Research and Developments in Wire Electrical Discharge Machining (WEDM): A State of Art Review

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***Abstract*– Wire electrical discharge machining (WEDM) is being widely used for a long time for machining conductive work materials which are difficult to be machined by the main stream machining processes. WEDM has evolved from a simple means of making tools and dies to the best alternative of producing micro scale parts. This could be achieved with high degree of dimensional accuracy and surface finish. This paper reviews the comprehensive history of WEDM process and its parameters, performance of measures and applications. The review of research literature focuses on machining of metal matrix composite (MMC) by WEDM and the possible trends for future research in this area.**

***Keywords*- WEDM, MRR, Surface roughness, Kerf, Al-alloy, MMC.**

I. INTRODUCTION

The use of traditional machining to machine new materials of high hardness and *toughness* or hard composite materials causes serious tool wear. These materials are difficult to be machined by conventional manufacturing techniques such as milling, drilling, and turning etc. Hence non traditional machining processes such as electro chemical machining (ECM), ultrasonic machining, and electro discharge machining (EDM) are employed. Wire electrical discharge machine (WEDM) is a special form of the traditional EDM. The WEDM process can be successfully employed to machine electrically conductive parts irrespective of their hardness, shape and toughness [1-2].

II. WEDM

A. Working Principle of WEDM

In the year 1770 English scientist Joseph Priestly discovered the erosive effects of electric discharges. Erosion was caused by intermittent arc discharges occurring in air between the two electrodes and the work piece when connected to DC power supply. This was also called arc machining or spark machining. Two Russian scientists BR Lazarenko and LI Lazaranko carried out the pioneering work on EDM [3]. The wire electrical discharge machining is a special form of traditional EDM process in which the continuously moving thin wire of electrically conductive material works as an electrode. The material is removed by a series of discrete discharges occurring between the wire electrode and the work piece material in the presence of dielectric fluid. The material erosion mechanism is based on thermo electric model wherein electrical energy turns into thermal energy through series of electric sparks. This generates a plasma channel during the pulse on time and raises the temperature as high as 200000C [4], which initializes the melting and evaporation of both work piece and wire electrode. When the pulse is turned off, plasma channel breaks down and circulating dielectric fluid flushes out molten material in the form of microscopic debris. This action is repeated hundreds of thousands times each second during WEDM processing. This removes material from the work piece in shape opposite of the wire [5-6].

As the material removal per discharge is very small, discharges should occur at high frequencies (103-106Hz). For every pulse, discharge occurs at a single location. As a result a small crater is generated both on the wire electrode and workpiece surface. The figure 1 and 2 represents the WEDM process. The electrically conductive workpiece is mounted on the machine table. The machine tool is in the form of a continued moving wire which is wound on two wire reels called supply reel and take up reel. A continuous stream of dielectric fluid is fed to the machining zone. The wire is separated by certain thickness of dielectric fluid in the gap as shown in figure 2. There is no contact between workpiece and the wire (tool) and therefore it eliminates the mechanical stresses developed during the machining. The work is mounted on CNC work table which can be moved in 'x' and 'y' direction according to the cut desired. The complex two dimensional shapes can be cut on the workpiece by controlled movement of the x-y work table [7]. The thin wire is fed continuously through the workpiece by a microprocessor. This enables the parts of complex shapes to be machined with extra ordinary high accuracy. The microprocessor also continuously

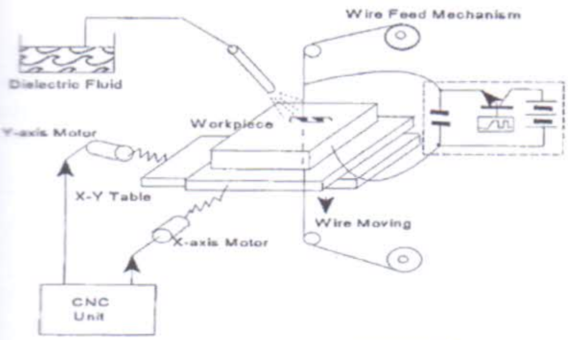


Fig 1 Schematic diagram of WEDM [7]

maintains the gap between the wire and the workpiece. The wire makes several machining passes along the profile to be machined.

