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# The Effect of Ultrasonic Vibration of Workpiece in Electrical Discharge Machining of AISIH13 Tool Steel

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***Abstract*****—**In the present work, a study has been made on the combination of the electrical discharge machining (EDM) with ultrasonic vibrations to improve the machining efficiency. In experiments the graphite used as tool electrode and material of workpiece was AISIH13 tool steel. The parameters such as discharge peak current and pulse duration were changed to explore their effect on the material removal rate (MRR), relative tool wear ratio (TWR) and surface roughness. From the experimental result it can be seen that ultrasonic vibration of the workpiece can significantly reduces the inactive pulses and improves the stability of process. It was found that ultrasonic assisted EDM (US-EDM) is effective in attaining a high material removal rate (MRR) in finishing regime.

***Keywords*****—**AISIH13 tool steel; Electrical discharge machining (EDM); Material removal rate (MRR); Surface roughness (Ra); Tool wear ratio (TWR); Ultrasonic assisted EDM (US-EDM).

## I. Introduction

AISIH13 tool steel is a versatile chromium-molybdenum hot work steel that is widely used in hot work and cold work tooling application. With respect to application and properties of AISIH13 tool steel, electrical discharge machining is well known method for its machining. Electrical discharge machining (EDM) is known to be applicable to conductive material regardless of their physical and mechanical properties. In the EDM process the material is removed by successive electrical discharges occurring between an electrode and a work piece immersed in a dielectric fluid. Every discharge ionizes a very restricted area between, the closest opposing peaks of roughness of the electrodes and generates a localized plasma channel, within a vapor bubble bridge, in which the temperature can be as high as 8000-10000 ºC [1]-[3]. The plasma pressure has been estimated to be up to several hundreds of bars. This hot plasma may lead to melting and evaporate of both electrodes [3]. At the end of the pulse, when the current is stopped, the pressure suddenly falls, causing the superheated molten liquid on the surface of both electrodes to explode into the liquid dielectric, leaving a crater on the electrode surfaces and creating small solid and/or hollow debris [1], [3].

Several researchers have reported that ultrasonic assisted *EDM* of steel improves discharge characteristics [5]-[7]. Gao and Liu [5] reported that the workpiece vibration induced by ultrasonic action has a significant effect on the performance of the micro-EDM process and efficiency of the ultrasonically aided micro-EDM is up to eight times greater than Micro-EDM. Murti [6] showed that ultrasonic assisted *EDM* of steel significantly reduced inactive pulses. Zhixin et al. [7] reported that for machining of advanced ceramics, the combination of ultrasonic machining and *EDM* may provide a higher *MRR*. Lin and Yan [8] have pointed out that *EDM* of titanium alloy by using ultrasonic tool vibrations give higher *MRR* and eliminate the recast layer.

In this paper the authors have investigated in detail the Material removal rate, electrode wear and surface roughness produced in EDM and ultrasonic assisted EDM (US-EDM) on AISIH13 tool steel.

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## II. Experimental Setup and Procedure

### *A. Experimental setup and equipments*

An electrical discharge machine (*Charmilles-Roboform 200*) with servo-control generator *(Iso-pulse*) was used to conduct the experiments. For ultrasonic assisted tests, an ultrasonic head (*BANDELIN-HD 2200*) was attached to the *ED* machine. Fig.1 schematically displays the machining equipments that used in this study. The specific fixture was manufactured for holding and adjusting the Ultrasonic head on ED machine. Discharge currents can apply the perturbation effects on piezoceramics application therefore in this work the ultrasonic converter was electrical isolated from machining region (fig.2). The piezoelectric transducer has a power output range of 0-200W and operates at a frequency of 20KHZ. The PC based dual channel digital storage oscilloscope (TNM-DS20080) has been employed to capture and hold random frames of gap voltage and current variations against time, which then will be stored on the PC hard disk.

### *B. Materials and variables of experiments*

For full factorial experimental design three independent variables, namely, workpiece vibration, pulse current (I) and pulse on time were selected. The levels of each variable and the other input parameters were shown in table I.With respect to incapability of graphite in oscillation with ultrasonic frequency the workpiece's vibration was used in this study.

