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A Review on Travelling Wire Electro Chemical Discharge Machining

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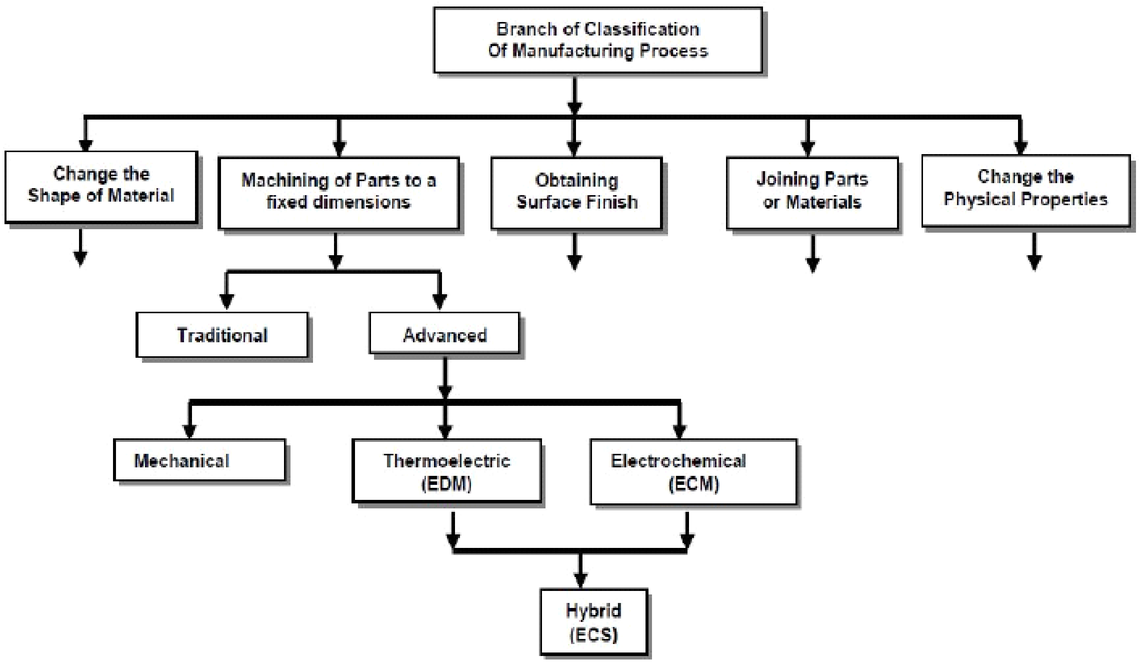
Abstract: *In today's time of advanced technology micro finish of the components became a need of the cutting process. On the other hand optimization of the process is also equally important. There are a number of cutting processes for various materials whether conductive of non-conductive are available out of those one such process is TW-ECDM (Hybrid machining process utilizing properties of ECM and TW-EDM) which is mainly used for cutting of non-conductive materials. In this paper a review of various researches has been concluded to find the parametric optimization of the TW-ECDM process parameters. This paper is focussed on the review study of the past researches done till now in field of TW-ECDM. Based upon the past researches a pilot experiment has been performed and some of the results have been sorted out.*
Keywords: TWECDM, Hybrid Machining, Micro Machining, Non-traditional Machining, Advanced Machining

I. INTRODUCTION

Engineering is moving the world towards the advancement and researches in every field of science is making those researches to be tomorrow's need. TW-ECDM is also such of a micro machining research technique which will be need of super finished components especially non-conductive. Non conventional machining has taken place of conventional machining process in various terms and now hybrid machining(i.e combinations of two or more than two machining processes) is becoming area of interest now a days. Vinayak et.al.[1] given a general classification of manufacturing process as shown below.



Concentrating specially on the development of this particular hybrid machining process we found that Erosion of metal due to electric sparks was very first investigated by Sir Joseph Prisetly but it was not used for the purpose of machining. The construction of first spark erosion machining and a controlled method of metal machining process was later developed by Lazarenko(Russia). The first British patent was granted to Rudder off for developing the electro spark machine. Later, Lazarenko provided a new dimension to the manufacturing process with the introduction of controlled electrical spark machining system called as electrical discharge machining(EDM).In late seventies, there search works have also been made in the development of WEDM for cutting and machining very hard conducting materials to generate the complicated machining surface of the job.

