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# TRENDS IN SURFACE MODIFICATION OF COLD WORK DIE STEEL USING ELECTRIC DISCHARGE MACHINING: A REVIEW

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*Abstract*— **Electric Discharge Machining (EDM) is became one of the most useful, effective, efficient and popular un-conventional machining process in the dies and tool manufacturing industries. It is also widely accepted machining process in Automobile and Aerospace industries to produce intricate and complex shapes irrespective of its hardness. EDM removes material through discrete electric discharge between tool (electrode) and work (both electrically conductive) in presence of dielectric medium with very small gap(about 0.025mm) between tool and work. Since last few years researchers started to explore possibilities and potential of Electric Discharge Machining for surface modification. Researchers have made efforts to create fresh and harder alloys surface on machined component for improve its working life and wear resistance. Wear is become one of the most stringent reason for reduce the life of metal forming dies, tools and many engineering components which have relative motion during operation. In this paper a review on the surface modification of various cold work die steels while machining with EDM using P/M electrode produce with various metal powders and by mixing various metal powders in dielectric has been carried out.**

*Keywords* — **EDM, SURFACE MODIFICATION, PMEDM, P/M ELECTRODE, MRR, TWR, SR**

## I. INTRODUCTION

Electro-discharge machining (EDM) was discovered in the year 1770 by English scientist Joseph Priestly because of erosive effect of electric discharge. In 1943, efforts were ended for the first period to machine diamonds and metals with electrical discharges by soviet scientists the Lazarenkos [1]. Electric Discharge Machining (EDM) is a thermo electric advanced machining Process, where electrical energy is used to generate spark between a tool and work and material is removed due to thermal energy of the spark [2]. The Heat generated due to spark has a capabilities to melt and vaporizes minute particles of work piece material, which are then flushed away from the gap by the continuously flushing dielectric fluid[3].Electrical discharge machine (EDM) is mainly used in die, tool and mould making industries for machining difficult-to-cut material. The various tool and die steels material with heat treated are became difficult-to-cut when machining with conventional machining process. EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis [4, 5]. Work material to be machined by EDM has to be electrically conductive. No a day we see the advancement of technology in every aspects, there is a continuously increasing demand for materials with surfaces that are able to withstand stringent applications. Hard and abrasion-resistant machined surface is a major requirement in the case of cutting tools, press tools, dies and punches as well as also in of aerospace mechanisms and structures because of weight and space limitations. Efforts are being made by no's of researchers to exploring various ways and techniques to hardening surface of work pieces while machining, with the aim of increasing their working life and wear resistance[1,2,4].

## II. WORKING PRINCIPLE OF EDM

Electric Discharge Machining (EDM) is categorized under thermoelectric advanced machining processes in which heat energy produced due to sparking between a tool and work, which used to removed materials from work. A very short duration spark is generated by maintaining narrowest gap between tool and work (both electrically conductive) with help of servo mechanism. The total cycle time is only a few micro seconds with a very high frequency of sparking. Frequency of sparking is high as thousands of sparks per second. The effect of spark is on very small area with a very high temperature (8000 ♂ C to 12000 ♂ C) capable of melting and partly vaporizing material of tool and works both in dielectric medium. Finally cavity produced is same as shape of tool [3, 4, 5, and 6].Working principle of EDM is shown in fig.1.

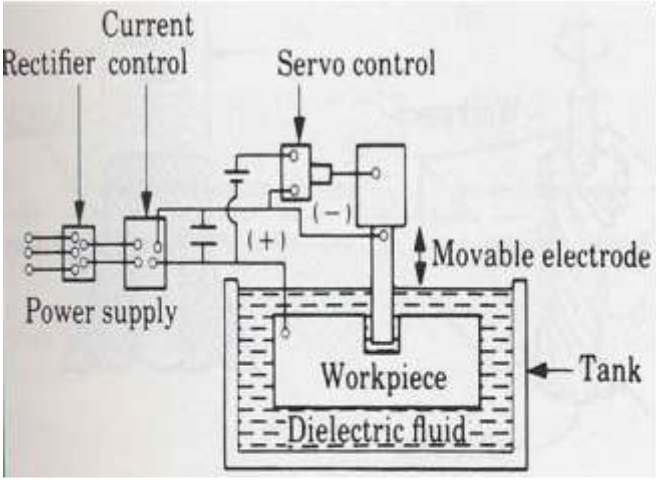


Fig. 1. Working Principle of EDM

## III. EDM PROCESS PARAMETERS

### 3.1 Discharge Voltage.

Discharge voltage in EDM is related to the spark gap and breakdown strength of the dielectric. Before current can flow, the open gap voltage increases until it has created an ionization path through the dielectric. Once the current starts to flow, voltage drops and stabilizes at the working gap level. The preset voltage determines the width of the spark gap between the leading edge of the electrode and work piece. Higher voltage settings increase the gap, which improves the flushing conditions [7].