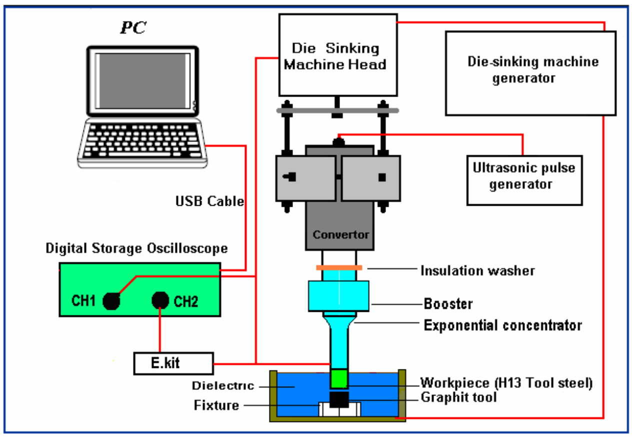


Fig. 1 machining equipments schematic.

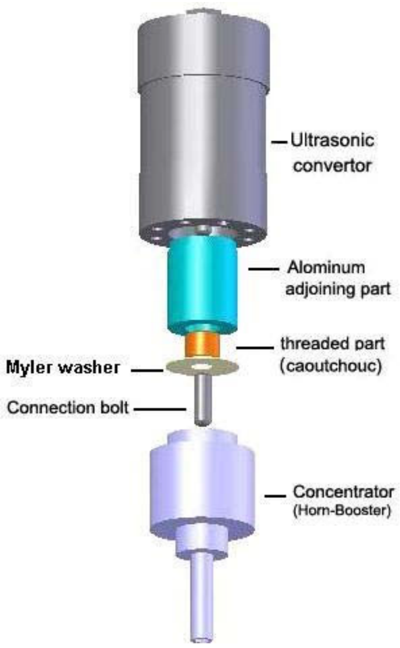


Fig. 2 Electrical insulated ultrasonic head.

To eliminate the machining depth effect on gap flushing condition, the workpiece and tool electrode were made in same diameter (12.7mm). the total specifications of workpiece and tool materials were shown in tables II and III. Fig.4 shows the flushing (R) and machining time (U) that used for improving the flushing condition.

The work piece material used for experiments was AISI H13 tool steel with cylindrically shape rod (Fig.3), which fastens tightly with threading joining to the ultrasonic concentrator tip. In order to obtain the maximum amplitude of vibration, the length of the concentrator and workpiece is made half of the sound wave length in the concentrator and workpiece materials, therefore the dimensions of workpiece was determined after numerous pilot tests as Fig.3 and a myler washer used for couplant layer between concentrator and workpiece.

TABLE I
PROCESS VARIABLES USED FOR THE EXPERIMENTS IN EDM AND US-EDM

| | |
|---|---|
| Gap distance [μm] | 50 |
| Open voltage [V] | 200 |
| Pulse interval time T0 [μs] | 6.4 |
| Vibration amplitude [μm] | 0,15 |
| Discharge current I [A] | 4,8 |
| Discharge duration Ti[μs] | 6.4 ,12.5,25,50 |
| Tool polarity | Positive |
| Flushing type | Normal submerged |
| Machining time U [s] | 0.8 |
| Flushing time R [s] | 0.1 |
| Generator mode | Iso-pulse |
| Dielectric | Oil Flux ELF2 |

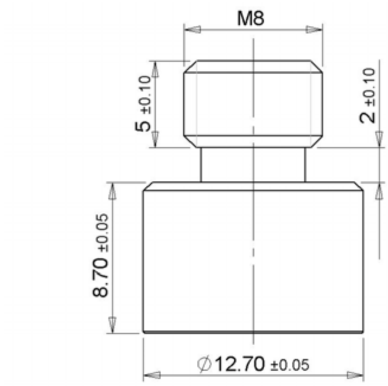


Fig. 3 The dimensions of AISIH13 workpiece.

