Study of Powder Mixed Dielectric in EDM-A Review

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***Abstract*-Electrical discharge machining (EDM) is one of the most extensively disseminated manufacturing technologies, in particular as regards the generation of precise and difficult geometrical shapes on hard metallic components. EDM has been employed to effect/change surface properties by varying the electrode material and by adding various powders in the dielectric. Presence of metal partials indielectric fluid diverts its properties, which reduces the insulating strength of the dielectric fluidand increases the spark gap between the tool and work piece. As a result, the process becomesmore stable and metal removal rate (MRR) and surface finish increases. The EDM process ismainly used for making dies, moulds, parts of aerospace, automotive industry and surgicalcomponents etc. This paper reviews the research trends in EDM process by using water and powder mixed dielectric as dielectric fluid.**

Keywords—EDM, Powder-mixed EDM, Dielectric Fluid.

I. INTRODUCTION

Accompanying the development of mechanical industry, the demands for alloy materials having high hardness, toughness and impact resistance are increasing. Nevertheless, such materials are difficult to be machined by traditional machining methods. Hence, non-traditional machining methods including electrochemical machining, ultrasonic machining, electrical discharging machine (EDM) etc. are applied to machine such difficult to machine materials.

Although the erosive effect of electrical discharge machining was first invented by an English scientist Joseph Priestly in 1770 the machining of metals and diamond with electrical discharges has been done only in 1930s. In 1980s with the initiation of Computer Numerical Control (CNC) in EDM brings remarkable advancement by improving the efficiency of the machining operation. The improvement of EDM have since then been intensely sought by the manufacturing sector yielding enormous economic benefits and generating keen research interests [1].

EDM is basically a non conventional machining and the basic principal followed is the conversion of electrical energy into thermal energy through a series of discrete electrical discharges occurring between the electrode (tool) and workpiece immersed in a dielectric fluid .Spark is initiated when high voltage is applied between the electrode and workpiece at smallest point distance as shown in Fig. 1. Metal starts eroding from both the surfaces of workpiece as well as electrode. After each discharge, the capacitor is recharged from the DC source through a resistor and the spark that follows is transferred to the next narrowest gap. At the end sparks spread over the entire workpiece surface leads to its erosion, or machining to a shape which is mirror image of the tool.[2]

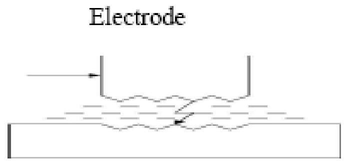

Fig. 1. Spark initiation in EDM process [2]

The dielectric fluid helps discharge energy to concentrate into a channel of very small cross-sectional area. It also acts as coolant and flushes away the particles of machining from the gap. The electrical resistance of the dielectric fluid influences the discharge energy at the time of spark initiation. Early discharge will occur, if the resistance is low. If resistance is large, the capacitor will attain a higher value of charge before the spark occurs. As the erosion on the workpiece surface takes place the tool has to be advanced through the dielectric towards it. A servo system, which is employed to maintain the gap voltage between the workpiece and electrode with a reference value, is to ensure that the electrode moves at a proper rate towards workpiece, and to retract the electrode if short circuiting occurs. The volume of material removed per discharge is typically in the range of 10^{-6}–10^{-4} mm^3 and the metal removal rate (MRR) is usually between 2 and 400 mm^3/min depending on specific application. During the EDM process the electrical energy created between workpiece and electrode passes through a gap in dielectric fluid. The energy over a small region leads to deeper crater which reduces surface finish; hence dielectric fluids with high thermal conductivity are needed to improve the performance.

