fig. 3.1, and the carbon percentage is low at high pulse current and low pulse on-time i.e. 20A and 50μs, as shown in Fig. 3.2. At low pulse current and high pulse on-time the pyrolysis effect of the dielectric fluid will increase which tend to increase the % of carbon on the EDMed surfaces. At high pulse current and low pulse on-time the pyrolysis effect of the dielectric fluid will decrease which results in a decrease the % of carbon on the EDMed surface. Further, it was observed that the increase in % of carbon on EDMd surfaces is three to ten times greater than that on the un machined surface or bulk material of the work piece and there was no significant change in the other composition of material viz. Chromium, Vanadium, Tungsten and Molybdenum. This was also confirmed by the other authors[9].

Conclusions

The present work has investigated the Surface characterization and the increase in carbon percent in the Electric Discharge Machined surface of High Speed Steel work piece. The main conclusions of this study may be summarized as follows.

- At low pulse current and low pulse on-time, the craters were shallow and the density of global appendages and pockmarks were low, whereas at higher pulse current and pulse on time, the craters were deeper and global appendages were most evident.
- It is also observed that the EDM conditions have no significant effect on the microstructure of the bulk material work piece. The damage caused by the EDM surface is limited to certain depth only and the intensity of the changes will depend on the variation of pulse current and pulse on-time.
- EDMed surface presented an abundance of cracks, especially at high pulse current and pulse on-time. The crack formation was associated with the development of high thermal stresses exceeding the fracture strength of the material, as well as with plastic deformation. These cracks were formed as a result of the exceedingly high thermal stresses usually at the insert surface as the latter was cooled at a fast rate after the discharge.

References


