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Experimental Study of Electrical Discharge Drilling Process for Carbon-Carbon Composites

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Abstract—*In present work a study has been made on machining of carbon-carbon (C/C) composite. C/C composite is a new advanced engineering material with extraordinary mechanical and thermal properties. Carbon-carbon composites are highly potential materials in aeronautical and aerospace industries because of its favourable properties like high strength, high service temperature and low density. The processing of C/C composites is very challenging due to its brittle nature. Literature confirms the feasibility of producing accurate holes using electrical discharge machining. The present research endeavor is an attempt to investigate experimentally the electric discharge drilling process for C/C composites. A copper tool electrode of 8mm diameter was used. Pulse current, pulse-on-time, pulse-off-time and tool rotation are selected as input parameters and material removal rate and tool wear rate as response parameters. After experimentation, it has been found that electrical discharge drilling can be used for making accurate holes in carbon-carbon composites..*

1. INTRODUCTION

Carbon-carbon composites are new engineering materials with potential to use considerable in the aeronautics and aerospace industry. The material properties of these composites are high strength, high service temperature and low density. But their intrinsic brittle behavior and hardness place them in the category of difficult to machine materials and therefore limits its use. The conventional machining of carbon-carbon composites results in high tool wear. The layers of high strength carbon fiber rapidly wear down the cutting edge of tool while in contact. As the tool loses its sharpness, it may catch fibers and pull them apart instead of cutting them and also causes delamination. Because of its increasing application, there is a need to ascertain their defect free machining. Electric discharge drilling (EDD) can be used to produce holes in carbon-carbon composites. EDD is a non-contact type advanced machining process in which material removal takes place due to melting and vaporization by thermal energy of electric spark between tool and workpiece. The material is removed in the form of debris and at the same time tool rotation enables better flushing of debris from machined areas.

2. LITERATURE REVIEW

Hocheng et. al [1] investigated feasibility analysis of C/C composites using EDM and examined MRR, surface topography and recast layer formation. They had taken pulse current and pulse-on-time as input variables and concluded that smaller pulse current can be used to prevent the formation of delamination.

George et. al [6] experimentally investigated optimal parameters settings for machining of C/C composites with 1.6mm cylindrical copper tool electrode. They have observed 89.28% reduction in electrode wear rate at I_p=1A, T_{on}=150µs, V_g=20V and 116.67% increase in material removal rate at I_p=9A, T_{on}=750µs, V_g=100V. They have also concluded that pulse current is most significant parameter followed by gap voltage and pulse-on-time.

3. ELECTRICAL DISCHARGE DRILLING

Electric discharge machining is one of the most widely used unconventional processes, which is capable to machine complex and intricate shapes for the hard to cut materials of any hardness. It is non-contact type machining process in which tool electrode does not come in contact with workpiece. The EDM process is based on extirpation of material through melting and evaporation. Both the tool electrodes (cathode) and workpiece (anode) are kept submerged in the dielectric and a high voltage DC current is supplied in the form of about 5KHz frequency pulses. Further breaking down of dielectric occurs due to the supply of DC current which causes flow of electrons from cathode to anode. Due to bombardment of electrons at the anode surface, a high pressure plasma channel is formed between tool and workpiece. The formation and collapse of plasma channel causes material removal. The regularly occurring sparks owing melting and vaporization of tool and workpiece both. Electric discharge drilling is a collaborative hybrid machining process of EDM and conventional drilling. However, there is no contact between tool and workpiece as in case of conventional drilling. The material is removed by melting and evaporation and tool rotation assists the process by efficient expulsion of debris from machined areas at the same time.

4. EXPERIMENTAL SETUP

A SPARKONIX make Z-axis numerically controlled EDM machine has been used for performing the experiments. A separate attachment for giving rotation to tool electrode is mounted on the servo head of EDM.

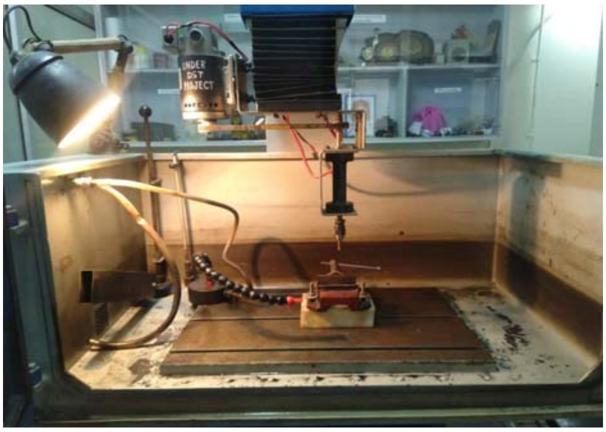

Figure 1: Experimental setup for Electrical Discharge Drilling setup mounted on servo head

5. WORKPIECE AND TOOL MATERIAL

Carbon-carbon (C/C) composite is selected as workpiece as there are several challenges during processing of C/C composites by conventional as well as non-traditional machining processes. The size of C/C composite plate is 120mm × 100mm × 2mm.