II. PROCESS PARAMETERS

A. ELECTRICAL PARAMETERS

a) PEAK CURRENT

The peak current is basically a most important machining parameter in EDM. It is the amount of power used in EDM and measures in unit of amperage. During each pulse on-time, the current increases until it reaches a preset level, which is expressed as the peak current. In both die sinking and wire-EDM processes, the maximum amount of amperage is governed by the surface area of the cut. Higher amperage is used in roughing operations and in cavities or details with large surface areas. Higher currents will improve MRR, but at the cost of surface roughness and tool wear rate. All these factors are more important in EDM because the machined cavity is mirror image of tool electrode and excessive wear will obstruct the accuracy of machining. New improved electrode materials, especially graphite, can work on high currents without much damage [3].

b) DISCHARGE VOLTAGE

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 and helps to stabilize the cut. MRR, tool wear rate (TWR) and surface roughness increases, by increasing open circuit voltage, because electric field strength increases. However, the impact of changing open circuit voltage on surface hardness after machining has been found to be only marginal. Discharge voltage in EDM is related to the spark gap and breakdown strength of the dielectric [4].

c) PULSE ON TIME AND PULSE OFF TIME

These are expressed in units of microseconds. Because all the cutting is done during pulse on time, so the duration of these pulses and the number of cycles per second (frequency) have vital role. Metal removal is directly proportional to the amount of energy applied during the pulse on time [5]. This energy is controlled by the peak current and the length of the pulse on-time. Pulse on-time is commonly referred to as pulse duration and pulse off-time is called pulse interval. With longer pulse duration, more workpiece material will be melted away. The resulting crater will be broader and deeper than a crater produced by shorter pulse duration. This will increase the surface roughness. Extended pulse duration also allow more heat to sink into the workpiece and spread, which means the recast layer will be larger and deeper heat affected zone. However, extreme pulse duration can be counter-productive. When the optimum pulse duration for each tool and workpiece material combination is exceeded, material removal rate starts to decrease. Long pulse duration can also restrict electrode from machining. At this situation, increasing the duration further causes the electrode to grow from plating build-up. The cycle is completed when sufficient pulse interval is allowed before the start of the next cycle. Pulse interval will affect the speed and stability of the cut. According to theory, the shorter the interval, the faster will be the machining operation. But if the interval is too short, the expelled workpiece material will not be flushes away with the flow of the dielectric fluid and the dielectric fluid will not be deionized. This will cause the next spark to be unstable and slows down cutting more than long, stable off times. At the same time, pulse interval must be greater than the deionization time to prevent continued sparking at one point [6]. Modern power supplies allow independent setting of pulse on-times and pulse off-times. Typical ranges are from 2 to 1000µs. In ideal conditions, each pulse creates a spark. However, it has been observed practically that many pulses fail if duration and interval are not properly set, causing a loss of the machining efficiency.

d) POLARITY

The polarity of the electrode can be either positive or negative. But the excess material is removed from side which is positive. In general, polarity is determined by experiments and is a matter of tool material, work material, current density and pulse length combinations. Modern power supplies insert an opposite polarity “swing pulse” at fixed intervals to prevent arcing. A typical ratio is 1 swing pulse for every 15 standard pulses .

e) ELECTRODE GAP

Basic requirements for good performance are gap stability and the reaction speed of the system; the presence of backlash is particularly undesirable. The reaction speed must be high in order to respond to short circuits or open gap conditions. Gap width is not measurable directly, but can be inferred from the average gap voltage.

B. NON-ELECTRICAL PARAMETERS

a) DIELECTRIC FLUSHING

The dielectric fluid used in EDM have characteristics of high dielectric strength and quick recovery after breakdown, effective quenching and flushing ability, good degree of fluidity and easily available. TWR and MRR are affected by the type of dielectric and the method of its flushing .A control feature that is available on many machines to facilitate chip removal is vibration or cyclic reciprocation of the servo-controlled tool electrode to create a hydraulic pumping action.

b) ROTATING THE WORKPIECE

In addition to the flushing of the dielectric, the techniques of applying rotational motion to the sparking process also affect the EDM performance. Work piece rotary motion was also studied by researchers to improve the circulation of the dielectric fluid in the spark gap and temperature distribution of the workpiece yielding improved MRR and SR.

c) ROTATING THE ELECTRODE

Similarly, the performance measures of the EDM process also improves by the introduction of the rotary motion to the electrode. It serves as an effective gap flushing technique, which significantly improves the MRR and SR. It was found that the vibratory motion yields comparable effects as the rotary motion of electrode improving the MRR, enhancing the surface quality of workpiece and increasing the stability of machining process.