1.1 History: ECDM Electro Chemical Discharge machining method firstly investigated by Kelogg in 1950 by studying the effects on molten state. Hickling and Ingram in1964 introduced a new name for the process as

"Contact Glow Discharge Electrolysis(CDGE)". Drilling of micro holes in glass was demonstrated by Kurafuji and Suda(1968). Electrolyte composition was also discussed. "Discharge machining of non-conductors"(DMNC) came in light by Cook et al.in 1973. Wire electrochemical discharge machining(WECDM) name was given by Tsuchiya et al.[2]in 1985 when a wire was used as tool electrode.

1.2 Basic Components of TW-ECDM: As TW-ECDM is similar to ECDM except the tool the basic principle of both TW-ECDM and ECDM is same. TW-ECDM generally employs a continuously travelling wire electrode to slice the work piece. Tool Electrode(Wire), Auxiliary electrode(usually graphite), a non-conducting work-piece material, electrolyte(titrated), Stepper motors(controlling wire feed rate and work-piece motion), microstepping devices, job fixture and software(controlling the stepper motors) etc. are the main components of the TW-ECDM setup. Various researchers have used different types of setups but the basic components are same. A general 3-D model of TW-ECDM setup been shown as below:

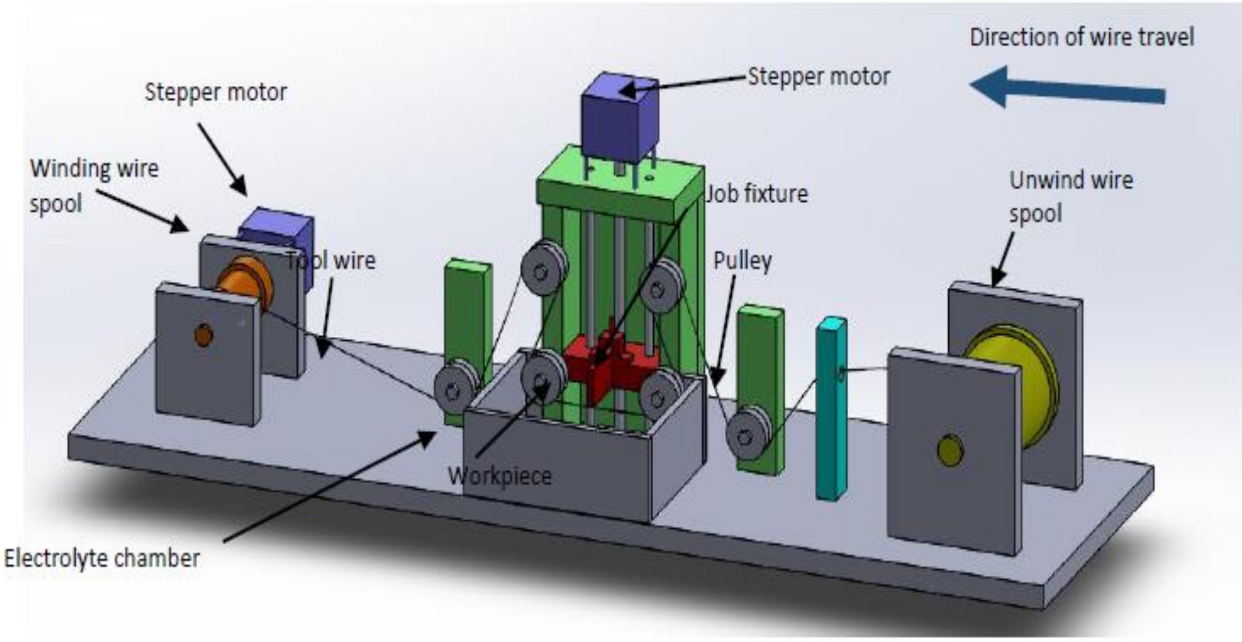


Fig 1: A 3-D Catia model of TWECDM setup.