### 3.2 Peak Current

This is the amount of power used in discharge machining, measured in units of amperage, and is the most important machining parameter in EDM. During each on-time pulse, the current increases until it reaches a preset level, which is expressed as the peak current. Higher currents will improve MRR, but at the cost of surface finish and tool wear.

### 3.3 Pulse on time & off time

Each cycle has an on-time and off-time that is expressed in units of microseconds. Since all the work is done during on-time, the duration of these pulses and the number of cycles per second (frequency) are important. Pulse on-time is commonly referred to as pulse duration and pulse off-time is called pulse interval. With longer pulse duration, more work piece material will be melted away.

### 3.4 Pulse wave form

The pulse shape is normally rectangular, but generators with other pulse shapes have also been developed. Using a generator which can produce trapezoidal pulses, Bruyn (1968) succeeded in reducing relative tool wear to very low values [8].

### 3.5 Polarity

The polarity of the electrode can be either positive or negative. In general, polarity is determined by experiments and is a matter of tool material, work material, current density and pulse length combinations.

### 3.6 Electrode gap

The tool servo-mechanism is of considerable importance in the efficient working of EDM, and its function is to control responsively the working gap to the set value. Mostly electro-mechanical (DC or stepper motors) and electro-hydraulic systems are used, and are normally designed to respond to average gap voltage. Gap width is not measurable directly, but can be inferred from the average gap voltage [9].

### 3.7 Type of dielectric flushing

Basic characteristics required of a dielectric in EDM are high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability. TWR and MRR are affected by the type of dielectric and the method of its flushing. The dielectric fluid is flushed through the spark gap to remove gaseous and solid debris during machining and to maintain the dielectric temperature well below its flash point. Flushing methods can be broadly divided into four categories – normal flow, reverse flow, jet flushing and immersion flushing [10].

### 3.8 Duty Cycle

Duty cycle is a percentage of the on-time relative to the total cycle time. Generally, the higher duty cycles mean increased cutting efficiency. Duty cycle is calculated in percentage by dividing the on-time by the total cycle time (on-time + off-time).

### 3.9 Frequency

Frequency is the number of cycles produced across the gap in one second. The higher the frequency, finer is the surface finish that can be obtained. The number of cycle per second increase, the length of the on-time decreases, Short on-times remove very little metal and create smaller craters. This produces a smoother surface finish with less thermal damage to the work piece. Frequency is calculated by dividing 1000 by the total cycle time (on-time + off-time) in microseconds.

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### 3.10 Average Current

Peak current is the maximum current available for each pulse from the power supply / generator. Average current is the average of the amperage in the spark gap measured over a complete cycle. It is calculated by multiplying peak current by duty cycle.
Average Current (amperes) = Duty Cycle (%) x Peak Current

## IV. REVIEW ON SURFACE MODIFICATION USING EDM

Since last decades efforts have been made by various researchers to use EDM as a surface treatment or an additive process. Researchers reported surface changes of various materials and process established itself in the various manufacturing industry [11]. Research carried out for surface modification using EDM may be divided in to two categories: Surface modified with help of P/M electrode (green, semi sintering or sintering powder metallurgy electrode) and surface modified by adding appropriate amount of metals powder in to dielectric (this process also known as a Powder Mixed Electric Discharge Machining - PMEDM)