TABLE II
AISI H13 TOOL STEEL PROPERTIES.

| | |
|---|---|
| Material | AISI H13 tool steel |
| Thermal conductivity at100°C [W/(m. K)] | 24.30 |
| Density [kg/dm$^3$] | 7. 80 |
| Specific heat [J/(kg .K)] | 460 |
| Electrical resistivity [μΩ.cm] | 52 |
| Modulus of elasticity [N/mm$^2$] | $215\times10^3$ |

TABLE III
PROPERTIES OF TOOL ELECTRODE MATERIAL

| | |
|---|---|
| Material | graphite |
| Density [kg/dm$^3$] | 1.82 |
| Hardness Rockwell "H" | 75 |
| Electrical Resistivity [μΩ.cm] | 1.22 |
| Average Grain Size [μm] | 9 |
| Flexural Strength [MPa] | 55 |

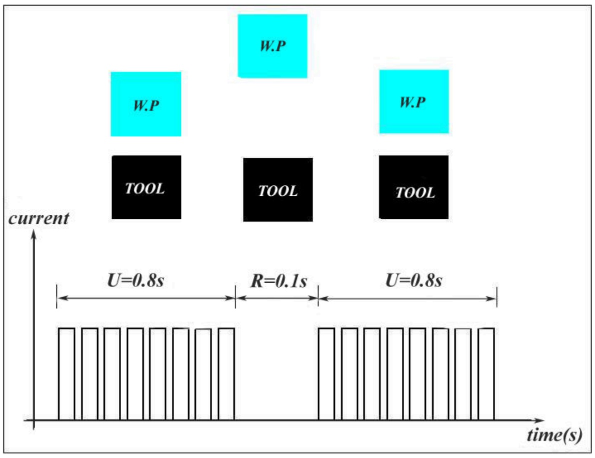


Fig. 4 Schematically representation of machining time (U) and flushing time (R).

## III. EXPERIMENTAL RESULTS AND DISCUSSION

### *A. Effect of ultrasonic vibration of workpiece on material removal rate (MRR)*

fig. 5 illustrates material removal rate (MRR) with and without ultrasonic employment and fig. 6 represents the ratio of ultrasonic assisted EDM (US-EDM) material removal rate to EDM material removal rate against pulse-on time on two discharge current settings (4 and 8A).

The MRR Ratio has been calculated by using the following equation:

$$\text{MRR Ratio} = \frac{V_{US}}{V_{ED}} \qquad (1)$$

Where $V_{US}$ and $V_{ED}$ are the volumetric material removal rate of workpiece with and without ultrasonic vibration respectively.

As shown in figs. 5 and 6 material removals rate is usually higher under application of ultrasonic vibration (except long pulse duration).

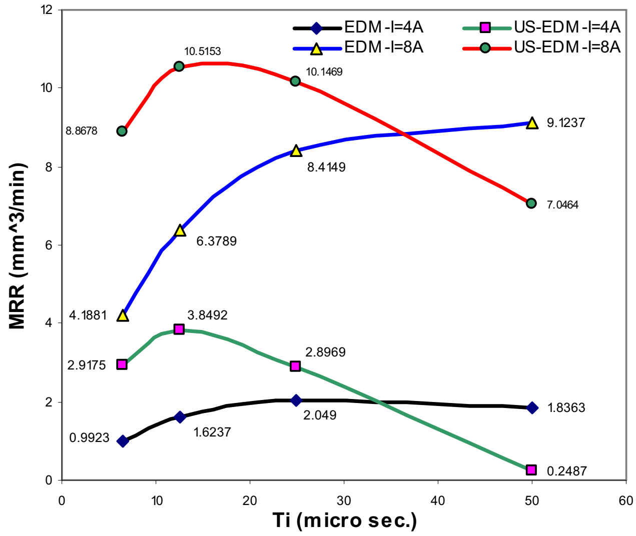


Fig. 5 Material removal rate against pulse-on time with and without ultrasonic vibration of workpiece.

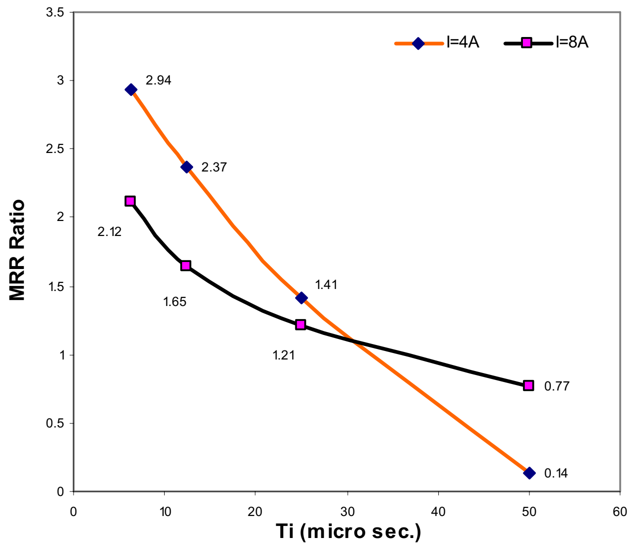


Fig. 6 Relative ultrasonic assisted EDM material removal rate to EDM material removal rate against pulse-on time.