II. Machining Mechanism

The two electrodes used in the process used *i.e* Tool electrode and auxiliary electrode are connected to DC power source. Both the electrodes are dipped in electrolyte. Auxiliary electrode is generally 100 times more in diameter then the tool electrode. As the voltage gradually increased formation of bubbles on tool electrode periphery can be seen. This bubble formation may be due to joule heating effect giving rise to local temperature. Hydrogen bubbles are formed at tool electrode and oxygen bubbles at auxiliary electrode. On further gradual increment of voltage more bubbles at higher rate starts generating. At critical voltage(30 V) sparking can be seen[3]. The workpiece is to be placed near the vicinity of spark region to take its advantage. Hence material removal process starts via combined effect of melting, vaporisation, chemical reaction and cavitation erosion[4] as the sparking taking place in electrolyte chamber continuous heating problem as in LBM is not a problem in this process[5].
Variable input parameters to be considered in ECDM process are pulsed and non pulsed Voltage, type of electrolyte, concentration of electrolyte, shape, size and material of the electrodes, electrode gap, temperature[6], wire feed rate, wire tension, polarity(direct and reversed)[2] etc.
Machining can be done both by direct polarity and reverse polarity. Vinayak et als[1] given a comparison of machining done by both the polarities as below:

Table1: Comparison of machining by Direct and Reverse polarity.

	Direct Polarity	Reverse Polarity
Cathode	Tool electrode	Auxiliary electrode
Anode	Auxiliary electrode	Tool electrode
Surface Finish	Better than Reverse polarity	Good
Gas generated	Hydrogen	Oxygen
Material Removal Rate	Good	Better than direct polarity

III. Merits and Demerits of TW-ECDM

3.1Merits are as follows:

(i) Electrically non-conductive, hard & brittle materials (glass, ceramics, FRP, quartz) can be machined very easily and precisely.
(ii) Slot cutting on non-conductive work piece can easily be done.
(iii) Profile cutting operation on hard non-conducting materials can be done.
(iv) Low machining cost and precise cutting.

3.2Demerits of TW-ECDM are as follows:

(i) Application is limited up-to non-conducting materials only.
(ii) High over cut occurs due to side sparking.
(iii) Surface finish is poor(if optimized parameters are not taken in consideration).
(iv) Low material removal rate.
(v) Wire breakage problem arises on increasing voltage after a certain limits.

IV. Applications

The TW-ECDM process has great potential for machining non-conducting engineering materials irrespective of physical and metallurgical properties of the material. Hence materials like ceramics, FRP, alumina, composites, glass, diamond, ruby etc. can be machined using appropriate parameters. The TW-ECDM can also be used in case of micro-machining operation. It can be used for grooving on electrically non-conducting materials.

V. Literature Survey

Y.P. Singh et al.[4] fabricated a TW-ECSM set-up for machining piezoelectric PZT ceramic. Based upon his investigations he proposed that MRR (material removal rate) increases with increase in voltage and increase in concentration up to 20 wt.% (in actual 20wt.%). Beyond this concentration MRR starts decreasing. Average over cut in range of 0.3-0.8mm(with average of 0.67mm) with wire of 0.5mm diameter as tool is observed. Evidences of melting were also observed. Large cracking sometimes observed when machining is done at higher voltages but no such cracking at lower voltages.

Bhattacharyya et al.[6] developed a ECDM machining set-up using modular mechatronic features for experimental investigations on aluminium oxide ceramic workpiece. Pulsed DC voltage(70-90)V electrolyte concentration(20-30)%, NaOH as electrolyte were taken as process parameters to investigate material removal rate(MRR) and overcut(OC). He observed for higher MRR high electrolyte concentration wit high voltage is to be used but OC also gets increased. So for more accurate and precise cutting(i.e low over cut) low concentration electrolyte has been suggested. He prosed 80V and 25% concentration electrolyte to be the optimized condition for higher MRR and better dimensional accuracy. Tool with taper side wall and flat front tip has been best suggested for controlled machining.