Copper is used as tool electrode for EDD. The reason for selecting copper is its high electrical as well as thermal conductivity. The electrode used is pure copper of 8930 kgm^{-3} density with a melting point of 1083 ^{o}C. These tool electrodes are in cylindrical shape with diameter of 8mm.

Figure 2: Keyless Drill chuck with copper tool ø8mm

Figure 3: Holes of 8mm dia. machined on C/C composites

6. SELECTION OF INPUT AND OUTPUT PARAMETERS AND THEIR LEVELS

In present work, four independent input parameters are pulse current (I_P), pulse-on-time (T_{ON}), pulse-off-time (T_{OFF}) and tool rotation (rpm) are selected for experimental study. Material removal rate and tool wear rate are taken as response parameter for evaluation of EDD process performance. The feasible range of input process parameters for C/C composite is selected from pilot experiments conducted varying one parameter at a time approach. In pilot experiments, pulse current is varied from 1.5-12A, pulse-on-time varied from 15-150µs, pulse-off-time varied from 8-450µs and tool rotation is varied from 600-1200rpm. After analyzing the pilot experiment results, the feasible range of maximum MRR and lesser TWR is selected for experimental study. The levels of input parameters are given in Table 1.

Table 1: Levels of input parameters

Input parameters	Level 1 (Low)	Level 2 (Medium)	Level 3 (High)
Pulse Current (A)	9	12	15
Pulse-on-time (µs)	90	120	150
Pulse-off-time (µs)	15	45	90
Tool rotation (rpm)	500	700	900

7. RESULTS AND DISCUSSION

7.1 Analysis of Material Removal Rate (MRR)

The effects of pulse current on MRR at different combinations of other input parameters are shown in figure 4. It is found that greater MRR is observed at high pulse current in almost in all experiments. However, there is a considerable decrease in

MRR beyond 12A pulse current at T_{on}=90µs and T_{off}=15µs. This is due the fact that at such small pulse-off-time, the debris does not get sufficient flushing time. The effect of pulse-on-time on MRR is shown in figure 5. It can be found that MRR is increasing with increase in pulse-on-time as at higher pulse-on-time permits more time for heat energy to get interior to the workpiece. Figure 6 represents the effect of pulse-off-time on MRR. Pulse-off-time is the time duration between two consecutive sparks between the tool and the workpiece. It can be seen that higher MRR can be found that at 15µs and further increase in pulse-off-time results in decreased MRR. Figure 7 illustrates the effect of tool rotation on MRR. It can be found that higher value of MRR can be observed at higher rpm of tool rotation.