This is required to attain the desired dimensional accuracy and the surface quality. The high frequency electrical pulses generated by the electronic unit of the machine tool are fed to the running wire through the tungsten carbide contacts.

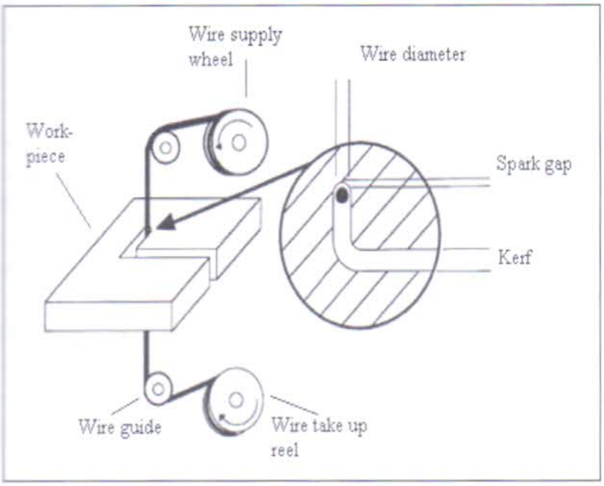


Fig 2. Details of WEDM cutting gap [7]

The dielectric fluid supply can be regulated with the help of a pump. The wire tension can be adjusted with its mechanism. Loose wire or insufficient wire tension gives rise to vibrations hence rough surface generated with larger size kerf width.

B. Process Parameters of WEDM

The process parameters can be broadly divided into two categories i.e. electrical and non electrical parameters.

1)Electrical Parameters: The major electrical parameters are as follows-

Discharge voltage: It is related to spark gap and breakdown strength of the dielectric fluid. Higher voltage setting increases the gap thereby improving the flushing conditions.

Peak current: It is the amount of power used in the discharge and forms the most significant parameter. Higher peak current is applied during the roughing operation.

Pulse duration: It is also referred as pulse on time. The material removal rate (MRR) depends upon the amount of energy applied during the pulse duration [8].

Pulse interval: It is also referred as pulse off time. This mainly affects the machining speed. Shorter interval results in faster machining operation but too short pulse interval will lead to erratic cycling. Pulse interval must be greater than the deionization time to prevent the sparking at one point [9].

Electrode gap: This is set by servo mechanism and is designed to respond well to the average gap voltage [10].

Electrode polarity: This may be positive or negative but modern power supplies insert an opposite polarity "swing pulse" at fixed intervals. This prevents the arcing. A typical ratio is one swing pulse for every 15 standard pulses [1].

Pulse wave form: This is generally rectangular but other forms of pulses also have been developed. A trapezoidal form pulse helps in reducing the tool wear [11].

2) Non Electrical Parameters: The non electrical parameters are flushing of dielectric fluid, workpiece rotation and the electrode rotation.

Flushing pressure of dielectric fluid affects the surface roughness (SR) and tool wear rate (TWR) [12-14]. The flushing pressure also influences the crack density and recast layer [13].

Workpiece rotatory motion improves the circulation of the dielectric fluid in the spark gap. Also it improves the temperature distribution of the work piece, yielding better surface finish and MRR [15]. The improvement in MRR and SR has also been reported due to effective gap flushing caused by electrode rotation [16-18].

C. Performance Measures

The performance measures are material removal rate, surface roughness, kerf width and tool wear rate (TWR). In MRR research, the material removed mechanism and methods of improving MRR have been reported by various researchers.The research work on tool wearing process methods of improving the TWR has been reported by [25-27]. The kerf and MRR are highly influenced by open circuit voltage and pulse duration [28]. The surface roughness is investigated on DC53 die steel and the significant variables found to be pulse on time and pulse peak current. The surface roughness increased with increase in pulse on time and pulse peak current [29].

D. Applications of WEDM

The WEDM is a suitable machining option in meeting the demands of today's modern applications. It has been commonly used in aerospace, automotive, mold, tool and die industries. WEDM applications are also found in medical, dental and jewellery industries [30].