Tandon et al.[5] approached electrochemical spark machining (ECSM) for cutting and drilling hole in composites(FRP) on place of conventional drilling method. Kevlar- fiber-epoxy and Glass-fiber-epoxy material were machined using copper as tool material. With increase in voltage MRR(Material Removal rate), TWR(Tool Wear Rate), OC(Over Cut) had found to increase but RWR(Relative Tool Wear Rate) decreased in case of cutting glass epoxy composite. In case of drilling of holes in this material MRR, TWR & OC was increase in electrolyte conductivity and decrease with increase in tool diameter.

Basak, et al.[7] proposed a theoretical model to explain spark generation during ECDM process. When the machined material is electrically conducting, the process is usually termed 'electrochemical arc machining' (ECAM), whereas for non-conducting work materials it is termed 'electrochemical discharge machining' (ECDM).Although in both cases electrical discharge takes place through the electrolyte and plays a critical role, the mechanism of spark generation has not been investigated adequately.

Jain et al.[9] conducted a number of experiments for machining of electrically non-conducting materials like ceramics, composites, cermet etc. using electro chemical spark machining(ECDM) process. He concluded that machining depth increases with rotation of tool. When the machining depth 10 was maximum, then orbital rotational tool was used. Geometrical parameters and surface integrity of the machine surface had been studied and resulted that the material removal process that was basically thermal phenomenon.

Kulkarni et al.[11] performed an experimental study to investigate the discharge mechanisms in ECDM. His work was to measure the time varying current during this process to reveal the basic mechanisms of temperature rise and

MRR. Experiment was performed at 155 volt and 3% HCL as the electrolyte in three cases where 1% HCL is used in different work piece such as silicon, brass, copper and tantalum. Hydrogen gas bubbles were formed at a highly conducting spark channel for a very short duration of time is shown.

Peng, and Liao found[14], in the TW-ECDM, the apparent spark release with proper amount of bubble around the wire demands a voltage higher than the transition voltage. Only when the voltage is larger than the transition voltage, the relationship between the voltage and current can be positively dependent. The electrochemical discharge machining (ECDM) has been proved to be a potential process for the machining of high-strength non-conductive materials. Traveling wire electrochemical discharge machining (TW-ECDM), a newly developed technology, is used to slice the small size (10–30mm diameter) optical glass and quartz bars. The electrical–thermal etching effect and its feasibility are investigated. The pulsed dc power proves better spark stability and more spark energy release proportion than constant dc power. The input power is modulated to obtain the appropriate frequencies and duty factors for machining glass and quartz materials. The ion translation rate, the electrolyte immersing depth and the concentration of the alkali are found to be the dominant factors of bubbles reaction.

Yang, et al[16] showed experimental result of TW-ECDM machining operation. It was proposed that materials with high hardness, brittleness, strength and electrical insulation, which are difficult-to-cut, can be machined. In ECDM, the electrochemical reaction produces hydrogen bubbles, which accumulate around the cathode. A thin gas layer forms on the surface of the electrode and isolates the electrode from the electrolyte. When a voltage that exceeds the critical voltage is applied, continuous discharge occurs. The material near the electrode is removed by the discharge erosion and chemical etching. The use of WECDM to cut electrically insulating materials has only recently been investigated. However, the breakdown of the gas in the bubbles and the vibration of the wire in WECDM strongly affect the shape accuracy. Their work aims to improve the over cut quality by adding Sic abrasive to the electrolyte. A mechanism that combines discharge, chemical etching and abrasive cutting is studied.

Doloi et al.[17] investigated into travelling wire electrochemical discharge machining of non-conducting materials such as hylum based fibre reinforced composite. TW-ECDM process is a complex combination of TWEDM and ECM. This process can also be used for micro cutting and grooving on non conducting materials. They set up the machine systems and developed the system to investigate the parametric influences on MRR and OC.

Han, et al.[18] proposed a new method to improve the surface integrity and spark discharge distribution of wire electrochemical discharge machining (WECDM) process by roughening the wire tool surface. Limitation of the conventional WECDM processes was the low cutting depth because of the low spark discharge occurrence on the wire surface. Preliminary investigation demonstrated that using the conventional wire with fine surface roughness (Ra=0.14 .m) the machining with 1.1 mm cutting depth was not available because of serious lack of spark distribution around the wire surface. They introduced that wire surface roughening is proposed to enhance spark discharge distribution over the tool surface and lower the working voltage. Side insulation of the wire is also introduced to minimize the reactive wire surface area.