C. POWDER PARAMETERS

In powder mixed electric discharge machining (PMEDM) to avoid the wastage of kerosene oil, a small dielectric circulating system is designed. A stirring system is incorporated to avoid the particle settling. For constant reuse of powder mixed dielectric fluid, magnetic forces are used to separate the powder particles from the debris produced due to machining. PMEDM has a different machining mechanism from the conventional EDM. In this process, a suitable material in the powder form is mixed into the dielectric fluid of EDM.

III. LITERATURE REVIEW

A. EDM WITH WATER AS DIELECTRIC FLUID

In year 2004 Leao and Pashby investigated that some researchers have studied the feasibility of adding organic compound such as ethylene glycol, polyethylene glycol 200, polyethylene glycol 400, polyethylene glycol 600, dextrose and sucrose to improve the performance of demonized water [7]. The surface of titanium has been modified after EDM using dielectric of urea solution in water [8]. The nitrogen element decomposed from the dielectric that contained urea, migrated to the work piece forming a TiN hard layer which resulting in good wear resistance of the machined surface after EDM.

Ekmekci presented an experimental work to measure residual stresses and hardness depth in EDM surfaces [9]. Stresses are found to be increasing rapidly with respect to depth, attaining to its maximum value around the yield strength and then fall rapidly to compressive residual stresses in the core of the material since the stresses within plastically deformed layers are equilibrated with elastic stresses. In 2005, Sharma investigated the potential of electrically conductive chemical vapor deposited diamond as an electrode for micro-electrical discharge machining in oil and water [10]. While doing a comparative study on the surface integrity of plastic mold steel in the same year Ekmekci also investigated found that the amount of retained austenite phase and the intensity of micro cracks have found to be much less in the white layer of the samples machined in de-ionized water [11]. A new application in EDM power supply was designed to develop small size EDM systems by Casanueva [12]. The proposed control achieves an optimum and stable operation using tap water as dielectric fluid to prevent the generation of undesired impulses and keep the distance between the electrode and the work piece within the desirable range. In the same year Kang and Kim studied in order to investigate the effects of EDM process conditions on the crack susceptibility of a nickel-based super alloy revealed that depending on the dielectric fluid and the post-EDM process such as solution heat treatment,cracks exist in recast layer could propagate into substrate when a 20% strain tensile force was applied at room temperature [13]. When kerosene as dielectric, it was observed that carburization and sharp crack propagation along the grain boundary occurred after the heat treatment.

However, using deionized water as dielectric the specimen after heat treatment underwent oxidation and showed no crack propagation behavior.

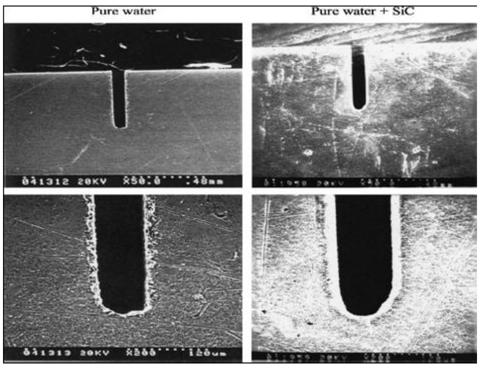

Fig.2. The micro-slit outlook profile SEM photos of using pure water alone and added SiC powder [14]

In year 2008 Han-Ming Chow and other scientist investigated the effect of using pure water and a SiC powder for titanium (Ti) alloy in micro-slit EDM, and found that by using pure water as an EDM dielectric fluid for titanium alloy yields a high MRR and relatively low electrode wear and small expanding-slit by employing negative polarity (NP) processes [14]. Pure water and a SiC powder cause high conductivity; therefore, the gap was larger than using pure

water in the EDM processes. Pure water and a SiC powder could disperse the discharging energy that refines
the surface roughness effectively and also attains a higher MRR simultaneously than that of pure water. Pure water and a SiC powder causes a larger expanding-slit and electrode wear than those of using pure water alone. However, pure water and a SiC powder attain a smaller amount of machined burr than that of using pure water alone. The SEM photo using pure water in Fig. 2 shows burrs formed on the slit edge. This is because there is a smaller discharge impact, which cannot remove molten material completely during the EDM processes. However, using pure water and SiC powder disperses energy and improves the surface roughness so fewer micro-slit burrs were created.