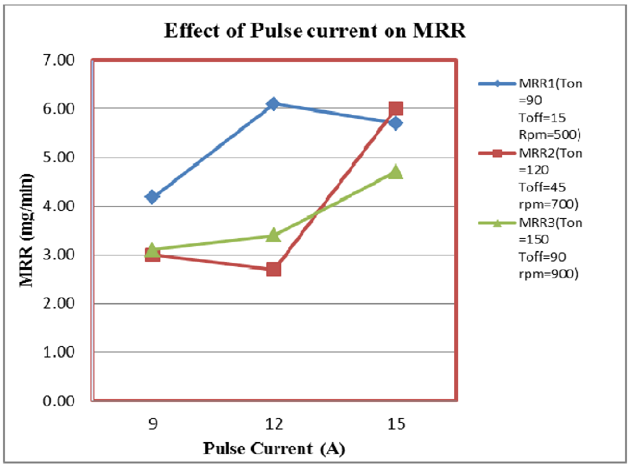

Figure 4: Effect of pulse current (I_P) on MRR

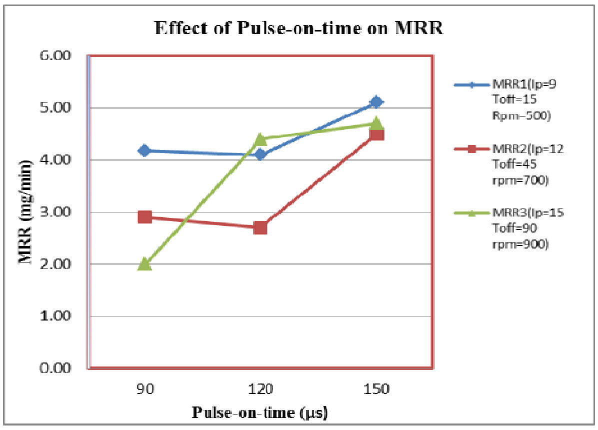

Figure 5: Effect of pulse-on-time (T_{on}) on MRR

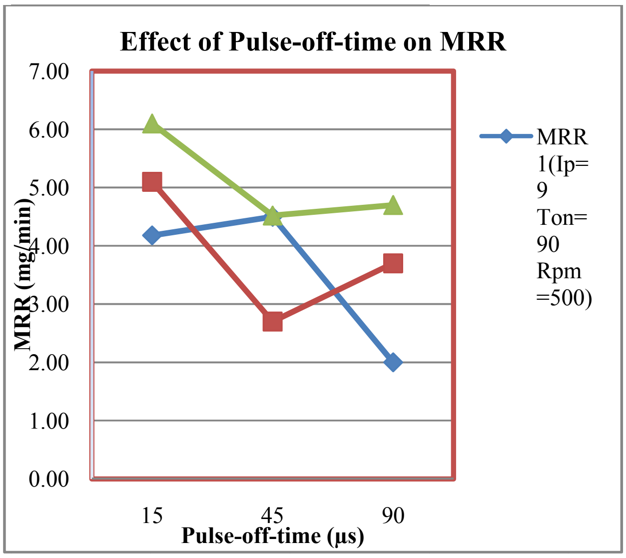

Figure 6: Effect of pulse-off-time (T_{off}) on MRR

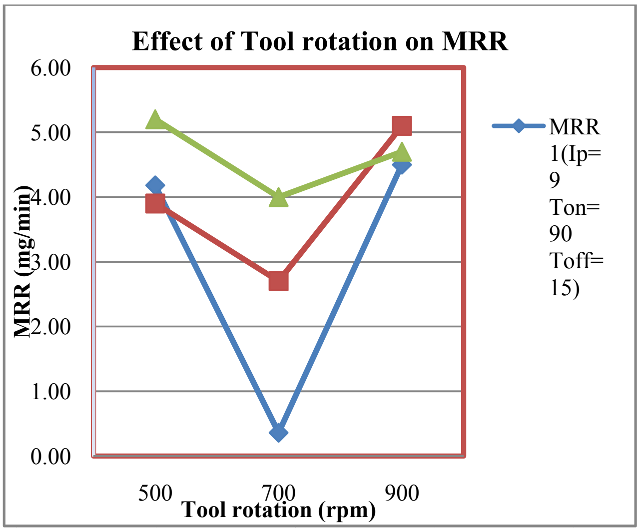

Figure 7: Effect of tool rotation (rpm) on MRR

7.2 Analysis of Tool Wear Rate (TWR)

In electrical discharge machining (EDM), tool wear occurs due to melting and evaporation of tool electrode caused by recurring sparks between tool and workpiece. The effect of pulse current on TWR at different combination of T_{on}, T_{off} and rpm is shown in figure 8.

