A study on wire breakage and parametric efficiency of the wire electro chemical discharge machining process

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Abstract: - The Wire Electrochemical Discharge Machining (WECDM) is a non-conventional process, typically used in cutting brittle and hard non-conductive materials. The WECDM is relatively new research area compared to its principle process- ‘Electro Chemical Discharge Machining (ECDM). In the current investigation, the wire breakage problem, commonly encountered while machining fine slots has been addressed. The aim was to reduce the wire breakage through optimum parametric settings, to understand the wire breaking voltages at different electrolytic concentrations along with its effect on the MRR, length of cut and width of cut. In this study, zinc diffused brass wire of fine diameter (0.20 mm) was used in experiments and the results of the same are being reported in the paper. The response parameters used in the investigation were MRR and width of cut; while the process parameters were workpiece feed rate, electrolyte concentrations and applied voltage.

Keywords - *WECDM, material removal, electrolyte concentration, wire breakage*

1. INTRODUCTION

Electro chemical discharge machining (ECDM) is a well known concept used in micro machining hard, brittle and conductive materials such as glass, ceramics and such materials which are very difficult to machine by traditional methods [1]. The applications of ECDM are tremendous ranging from creating fine micro asperities in MEMS, micro filter applications, micro fluidics etc. [2].

The basic principle of the process is based on the electrochemical discharge phenomenon, in which hydrogen gas is evolved at the cathode due to electrochemical reactions. The increase in voltage causes the hydrogen bubbles to eclipse the tool surface, thereby temprorily blocking the electron flow. Once the critical voltage value (around 28 V) is reached, the bubbles collapse and the sparks begin to occur; thereby, establishing the flow of electrons between the two electrodes (negative ‘tool’ and the positive ‘electrolyte’). The sparking process is very fast and continuous.

The research potentials and summary of the extended literature review in ECDM has been earlier discussed [3] along with the mechanism of its material removal and the concepts proposed by various research in this field has already been briefed [4].

In a slight variation from the drilling and milling (micro channeling) applications of ECDM, the concept of cutting materials with wire electro chemical discharge machining started from its parent primary version of Wire electric discharge machining (WEDM). The concept of WEDM was introduced in the 1970’s [5] and it was academically reported in 1985 by Masuzawa *et al.* [6] for micromachining of wires. The WEDM process is capable of machining very hard materials (titanium, zirconium, inconel, mnemonics etc.) with high dimensional accuracy and is particularly used in tool and die making industries, aerospace, nuclear and automotive industries [7-9]. The Wire electric discharge grinding (WEDG), a variant process of EDM; is typically used to generate fine micro and nano features on tooling. The WEDG process has been reported to machine fine holes (upto ø 0.5 µm) using Si electrodes [10].

Some relevant applications of TWEDM were mentioned in the wire electric discharge machining application [15], wherein using an ANFIS model the prediction was done for the white layer thickness and average surface roughness. The predicted results with reference to the process parameters were accurate to the tune of an error of 10%, which was considered well enough for such studies and applications. Immediately, following this development in the year 1985, the concept of travelling wire electro chemical discharge machining (TWECDM) was first proposed by Tsuchiya *et al.* [11] for non-conducting materials like glasses and ceramics and has been further elaborated by Jain *et al.* [12] and Peng and Liao [13]. The TWECDM process was capable to perform slicing of large volumes without the need for high cost full form electrode tools. The process is yet to be commercialized and hence finds extensive research interests.

In the wire electro chemical discharge machining (WECDM) process, a travelling wire (representing tool electrode) moves through the electrolyte media and helps in cutting the workpiece at better material removal rates, than normal ECDM. The WECDM is an advanced machining process, which can cut non-conducting workpiece, irrespective of their reflective properties and time of machining; which is a limitation in ion beam machining, electron beam machining and laser beam machining. It is also an economic process as compared to ultrasonic machining, wherein the transducer cost is high.