B. EDM WITH POWDER-MIXED IN DIELECTRIC FLUID (PMEDM)

The mechanism of PMEDM is totally different from the conventional EDM . A suitable material in the powder form is mixed into the dielectric fluid of EDM[15]. When a suitable voltage is applied, the spark gap filled up with additive particles and the gap distance setup between tool and the workpiece increased from 25–50 to 50–150 mm. The powder particles get energized and behave in a zigzag fashion Figure 4. These charged particles are accelerated by the electric field and act as conductors. The powder particles arrange themselves under the sparking area and gather in clusters. The chain formation helps in bridging the gap between both the electrodes, which causes the early explosion. Faster sparking within discharge takes place causes faster erosion from the work piece surface.

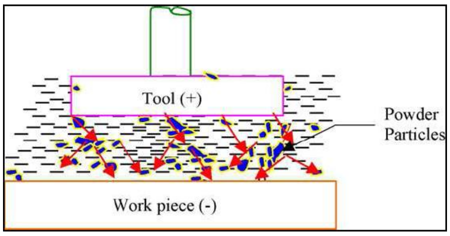

Fig. 3. Principle of powder mixed EDM [17]

An extensive survey has been done by so many researchers [1,2,16] on powder mixed dielectric and research findings revealed that the dielectric fluids with powder particle offers
significantly better thermal properties relative to those of conventional dielectric fluids. In the powder mixed EDM powder of different materials are mixed in dielectric fluid. The floating particles impede the ignition process by creating a higher discharge probability and lowering the
breakdown strength of the insulating dielectric fluid. As a result, MRR, SR is increased, TWR is lowered and sparking efficiency is improved. The nano powder suspended in dielectric medium increases the gap between tool and workpiece which in turn causes the stability of the process, thereby increasing the machinability. H.K. Kansal proved that PMEDM holds a bright promise in application of EDM,
particularly with regard to process productivity and surface quality of workpiece[8,14,17].

Furutani in 2001 investigated by using titanium powder in kerosene dielectric and obtained titanium carbide layer of hardness 1600HV on carbon steel with a negatively polarized copper electrode, 3A peak current and 2µs pulse
duration[18] and also a deposition method for solid lubricant layer of molybdenum disulphide by suspending its powder in the dielectric to produce parts for ultra high vacuum applications has been proposed in the year 2003.

Early in year1995 Miyazaki applied a plasma arc produced through a small diameter nozzle on steel [19]. Ceramic powder of silicon carbide was supplied to the processing region with the shielding gas of argon. The initial and running cost of plasma arc is much cheaper than laser beam and it is generally used in industries for cutting and welding applications. It was possible to obtain a hardness of 1000 VHN on AISI 1010 steel by self-quenching without any powder and 1200HV with silicon carbide particles. Fig. 4,5 and 6show SEM micrographs of OHNS die steel after machining with tungsten powder, graphite powder, and silicon powder mixed in the dielectric respectively. Remarkable surface modifications can be observed. After this in order to address the problem of powder settling, when we added a surfactant along with aluminium 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. It has been possible to achieve near mirror-finish using conductive powders (such as graphite and aluminium) and semi conductive silicon powders. Wong in1998 has been shown that besides the appropriate settings of electrode polarity and pulse parameters, there is a great influence of work material and powder properties on the response parameters such as MRR, TWR and surface roughness. Whilst graphite and silicon powders gave mirror-finish on SKH-54 work material, aluminium powder failed to give the same Fig. 7 [20]. The use of negative electrode polarity was found to be essential for achieving mirror-finish condition.