### 4.1 Surface modification using P/M electrode

**Gangadhar et.al (1990)** carried out experimental work to study the transfer of metallic ingredients from P/M compacted tools with 10% tin and 90% copper on a steel surface for enhancement of modification on steel surface. They observed chemical, physical and metallurgical changes on steel surface after machining 3 min. They observed changes in ingredients and composition on steel surface due to machining with P/M electrode. Two important parameters pulse current and frequencies with levels 2.3, 5.3, 9.0, 13.0 and 18.0 A and 5, 10, 20, 40, and 80 KHz respectively considered for enhancement of modified surface with negative polarity[12].
**Samuel and Philip (1996),** tried to carry out comparative analysis of EDMed machined surface with machining by using conventional electrode and electrode produce with P/M Process. They conclude that P/M electrodes produce from electrolytic copper compact at 500 MPa with sintering temperature 850 ♂ C are technologically feasible in EDM . P/M electrodes are found to be more sensitive to pulse current and pulse duration than conventional solid electrodes [13].
**Shunmugan and Philip (1999),** used compact electrodes to enhance improvements in abrasive wear produce from tungsten carbide powder containing 40% WC and 60% Fe. They conclude that with WC-coated HSS tools during machining 20% to 50% reductions in cutting forces as well as 25% to 60% improvement in abrasive wear resistance [14].
**Aspinwall et. al (2001),** used P/M electrode produce form WC/Co for machining AISI H13 die steel on EDM.The effect of EDM parameters for surface modification while machining of AlSl HI3 tool steel and roll texturing of 2% Cr steel using partially sintered P/M electrodes, they conclude the effects of EDM parameters on the hardness and composition of the white layer. P/M electrode of WC/Co increased the surface hardness due to the presence of W, C and Co [15].
**Simao et.al (2002),** used powder metallurgy (P/M) green compact and sintered electrodes of TiC/WC/Co for the surface modification/alloying and combined electrical discharge texturing (EDT) of Sendzimir rolls, used for the production of stainless steel strip. They observed as the compacting pressure and sintering temperature for P/M tool preparation increased, the physical, electrical, micro structural, thermal and mechanical properties of the electrode change leading to higher Texturing performance [16].
**Wang et.al (2002)** studied surface modification of carbon steel by using EDM with the help of Ti or other compressed electrodes. The machining conditions they have used were discharge current of 2.2 to 10 A, pulse duration of 2 to 12 µs and duty factor of 5.88 %. From the experimental results they found that, surface of the layer is rich in Ti and the formed layer consists of 51 % TiC, 48 % Fe and remaining impurities [17].
**Mohri et al (1993).**carried out experimental work for enhancement of surface modification of carbon steel and aluminum using composite electrodes of copper, aluminum, tungsten carbide and titanium in hydrocarbon oil. It was revealed that there existed the electrode material in the work surface layer and the characteristics of the surface layer changed remarkably. These surfaces had less cracks and higher corrosion and wear resistance [18].
**Soni et al (1996)** conformed that change in surface chemical composition of the machined surface of HCHCr steel due to migration of material from electrode to work piece material. The experiments were conducted by varying discharge current and electrode rotation to study the effect of these parameters on alloying of tool and work piece surfaces. The investigation was made on variation of micro-hardness, depth of resolidified layer and heat affected zone [19].
**Tsunekawa et al (1994)** carried out surface modification of aluminum using powder compact electrode containing 64 % Ti and 36 % Al and found the formation of fine dendrite precipitates of titanium carbide. The electrode was connected to negative polarity and kerosene was used as the working fluid [20].
**Moro et. al (2003),** observed the surface modification phenomenon with EDM in the practical usage. They were prepared semi sintered TiC electrode at forming pressure of 98.1 MPa and temperature of 900 0C respectively. The EDM process parameters were discharge current of 8 A, pulse duration of 128 µs, duty factor of 5.9 % and time of the experiment is 16 minutes. They found that tool made of TiC electrodes extends its tool life in the cutting condition [21].
**Patowari et.al (2010)** used artificial neural network model in surface modification by EDM using tungsten (75%) and copper (25%) powder metallurgy sintered electrodes. The P/M electrodes were made at a compaction pressure of 120 to 300

MPa and sintering temperature of 700 to 9000C. Two output measures, material transfer rate and average layer thickness, was correlated with sintering temperatures for EDC process [22].

**Hwang et.al (2010)** describes the deposition of TiC coating layer on the surface of Nickel by EDC using multilayer electrode. The machining conditions they considered were open circuit voltage of 90V, pulse on time of 20, 80 and 150 µs and discharge current of 8, 12 and 20 A. They found that, carbon element with high concentration could increase the combination of Ti and carbon (C) to become TiC, enhance the surface hardness of the coated layer, decrease surface roughness of the coated layer and reduces the formation of micro cracks[23].