Also fig. 6 shows a considerable difference of 3 times under low pulse-on time and low current setting (finishing regime) on the material removal rate.

A possible explanation for the differences is in the fact that, in the ultrasonic assisted EDM vibration of workpiece makes the gap vary very rapidly, a high frequency alternate pressure variation is generated [9]. As shown in fig. 7 when the workpiece electrode get down (A to B), gap pressure is increased, on the contrary when the electrode get back ( B to C and D), a big pressure drop is made, leading to compressive and rarefying wave front, and intensive ejecting micro-streams created [10]. This phenomenon can be acting as pump, causing better debris evacuation from the spark gap and better dielectric fluid renewal. This result in a reduction of short circuit and arcing pulses and increases the stability of process, result in retraction motions of machine's ram decreases (fig.8).

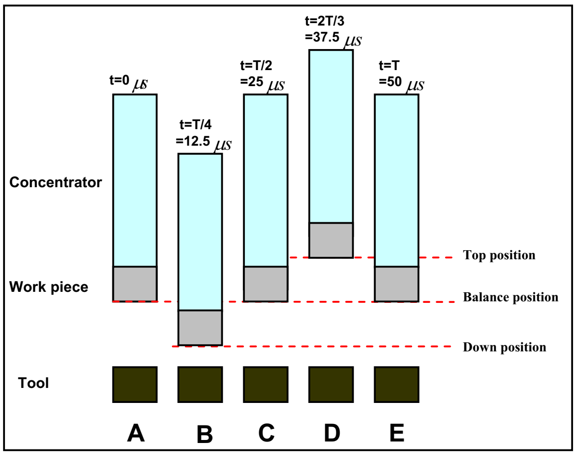


Fig. 7 Schematic of one alternation period of work piece vibration. T: alternation period.

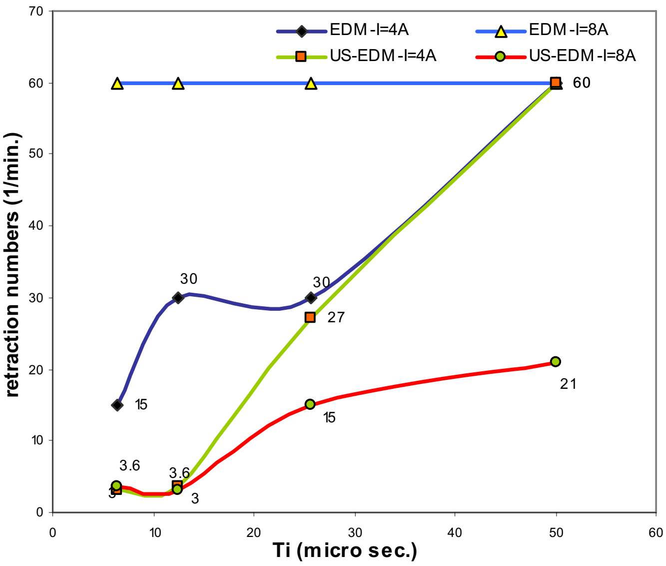


Fig. 8 Retraction number of machine's ram in EDM and ultrasonic assisted EDM.

## B. Effect of work piece vibration on surface roughness

Fig. 9 shows surface roughness (Ra) values for different pulse-on times for two discharge current (4 and 8A) with and without ultrasonic assistance.

Ultrasonic vibration imposes the suction force on molten pool and helps to bulk boiling and causing more super heated molten material to explode into the liquid dielectric. With every discharge pulse, the craters become deeper and the surface of machined surface is increased. Fig. 10 represents the topography of machined surfaces with and without ultrasonic assistance. In finishing regime (I=4A, Ti = 6.4 $\mu s$ ).

As shown in fig. 10 there is a significant difference between ED machined surface with and without ultrasonic vibration, in regards of carbon deposition.