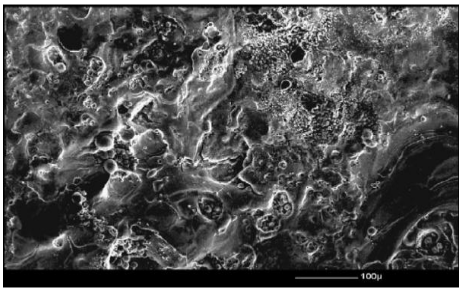

Fig.4. SEM micrographs of OHNS die steel after machining with tungsten powder (at I_p =6A, P_{on} =5μs and P_{off} =85μs, electrode-copper [19]

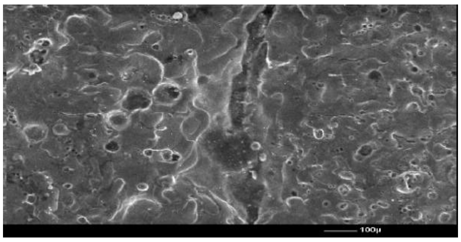

Fig.5. SEM micrographs of OHNS die steel after machining with graphite powder (at I_p =2A, P_{on} =5μs and P_{off} =57μs, electrode-copper) [19].

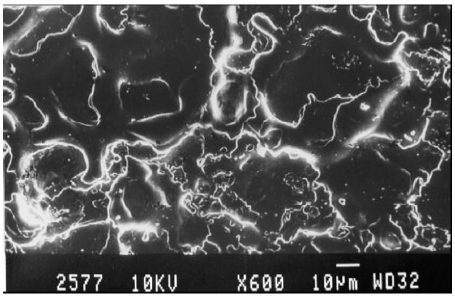

Fig.6. SEM micrograph of OHNS die steel after machining with silicon powder mixed dielectric (at I_p =2A, P_{on} =5μs and P_{off}=57μs, electrode-copper) [58].

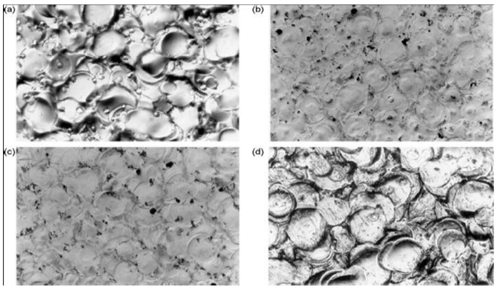

Fig.7. SEM micrographs of SKH-54 tool steel after machining with copper electrode(a) Without any powder, (b) with graphite powder, (c) with silicon powder and (d) with aluminium powder (at I_p =1A, P_{on} =7.5μs and P_{off} =11μs, magnification = 50×, polaritynegative [20].

IV. CONCLUSION

The contribution of EDM to industries such as cutting new hard materials make EDM technology remains indispensable. The review of the research trends in EDM in water and EDM with powder additives is presented. Powder mixed dielectric is a good research promising area. Most of the research work has been with Al, Si, and graphite powders and some with other types of powder like Cr, Ni, Mo, etc. , but only a few has touched the introduction of using Nano powders in to EDM. Most of the available research works on powder-mixed dielectric have studied the impact of such machining on MRR, surface roughness and TWR etc.

REFERENCES

[1] Gurmail Singh , "Investigations on Improvements of material Properties and Parametric Optimization of MRR, TWR and Roughness using Powder mixed dielectric in EDM Process" , A thesis in Master of Engineering submitted to Department of Mechanical Engineering , Thapar University , July 2010.

[2] Sharanjit Singh, Arvind Bhardwaj , "Review to EDM by Using Water and Powder-Mixed Dielectric Fluid" , Journal of Minerals & Materials Characterization & Engineering, Vol.10, No.2,(2011) pp.199-230.

[3] Ho, K.H., Newman, S.T., "State of the art electrical discharge machining." International Journal of Machine Tools & Manufacture, Vol. 43,(2003) pp. 1287–1300.