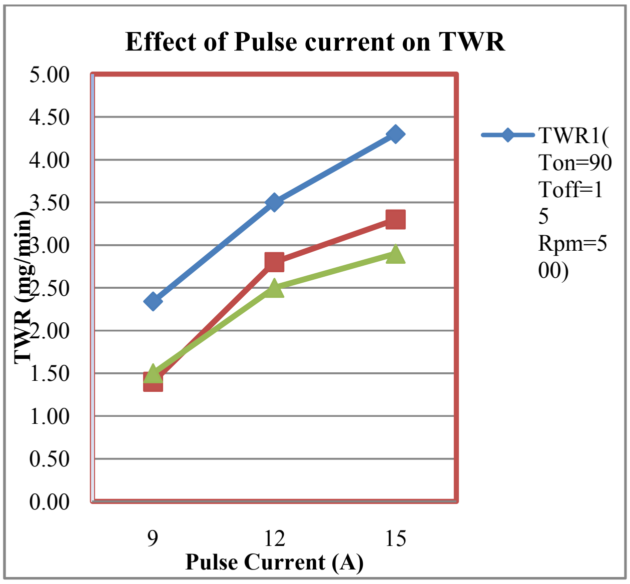

Figure 8. Effect of pulse current on TWR

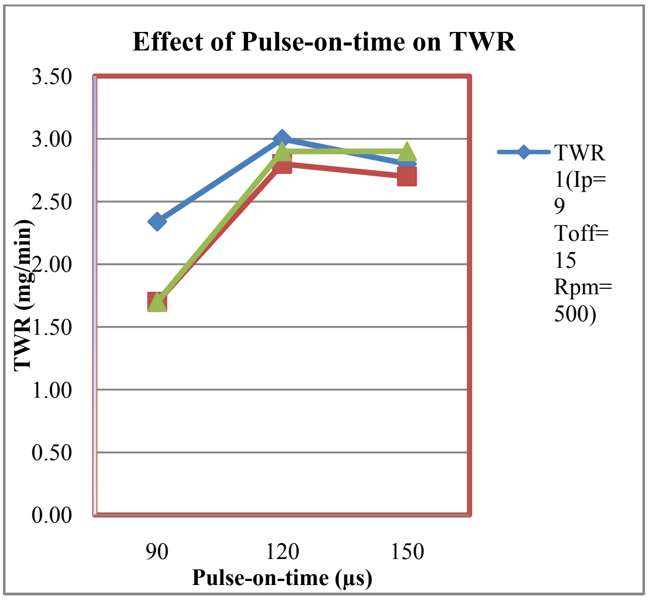

Figure 9. Effect of pulse-on-time on TWR

When there is increase in pulse current, higher TWR can be observed. AT higher level of pulse current largest value of TWR can be observed. This is due to fact that higher pulse current produces large intensity spark which in turn develop more heat between tool and workpiece. This results in extra melting of tool electrode.

Pulse-on-time is time during which spark takes place between tool and workpiece. Figure 9 shows the effects of pulse-on-time causes increased TWR. Higher TWR is found at 150µs pulse current. Figure 10 depicts the effects of pulse-off-time on TWR. It may have seen that a decrease in TWR at higher pulse-off-time. This is due to the fact that a large pulse-off-time results in short pulse and thus tool is exposed to heat for shorter duration and therefore results in lesser TWR. Figure 11 illustrates the effect of tool rotation in TWR. It can be observed that lesser TWR is observed at higher tool rotation. This may be due to the fact that high rpm of tool effectively flushing of debris from machining zone there by reducing the chances of secondary sparking between tool and debris and also between debris and workpiece.

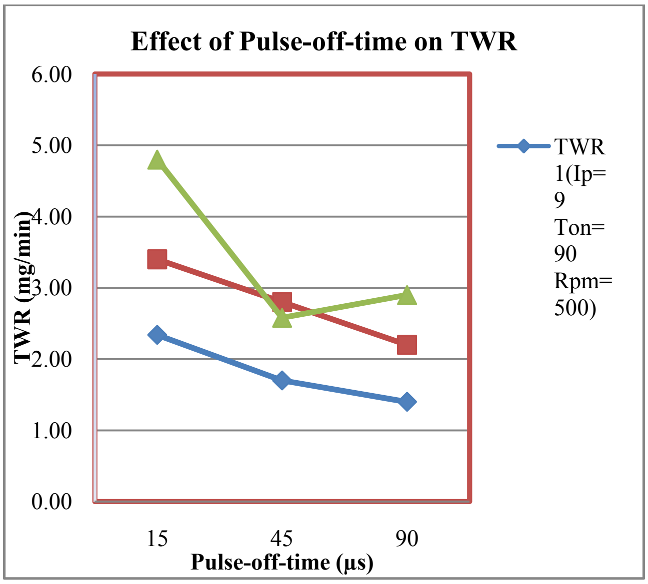

Figure 10. Effect of pulse-off-time on TWR

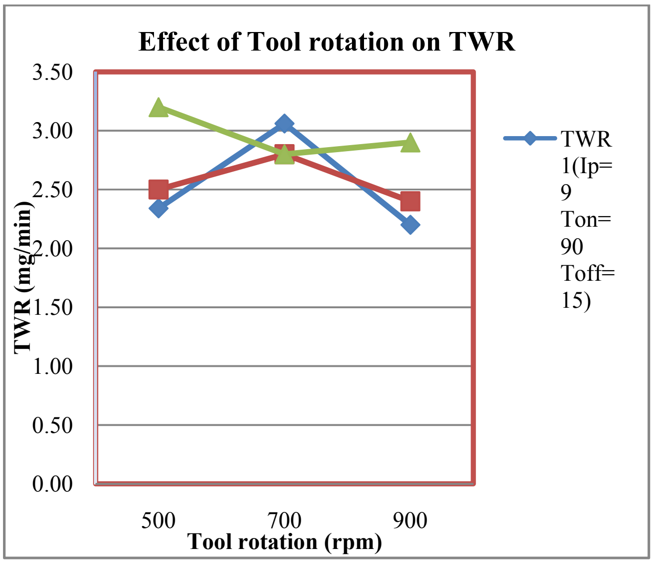

Figure 11. Effect of tool rotation on TWR

8. CONCLUSIONS

In present work, experimental study of electrical discharge drilling (EDD) process is performed on carbon-carbon (C/C) composite material with copper tool electrode. Holes of 8mm diameter are successfully machined with an experimental setup of EDD on conventional EDM machine. The experimental study of EDD process is concluded in following conclusions/observations:

i. Electrical discharge machining (EDM) is a feasible advanced machining process for machining of carbon-carbon composites.
ii. Pulse-on-time (T_{on}) should be kept at medium level for improved process performance in terms of MRR and TWR.
iii. Medium pulse-off-time (T_{off}) and higher rpm is found best suitable in order to obtain higher MRR and lower TWR.

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