As reported by Peng and Liao [13], while machining Al_20_3, the observed MRR was 0.06 mm^3/ min. The WECDM process was used to slice small sized optical glass and quartz bars (ø10-30 mm). In another study, Yang *et al.* [14] have used wire ECDM process on pyrex glass and improved performance was observed with the addition of silicon carbide (SiC) abrasives to the electrolytes. Small grit size abrasives reduced the surface finish as well as refined the micro cracks. The reported MRR was 0.03-0.09 mg/min and surface roughness was found to be in the range of 0.84-3.5 µRa.

The conducted literature review in the last few decades suggested that the WECDM process has been less researched as compared to the ECDM and its other variants; especially with respect to the wire breakage phenomenon. Hence, keeping this perspective in mind, the experimental investigations and analysis on wire breakage limits in the WECDM process have been undertaken.

2. EXPERIMENTATION

In the conducted experimental study, zinc diffused brass wire was used as the tool material and potassium hydroxide was used as an electrolyte (which was varied at different concentrations). The critical evaluation with respect to some basic parameters and some innovations are also being discussed. The in-house developed set-up is schematically shown in fig.1. In this arrangement, two micro controller driven stepper motors were used; amongst which, one was used for vertical movement of the work piece and the other (horizontal) for winding the wire. It also contained a wire tool, controlled by gantry type table-top apparatus, which was controlled with a stepper motor (category- Nema 23, torque- 10 kg. cm).

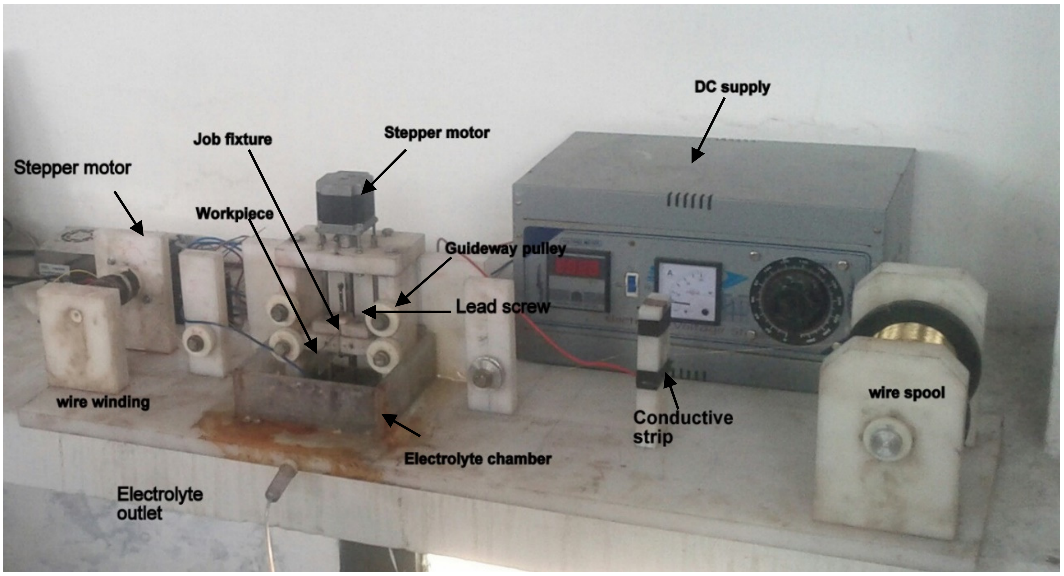

Fig.1 Fabricated WECDM setup

In the study, borosilicate glass was used as the work material, which is commonly used in the laboratories for testing samples in medical applications. A zinc diffused brass wire (0.20 mm diameter) was used as the cathode, which was wound on the spool and tightened through a stepper motor. The anode consisted of 'brass' (size around 20 mm^2) and was dipped in the electrolyte container. The set-up had an electrolyte chamber (1.5 liter volumetric capacity), stands and spools for wire movement. The feed rate was set using the MACH-3 CNC software, having a provision for steps upto 6400 per revolution, through computer programming. The electrolyte used in the experimentation process was KOH, which was varied in the concentration levels of 10-30 wt. %.