**Pantelis et al.(1998),** machined 0.4 % carbon steel with a tool electrode containing 70 % Fe and 30 % WC using both positive and negative polarity. The work surfaces were subjected to optical metallographic, SEM, EDS, X-ray diffraction analysis, surface roughness measurements and micro-hardness testing. It was concluded that EDM could become a useful and cheap alternative process for surface modification and major research efforts were required in this direction [24].

**Bai et al.(2006),** used distilled water and kerosene as dielectric media to carry out surface modification of super alloy Haynes 230 using Al-Mo composite electrode. Each sample was machined for 6 minutes. Distilled water gave higher hardness whereas kerosene gave better surface finish, finer surface morphology, thicker alloyed layer and slower oxidation rate. Current density at the negative electrode was higher than the positive electrode. They concluded that surface alloying effect was better in kerosene as compared to distilled water [25].

### 4.2 Surface modification by powder mixed dielectric

**Chow *et al.* (2000)** studied the effect of adding of SiC and aluminum powder in to kerosene as a dielectric for producing a micro slit in to a titanium alloy using EDM. It was concluded that due to addition of powder in dielectric, there was enhancement of higher gap distance, resulting ease of removal of debris and depth of material removal. SiC powder can produce a better material removal depth than Al powder added to the kerosene [26].

**Wong et al. (1998)** studied the effect of adding Al powder in to a dielectric while machined SKH- 51 work material. Powder concentrations 2 g/l was used and achieve mirror finish on surface of SKH- 51.They conclude negative polarity is essential for best mirror finish. There were also observed, great influence of powder properties on response parameters like MRR, TWR and SR

**Zhao et al. (2002)** performed experiment to study the effect of aluminum powder on machining efficiency and surface roughness of PMEDM. They performed rough machining with powder of 10µm granularity and 40 g/l of concentration. It was concluded that PMEDM can improve machining efficiency by selecting proper discharge parameters like peak current and pulse width [28].

**Tzeng and Lee (2001)** presented the effects of various powder characteristics on the efficiency of electro discharge machining on mould steel SKD-11 work pieces. They reach to conclusion that 70–80 nm powders produced the greatest MRR with least spark gap, followed by 10–15 µm, with 100 µm producing the lowest. For the TWR, the reverse trend was observed. Cr powder produced the greatest MRR, followed by Al, then SiC[29].

**Pecas and Henriques (2003)** carried out a study for finding the influence of silicon powder-mixed dielectric on hardened AISIH13 mould steel machined with copper electrode. The results indicated the positive influence of 2 g/l concentration of the silicon powder towards the reduction of the operating time required to achieve a specific surface quality. They found the use of PMD-EDM conditions promotes the reduction of surface roughness, crater diameter, crater depth and the white-layer thickness. [30]

**Kansal et al. (2007)** performed experiment on EDM to study the effect of silicon powder mixing into the dielectric for machining of AISI D2 die steel. They found for achieve high MRR Peak current and concentration of powder to be most significant parameters. High MRR was achieved at high concentration of 4 g/l and large Peak current of 10 A [31].

**Kung et al. (2009)** carried out a study to find the effect of PMEDM on MRR and EWR of machining cobalt-bonded tungsten carbide and reported optimal MRR at the aluminum powder concentration of 17.5 g/l. It was enumerated that EWR value tends to decrease with the aluminum powder concentration down to a minimum value after which it tends to increase. They observed higher MRR and EWR achieved when an increase of the discharge current, grain size, and pulse on time [32].

**Wu et al. (2009)** experimentally investigated the effect of PMEDM on MRR while adding surfactant with Al powder in to dielectric for machining SKD- 61. They observed 40 to 80% improvement in MRR of SKD-61 mold steel by adding surfactant to the dielectric. Due to added a surfactant along with Al powder in the dielectric and observed a more apparent discharge distribution effect which resulted in a surface roughness Ra value of less than 0.2µm. [33].

**Prihandana et al. (2011)** studied the variation of machining time due to adding of the nanographite powder in to dielectric with various concentrations. They found significant level of powder concentration is 2 g/l. Concluded that has a significant effect in reducing machining time up to 35% [34].