III. Research In WEDM On Materials Machining

Gato and Iuliano [31] performed WEDM tests on two composite materials i.e. 15% SiC_w/2009 Al-alloy composite and 20% SiC_p/ 2009 Al-alloy composite. The chemical composition of the matrix metal is shown in table1. The machining rates of both composites were found to be equal. The surface roughness of 15% SiC_w/2009Al-alloy composite is found to be less than that of 20% SiC_p/ 2009 Al-alloy composite.

TABLE 1
Chemical composition of the matrix metal

Metal	Cu	Mg	Si	Al
Al 2009	3.9	1.5	0.25	balance

The machining rates of the composites are shown in table 2.

TABLE 2
Cutting rate of 15% SiC_w/Al alloy and 20% SiC_p/Al alloy

Cutting number	Machining	15% SiC_w/ Al alloy	20% SiC_p/ Al alloy
1	Roughing	5.2 – 5.6	5.2
2	Finishing	14.2	14.2
3	Finishing	17.7	17.7

Rozenek et. al [32] experimentally investigated the effects of machining parameters like discharge current pulse on time, pulse off time and the voltage on machining feed rate and surface roughness in machining the metal matrix composites, $AlSi_7Mg/SiC$ and $AlSi_7Mg/Al_2O_3$. The feed rate and surface roughness followed the increasing trend with increasing discharge energy. The maximum cutting speed of composites was found approximately 3 times and 6.5 times lower than the cutting speed for Al-alloy.

Guo et.al [33] studied in the shaping particles reinforced material using WEDM. The material for machining was metal matrix composite (MMC) of 20% Al_2O_3 in 6061 Al-alloy. The process parameters were at four levels as shown in table 3.

TABLE 3
Factors and levels

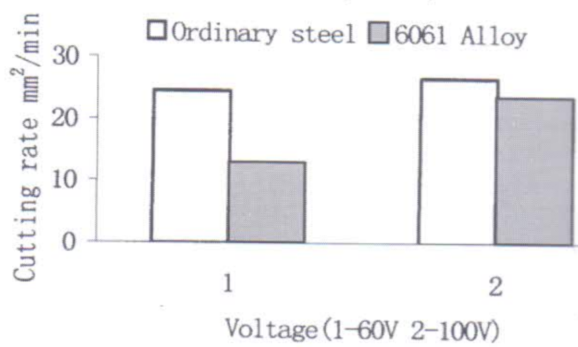
Factors	Levels 1	2	3	4
Pulse duration (A)	5μs	10μs	20μs	40μs
Pulse interval (B)	1μs	2μs	3μs	4μs
Voltage (C)	60V	100V	60V	100V
Current (D)	0.5A	1.5A	2.5A	3.5A

The experimental study was according to L16 orthogonal design using four process parameters as shown in table 4.

TABLE 4
The analysis of orthogonal experiment

Experiment series	Pulse duration (A)	Pulse interval (B)	Voltage (C)	Current (D)	Cutting Rate (mm^3/min)
1	1	1	1	1	0
2	1	2	2	2	5.55
3	1	3	3	3	0
4	1	4	4	4	11.4
5	2	1	2	3	0
6	2	2	1	4	17.41
7	2	3	4	1	11.96
8	2	4	3	2	7.77
9	3	1	3	4	22.28
10	3	2	4	3	47.56
11	3	3	1	2	18.18
12	3	4	2	1	12.04
13	4	1	4	2	41.56
14	4	2	3	1	10.89
15	4	3	2	4	56.32
16	4	4	1	3	24.37
K1	16.95	63.48	59.96	34.89	T=286.93
K2	37.40	81.41	73.91	73.06	
K3	100.06	86.46	40.94	71.93	
K4	133.14	55.58	112.48	107.41	
R	116.19	30.88	85.49	72.52	

The electrical parameters were found to have insignificant effect on the surface roughness but important effect on cutting rate. A comparative study was also made on machining the ordinary steel and Al6061 MMC. The effect of voltage on cutting speed and surface roughness are as shown in figure3 and 4 respectively.