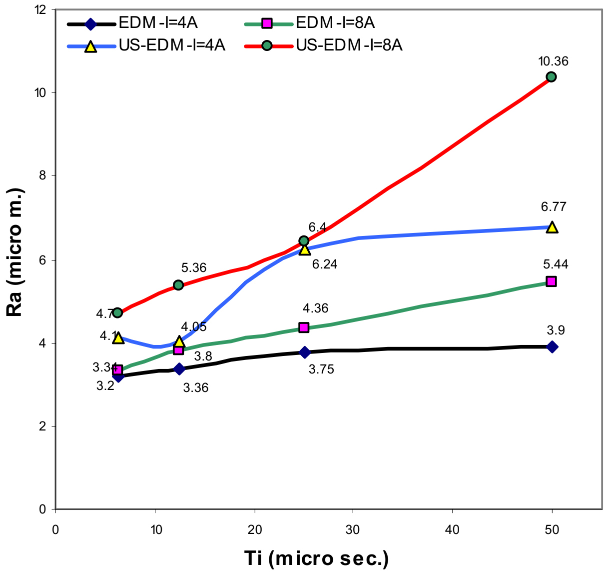


Fig. 9 Machined surface roughness against pulse-on time with and without ultrasonic employment

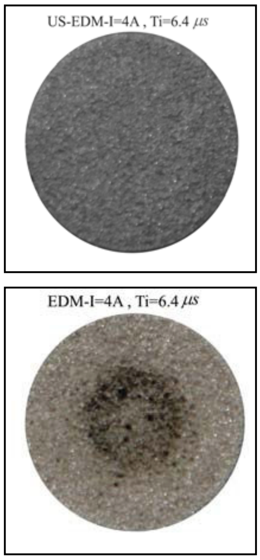


Fig. 10 Machined surface with and without ultrasonic vibration.

As discussed previously, ultrasonic vibration of workpiece creates cavitation and intensive micro ejecting micro-streams, can be acting as a pump, causing better flushing in the spark gap, preventing the carbon and graphite debris deposition on the machined surface.

## C. Effect of work piece vibration on tool wear ratio (TWR)

As shown in fig. 11, ultrasonic vibration of workpiece slightly decreases the tool wear ratio (TWR) on finishing regime.

We are in this opinion that this phenomenon is related to graphite's properties. Graphite is not melted with electrical spark but directly vaporized, therefore any melted molten pool not formed on the tool surface and with attention to considerable effect of ultrasonic vibrations on increasing of bulk boiling of melted materials in the melted cavity the MRR of melted workpiece increases more than graphite tool wear rate (TRR) and therefore tool wear ratio (TWR) is decreased. The exception is found at pulse-on time 50 $\mu s$. This result may be occurs due to insufficient flushing of the spark gap in roughing regimes.

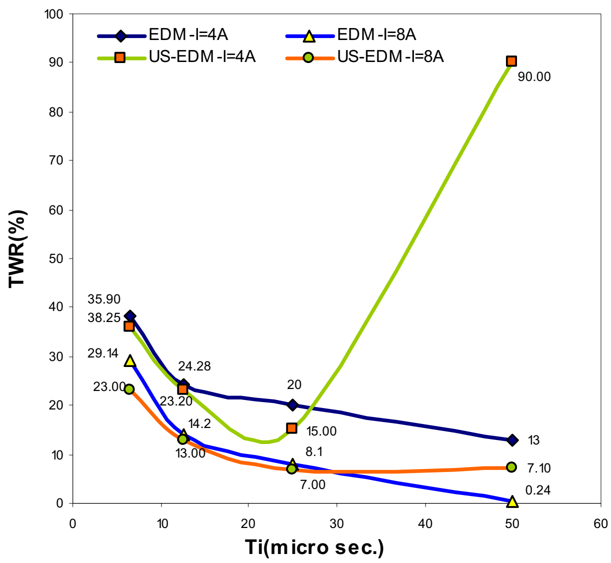


Fig. 11 Tool wear ratio against pulse-on time with and without ultrasonic employment.

## IV. CONCLUSION

The effect of work piece vibration in electric discharge machining of AISI H13 tool steel with graphite tool can be summarized as follows:

1. The material removal rate of the ultrasonic assisted EDM can be up to third times higher than EDM for small pulse durations and low currents.
2. The surface roughness value of the ultrasonic assisted EDM is slightly higher than EDM.
3. The ultrasonic assisted EDM significantly reduces arcing and short circuit pulses, thereby increasing the number of normal pulses and average pulse energy.
4. Ultrasonic vibration of work piece gives pressure variation all along the gap, results in better flushing and increases the process stability.

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