**Ojha et al. (2011)** experimentally investigated material removal rate (MRR) and tool wear rate (TWR) in PMEDM process with Chromium powder suspended dielectric for machining EN-8 steel. It was concluded that increase in powder concentration an increasing trend for MRR. Response surface methodology (RSM) has been used to plan and analyze the experiments. Peak current, pulse on time, diameter of electrode and concentration of chromium powder added into dielectric fluid of EDM were chosen as process parameters. TWR increased with lower range of powder concentration but then decreased. [35].

**Bhattacharya et al. (2013)** studied Surface Characterization and Material Migration during Surface Modification of Die Steels with Silicon, Graphite and Tungsten Powder in EDM Process. They observed improvement in surface properties like micro hardness, wear and corrosion resistance using various powder additives in PMEDM [36].

**Kumar and Batra (2012)** performed experiments to investigate the role of PMEDM for the surface modification. They used tungsten powder mixed in the dielectric medium. Substantial transfer of tungsten and carbon to the work piece surface and an improvement of more than 100% in micro hardness were recorded [37].

**Anil Kumar et al.(2010)** investigated the influence of grain sizes and concentration of aluminum powder for machining nickel base alloy Iconel 718 using PMEDM. Machining was carried out using round copper electrode. The machining characteristics are evaluated in terms of material removal rate, surface roughness and wear ratio. It is found that aluminum powder mixed in dielectric medium in EDM significantly affect the machining performance. Peak material removal rate and minimum surface roughness is obtained with 6g/l fine aluminum powder grains in dielectric medium [38].

**Jeswani M.L. (1981)** carried out experimental study to observe the effects of concentration of fine graphite powder in to kerosene as a dielectric for variation in MRR and Tool wear ratio. They used work material as a tool steel and observed 60% increase in MRR & 28% reduction in wear ratio. Concentration of 4g/L of fine graphite powder results in increasing the inter space of electric discharge initiation & lowering of breakdown voltage [39].

**Satpal Singh et al (2014)** carried out an experimental study for finding effect of tungsten powder on material removal rate (MRR) of PMEDM on EN 24 alloy steel. A fine powder of tungsten has been suspended in the EDM oil dielectric as an additive. Experiments have been designed using Taguchi L9 orthogonal array has been selected for 4-factors 3-levels design. The most significant factors contributing towards MRR and TWR have been identified. The results clearly showed that addition of tungsten powder has increased the MRR [40].

**Yan et al (2005)** carried out study to describe the effect of dielectric mixed with electrically conductive powder such as Al powder. They studied effect of PMEDM on the response variable ike gap distance, surface roughness, material removal rate, relative electrode wear ratio, voltage and waveform. They concluded that the dielectric with suspended electrically conductive powder can enlarge the gap distance and can improve the energy dispersion, surface roughness, and material removal rate [41].

## V. CONCLUSION

The use of EDM is increasing rapidly in dies manufacturing and tool rooms, and even in shop floors of modern industries to produce complex machining article from difficult-to-machine materials and stifled provide better surface integrity. Surface modification using EDM has added a new dimension to this technology. After an elaborate scrutiny of the published work on surface modification by this process, the following conclusions can be drawn.

1. A number of research studies have been carried out for observed improvements in surface properties of EDMed surface of various materials and the feasibility of the process is well established but steel this process is at experimental stage and need to identify and solve many related issue before the method can be formally accepted by the industry.
2. It is observed from available literature, machining of various material through EDM either using P/M electrode or powder suspended in dielectric medium can became a viable alternative reference to other expensive techniques like PVD, CVD etc for surface coating.
3. Surface modification on some important materials using EDM like AISI- A Series, Plastic mould steel P20, Water hardening die steel W- Series, and High speed steel are steel not covered.
4. Most of available research work using PMEDM studied the effect on output parameters like MRR, TWR and SR with straight polarity. There are very less work observed for surface modification using PMEDM.
5. There is less work found on surface modification using reverse polarity for PMEDM.
6. Use of metal powder mix with electrolyte able to produce mirror finish surface, high MRR, modified surface and higher inter electrode gap lead to flush debris easily.
7. There are also very less work found to study the effects of PMEDM on various properties such as microstructure, micro hardness, corrosion resistance, fatigue resistance, and wear resistance.
8. Very less work available on use of important alloying powder like chromium, manganese, molybdenum and vanadium in dielectric medium.
9. Most of available research work on PMEDM has been carried out by considering the effects of discharge current and pulse duration but variation in pulse interval has not been taken in to consideration in conjunction with pulse duration by way of duty factor.

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