The experiments were planned using basic approach of varying single variables at a time and keeping the other variables constant. In the presented studies, it was observed that the sparking started at around 30V; however, meaningful results in terms of material removal (MR) were achieved above 35 volts and at a further increase in the applied voltage levels of more than 65 V, frequent wire brekages occurred, hence the range of 35-55 V was fixed after the trial process. The experiments were conducted initially for three sets consisting of electrolyte concentrations of 10, 20 and 30 wt. % each. The breaking of wire got reduced when duty factor was adjusted [13], which provided some cooling time to the wire, therefore, the pulse on-time (300 ms) and pulse off-time (700 ms) were maintained as the constant parameters. Each experiment was run for 5 minutes time interval, at a constant wire feed rate of 0.33 mm/min and work feed rate of 0.08 mm/min. The trials were repeated four times and its average readings were taken, to minimize any inherent error. The samples were thoroughlly cleaned before and after each experiment using acetone and the readings on difference in its weights were taken on a well callibrated digital weighing machine (make SHIMADZU) having an accuracy of 0.01 mg.

3. RESULTS

The results of the first set of experiments are shown in Table 1, and the trends are plotted and shown in Fig.2. The results indicate that the MRR increased with an increase in the applied voltage (Fig.2) due to the increased thermal input leading to increased sparking effect. On an average, the MRR was maximum at 30 wt. % electrolyte concentration level and almost same level of MRR was observed at the values of 65V and 10 wt. % concentration.

Another interesting phenomenon was observed regarding the wire breakage especially when wire was kept in touch with the work material; a slight tension on the wire led to its breakage beyond 55 V (for the electrolyte concentrations of 20 and 30 wt.% of KOH). In case of working at lower electrolyte concentrations (10 wt. %), the wire breakage occurred at around 70 V. This increase in life of the wire at lower electrolyte concentrations could be due to the reason that the formation of bubbles at lower concentration is less and intensity of sparking is also less when compared to the higher concentration, which is evident from the Table 1. The MRR achieved at an applied voltage of 55V with 30 wt.% concentration electrolyte was still higher than the MRR at 10 wt.% concentration at 65 V, hence the wire breakage which could be seen after 55 V using 20 wt.% and 30 wt.% KOH was seen much later while using the 10 wt.% KOH after 65V. As the depth of the wire in the electrolyte increased, the length of the spark also increased, which can also be seen as a reason for the breakage of wire at the same voltage at which the machining took place. In this condition, the spark length was equal to the width of the workpiece (i.e. machining in the slot was taking place due to the capillary action). Excess voltage, excess tension in the wire, spark length of the wire and concentration of the electrolyte were the most likely factors affecting the wire breakage.

Table 1 Average MRR at different electrolyte concentrations and voltages

Applied voltage (V)	MRR (mg) at 10 wt.% electrolyte concentration	MRR (mg) at 20 wt.% electrolyte concentration	MRR (mg) at 30 wt.% electrolyte concentration
35	0.02	0.10	0.37
40	0.03	0.28	0.58
45	0.04	0.95	0.62
50	0.38	1.31	1.81
55	0.67	1.61	2.56
60	1.47	Wire breakage observed at applied voltage settings	
65	2.23		

It was also observed that the cutting channel length needed to be constantly maintained. In these experiements, the wire started cutting the workpiece from the bottom to top (Fig.4); during the experiments, even when the electrolyte level fell below 1 mm in relation to the wire, still the slot cutting took place, which was due to the capillary action (Fig.4). This occurred since the electrolyte got sucked through the already cut channel and fine sparking was evidenced as a result of this action. To maintain continous spark in the channel the workpiece needs had to be in contact with the electrolyte, the velocity of the workpiece had to be selected in such a way that the wire did not submerge into the electrolyte. The advantage of cutting from down to top was high, since the spark length of the wire is directly proportional to the thickness of the workpiece.

As seen in Table 1, the MRR increased with an increase in the applied voltage. It was observed that the wire breakage, took place beyond 55 V for the electrolyte concentration of 20 wt. % and 30 wt. %, whereas the wire continued to work at higher concentrations beyond the 55V values for lower electrolyte concentrations of 10 wt. %. The intensity of sparking observed was also comparitively less at lower concentrations than higher concentration (20 wt. % and 30 wt. %), this partially increased the life of the wire.