Adhikary et al.[19] found that Electrochemical spark machining (ECSM) process can be successfully applied for cutting of quartz using a controlled feed and a wedge edged tool. First time Contrary to the common belief that only cathode works as a tool, both cathode and anode have been used as a tool, i.e. ECSM with reverse polarity (ECSM-WRP) as well as ECSM with direct polarity (ECSM-WDP) used for machining quartz plates. Deep crater on the anode (as a tool) and work piece interface were formed in case of ECSM-WRP because of chemical reaction. Chemical analysis of electrolyte solution after the ECSM experiments, also agrees with the feasibility of dissolution of quartz into solution due to chemical reaction. Cutting of quartz plate was seen at a faster rate with reverse polarity as compared to the direct polarity. On the other hand in reverse polarity overcut, tool wear and surface roughness noted more compared to that of the direct polarity machining. Magnified view of the machined surface also shows a difference in the mode of material removal in ECSMWDP and ECSMWRP. The cutting is possible even if we make auxiliary electrode of small size. In conclusion, experiments have revealed that cutting can be performed simultaneously at both the electrodes (anode and cathode) during ECSM.

Cao et al.[22] proposed that Micro-electrochemical discharge machining (ECDM) improves the machining of 3D micro-structures of glass. To minimize structures and obtain good surface microstructures, the effects of the electrolyte, the $Pulse_{(on)}$ and $Pulse_{(off)}$ time ratio, the voltage, the feed rate, the rotational speed, and the electrolyte concentration in the drilling and milling processes were studied. In ECDM, voltage is applied to generate a gas film and sparks on a tool electrode; however, high voltage produces poor machining resolution. To obtain a stable gas film over the whole surface of the tool at a low voltage, a new mechanical contact detector, based on a load cell, was used; the immersion depth of the tool electrode in the electrolyte was reduced as much as possible.

Fascio et al.[23] revealed that micro fabrication of Pyrex glass is one of the key processes in MEMS(micro electro mechanical system). A lots of applications are there which need glass and that because of its unique properties like its chemical resistance, transparency, low electrical and thermal conductivity or biocompatibility. As some examples can be mentioned micro-accelerometers, micro-reactors, micro-pumps and medical devices like sensors or drug delivery devices.

VI. Pilot Experiment

A pilot experiment has been run on borosilicate glass slit using zinc diffused brass wire a tool to just check the basic cutting process. The effect of work piece feed (0.08 mm/min) on applied voltages ranging from 35-70 V and electrolyte concentrations of 10-30 wt.% concentration of KOH have been demonstrated. The general finding was that the MRR and length of cut increased with an increase in applied voltage and increase in the electrolyte concentration. The width of cut on an average also increased at higher voltages and 30 % wt. concentration and 10 % wt. concentration, but at 20% almost same width of cut was obtained.

SLOT 1: V=35VOLTS
CONCENTRATION=30%
WOC = .29mm

SLOT 2: VOLTAGE = 38VOLTS
CONCENTRATION = 20%
WOC = .34mm

SLOT 3: VOLTAGE=40VOLTS
CONCENTRATION = 25%
WOC = .38 mm

VII. Conclusion

TWECDM is till date a experimental setup and no major industrial application till date has been discovered but a lots of work going on to find the appropriate application. From the past researchers study on development and improvement in the TW-ECDM process we can conclude that it is a very good machining method having precise cutting efficiency. The variation with input parameters on output parameters like surface finish width of cut(WOC) length of cut(LOC), wire breakage can be observed.

- Width of cut: increases on increasing (i)pulse on time (ii) electrolyte concentration, (iii) voltage. Wider cut is observed while using NaOH electrolyte instead of KOH. Also increased wire tension less WOC.
- Length of cut: increase with High voltage NaOH electrolyte increases MRR, increased voltage.
- Wire breakage generally occurs on increasing the voltage above a limit i.e. around 65V-70V

Still a lot of work is to be done in the field of this process. So by varying the parameters usage of different abrasive we can have more researches to come further specially in the field of medical sciences and electronics where micro parts are very much important.

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