[4] Kansal. H.K., Singh, S., Kumar, P., Application of Taguchi method for optimization of powder mixed electric discharge machining, International Journal of Manufacturing Technology and Management, No.7, (2005) pp. 329–341

[5] Kansal, H.K., Singh, S., Kumar, P.,"Parametric optimization of powder mixed electrical ischarge machining by response surface methodology." Journal of Materials Processing Technology, Vol. 169, No. 3, (2005) pp. 427–436.

[6] Fuller, John, E., Electrical Discharge Machining. ASM Machining Handbook, vol. 16, (1996) pp. 557–564.

[7] Yan, B.H., Tsa, H.C., Huang, F.Y.,, "The effect in EDM of a dielectric of a urea solution in water on modifying the surface of titanium." International Journal of Machine Tools & Manufacture, Vol. 45,(2005) No. 194–200.

[8] Ekmekci, B., Elkoca, O., Tekkaya, A.E., Erden, A, "Residual stress state and hardness depth in electric discharge machining: de-ionized water as dielectric liquid." Machining Science and Technology, No. 9, (2005) pp. 39–61.

[9] Sharm, A., Iwai, M., Suzuki, K., Uematsu, T., "Potential of electrically conductive chemical vapor deposited diamond as an electrode for micro-electrical discharge machining in oil and water." New Diamond and Frontier Carbon Technology, Vol. 15,(2005) pp. 181–194.

[10] Ekmekci, B., Elkoca, O., Erden, A., "A comparative study on the surface integrity of plastic mold steel due to electric discharge machining." Metallurgical and Materials Transactions B: Process Metallurgy and Materials Processing Science, Vol. 36, (2005) pp.117– 124.

[11] Casanueva, R., Azcondo, F.J., Bran, C., Bracho, S., , "Analysis design and Experimental results of a high-frequency power supply for spark erosion." IEEE Transactions on Power Electronics, Vol. 20, (2005) pp. 361–369.

[12] Kang, S. H., Kim, D.E., "Effect of electrical discharge machining process on crack susceptibility of nickel based heat resistant alloy.", Materials Science and Technology, Vol. 21, (2005) pp.817– 823.

[13] Chow, H. M., Yang, L. D., Lin, C. T., Chen, Y. F., , "The use of SiC powder in water as dielectric for micro-slit EDM machining." Journal of materials processing technology, Vol. 195, (2008) pp. 160–170

[14] Kansal, H.K., Singh, S., Kumar P., "Technology and research developments in powder mixed electric discharge machining (PMEDM).", Journal of Materials Processing Technology, Vol. 184,(2007) pp.32–41

[15] Kuldeep Ojha , R. K. Garg, K. K. Singh , "MRR Improvement in Sinking Electrical Discharge Machining: A Review" , Journal of Minerals & Materials Characterization & Engineering, Vol. 9, No.8, (2010) pp.709-739,.

[16] Anand Pandey , Shankar Singh , "Current research trends in variants of Electrical Discharge Machining: A review" , International Journal of Engineering Science and Technology , Vol. 2(6), (2010), 2172-2191.

[17] Jeswani, M.L., , "Effect of addition of graphite powder to kerosene used as a dielectric fluid in electrical discharge machining." Wear, Vol. 70,(1981) pp. 133–139.

[18] Furutani, K., Saneto, A., Takezawa, H., Mohri, N., Miyake, H., "Accretion of titanium carbide by electrical discharge machining with

powder suspended in working fluid."Precision Engineering, Vol. 25, 2001.
[19] Wong , Y.S., Lim, L.C., Rahuman, I., Tee, W.M., "Near mirror-finish phenomenon in EDM using powder-mixed dielectric." Journal of Materials Processing Technology, Vol. 79,(1998) pp. 30–40.
[20] Okada, A., Uno, Y., Hirao, K., , Formation of hard layer by EDM with carbon powder mixed fluid using titanium electrode. In: Proceedings of the International Conference on Progress of Machining Technology, (2000) pp. 464–469