3.1. Material removal rate (MRR)

Material removal rate was measured in mg/5 min. Through the fig.2 it is clearly seen that, with an increase in the applied voltage, there was an increase in the MRR; while, when comparing the MRR between different electrolyte concentrations, it was seen that an increase in MRR took place after 40V for 30 wt. % and 20 wt. % of electrolyte concentrations. Considerable increase in MRR was observed after 45V for 10 wt. % concentration. The highest MRR value of 12.9 mg/5min was observed at 30 wt. % concentration and almost same results (12.5 mg/5min) were observed at the value of 10 wt. % KOH concentration.

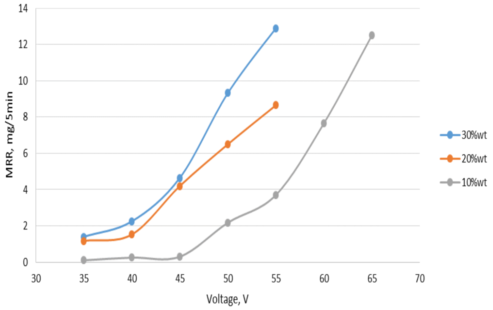

Fig.2 Material removal rate at various applied voltages and varied electrolyte concentrations.

3.2. Width of cut (WOC)

The width of cut at different concentrations and at different voltages is shown in fig.3 and Table 2. At 10 wt. % concentration and 40 V setting, the minimum width of cut was observed (value = 0.227 mm). The width further increased with an increase in the applied voltage. The highest width of cut of 0.412 mm was achieved at 65V. At 20 wt. % electrolyte concentration, the minimum width was observed (value = 0.275 mm at 35V) and an average of 0.3 mm cut was observed with no considerable increase in width of cut with the further increase in values of the applied voltage. At 30 wt. % electrolyte concentration, the trend of increase in the width of cut with an increase in the applied voltage was observed from minimum width 0.251 mm at 35 V to the maximum width of 0.33 mm at 55V.

Table 2 Average WOC at different electrolyte concentration and voltages

Applied voltage (V)	MRR (mg) at 10 wt.% (electrolyte concentration)	MRR (mg) at 20 wt.% (electrolyte concentration)	MRR (mg) at 30 wt.% (electrolyte concentration)
35	0.264	0.275	0.251
40	0.227	0.307	0.271
45	0.274	0.285	0.296
50	0.32	0.302	0.303
55	0.327	0.298	0.33
60	0.32	Wire breakage observed at applied voltage settings	
65	0.412		

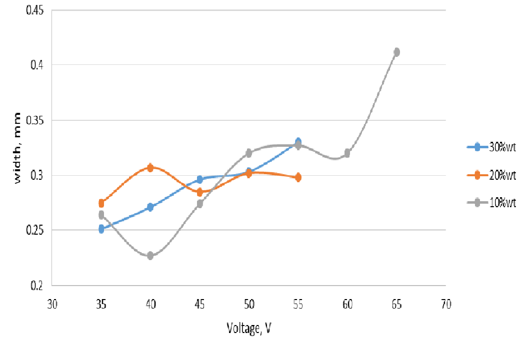

Fig.3 Width of cut at various applied voltages and varied electrolyte concentrations.

3.3. Length of cut (LOC)

The fig.4 and Table 3 illustrates the graph between the length of cut at different voltages and electrolyte concentrations. The longest cut observed was 8.8 mm (with V = 55 V. electrolyte concentration = 30 wt. % and width of cut = 0.316 mm) for the slot shown in figure 5. The 30 wt.% curve is almost horizontal and sieged to increase at same rate; hence, at higher concentration and at higher voltages workpiece feed needs to be higher. At 20 wt.% concentration the considerable increase in the length was observed beyond 40V and the highest achieved length in these conditions was 8.65 mm. At 10 wt.% concentration the increase in the length of cut was observed beyond 45V upto

65V. The highest observed length of cut observed was 6.202 mm at 65 V (for 10 wt.% concentration).