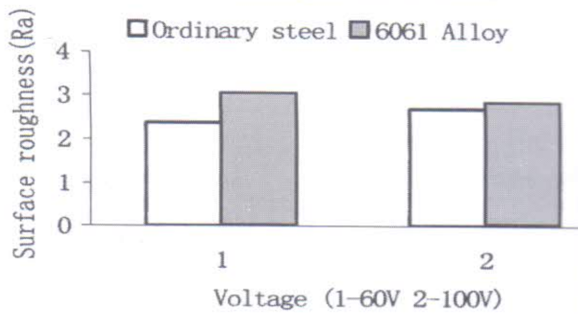


Fig. 4 : The effect of the voltage on the surface roughness [33].

The use of low energy resulted in wire breakage. The high machining efficiency can be attained with high pulse duration, high voltage, large machining current and at proper pulse interval.

Yan et. al [34] investigated the machining of Al_2O_{3P}/6061 Al-composite on WEDM with the reinforcement of 10 and 20 volume %. The machining performance was evaluated with pulse on time as machining parameter variable. The cutting speed is found to be highest for matrix alloy Al-6061 than the Al_2O_{3P}/6061 Al-alloy composites. Also both composites yielded similar cutting speed on WEDM. The increase in volume fraction of reinforcement resulted in wire breakage. The machined surface of 10 volume % Al_2O_{3P}/6061 Al- composite is smoother than that of 20 volume % Al_2O_{3P}/6061 Al-composite. The width of slit of cut for 20 volume % Al_2O_{3P}/6061 Al-composite was found to be much narrower than that of the metal matrix 6061 Al-alloy and the 10 volume % Al_2O_{3P}/6061 Al-composite.

Patil and Brahmankar [35] investigated the Al/SiC_P composite with WEDM. The various controlled parameters pulse on time, pulse off time, ignition pulse current, wire speed, wire tension and flushing pressure were studied on cutting speed and surface finish. A comparative study revealed that cutting speed is higher for unreinforced alloy than to the composite.

Manna and Bhattacharya [36] experimentally investigated the parameter settings in WEDM machining of Al/SiC-MMC. The open gap voltage was found as most significant influencing machining parameter for the MRR with pulse on period at the second place. The surface roughness was most influenced by wire tension and wire feed rate.

Saha et. al [37] worked on machinability of 5 volume % TiC/Fe in situ MMC on WEDM. The input parameters were pulse on time, pulse off time, wire feed rate and average gap voltage. The measures of performance were cutting speed and kerf width. They found that an increase in average gap voltage results in decrease of the cutting speed but increase in the kerf width.

Liu et. al [38] studied the behavior of wire electrical discharge machining of Al_2O_{3P}/6061 Al-composite. MRR was evaluated in light of machining voltage, current, pulse duration and electrolyte concentration. The comparative study was made on WEDM and electro chemical machining (ECM) under different conditions. It was found that the conditions of high current or high concentrations of electrolyte would promote the ECM activity and result in high MRR. Orthogonal analysis was applied and results suggested that for achieving the highest MRR, the applied current is most significant factor. This outcome was supported by experimental results.

IV. DISCUSSION AND FUTURE TRENDS

WEDM has replaced the conventional means of machining ceramics by ultrasonic machining which damages the surface integrity of components. Most of the published work belongs to silicon carbide reinforced MMCs and not much work is reported with Al_2O_3. Many MMCs are yet to be explored for suitable electrode material. Wire breakage during machining of MMCs is very common problem. Also this causes inaccuracy in the components. The traditional research purpose was not only to improve machining efficiency, but also to prevent from wire rupture during the process. Therefore one possible new WEDM challenge and future work area will be towards attaining higher machining efficiency with low wire consumption and frequency of wire breakage.

V. CONCLUDING REMARKS

WEDM is a well established non conventional material removal process. It has been commonly applied for the machining and micro machining of parts with intricate shapes and varying hardness requiring high profile accuracy. The developments of newer and more exotic materials have challenged the viability of the WEDM process in the future manufacturing environments.

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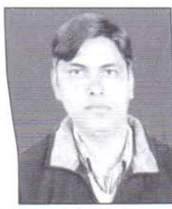

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