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Table 3 Average LOC at different electrolyte concentration and voltages

Applied voltage (V)	MRR (mg) at 10 wt.% (electrolyte concentration)	MRR (mg) at wt.% (electrolyte concentration)	MRR (mg) at 30 wt.% (electrolyte concentration)
35	0.206	0.668	1.49
40	0.343	1.276	3.79
45	0.475	4.079	6.424
50	1.654	6.409	8.363
55	2.9145	8.1515	8.75
60	4.937	Wire breakage observed at applied voltage settings	
65	6.202		

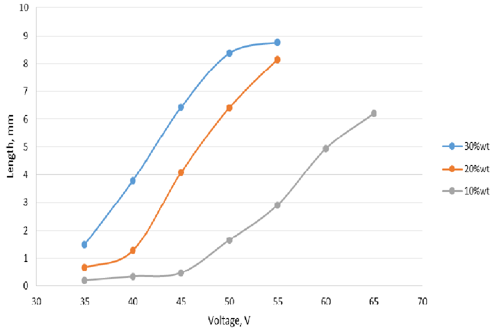

Fig.4 Length of cut at various applied voltages and varied electrolyte concentrations.

The images obtained through the digital optical microscope (make: "GAOSUO, magnification upto 500X and focus range from 0 to 40 mm) are indicted in the fig.5, which shows the maximum length of cut (8.8 mm) obtained at 55 V (at 30 wt.% concentration). The kerf width was considerably small and the heat affected zone was also not predominant and the overall finish appeared smooth.

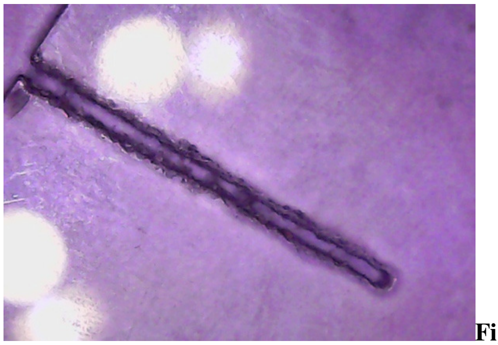

Fig. 5 Obtained slots (average width 0.316 mm and length 8.8 mm (at 55V, 30 wt. % KOH)

The slots upto a length of 8.8 mm were successfully cut using this method. Cutting of longer length slots requires increase in the work travel design and chamber height (i.e, providing longer stands). The average slot-widths produced were 0.29 mm.

The fig.6 shows the sparking taking place at an height slightly above the electrolyte surface. The slight increase in level of the sparking is mainly attributed to the capiliary action of the electrolyte, getting sucked through the already cut fine slot.

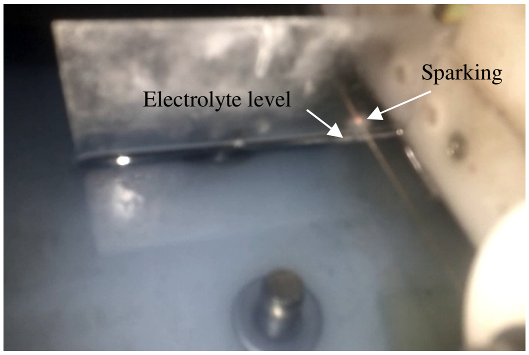

Fig. 6 Sparking occuring at some height above the electrolyte surface.

4. CONCLUSION

The WECDM is an attractive and economical process for machining non conducting and brittle materials. The paper incidates some initial findings on the in-house fabricated set-up, designed for fine slot cutting applications on borosilicate glass slides. The average width of the slots achieved was 0.29 mm, using a wire diamter of 0.2 mm zinc diffused brass wire. The effect of workpiece feed (0.08 mm/min) on applied voltages ranging from 35-70 V and electrolyte concentrations (ranging from 10-30 wt. % of KOH) have been demonstrated. The general finding was that the MRR increased with an increase in the applied voltage and with an increase in the electrolyte concentration. It is found that the wire breakage was more at higher voltages and concentration levels (20-30 wt.%). The interesting phenomenon on wire breakage and capilliary action have been illustrated in the paper, along with the digital optical microscopic images of the obtained specimens.

5. REFERENCES

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