A Review of Current Researches on Powder Mixed Electrical Discharge Machining (PMEDM) Technology

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Abstract Nowadays, electrical discharge machining (EDM) is becoming a more popular option for manufacturing hard material and complex geometry parts that are extremely difficult to cut by conventional machining processes. Continuous demand for the high-tech industry to use high and superalloys compelled the manufacturing industry to adhere EDM process. In present times, many researchers have been working in this area to find process suitability and optimum machining parameters. Powder mixed electric discharge machining (PMEDM) is a recent outcome in which different powders are mixed with the dielectric fluids to increase the material removal rate (MRR), surface roughness (SR), and property improvement of the machining surface. In this paper, an attempt has been made to review and discuss on PMEDM work of researchers. The paper discusses the EDM variables, optimum parameters, tool wear, surface texture, and mechanical properties of the machined surface. The outline of the discussion is stated in subsequent parts of the paper.

Keywords PMED · MRR · SR · Tool wear rate · White recast layer

1 Introduction

There has been substantial growth in modern manufacturing processes to machine exotic materials easily and accurately. Now, most of the manufacturing industry starts to prefer modern or unconventional machining processes rather than conventional machining processes. This is due to many reasons, such that, to achieve better efficiency, accuracy, and reliability. It has been the best choice since the last two decades to use high and superalloys as components for different high-tech industries to increase the durability of machines or mechanisms. Hence, substantial amounts

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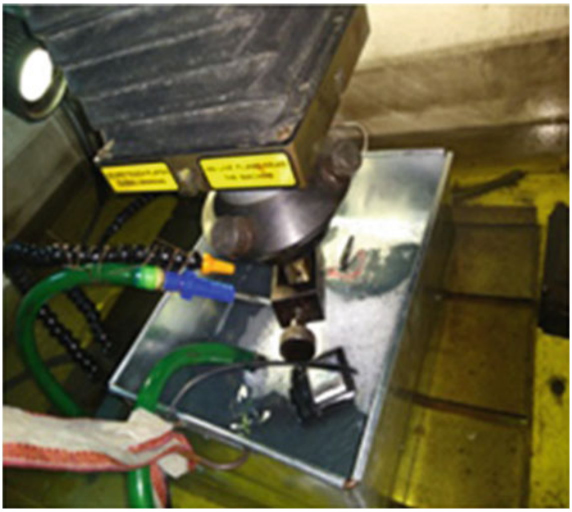
of pressure mount on manufacturing industries to process them by the conventional method. New and novel materials are almost impossible to cut by any existing conventional processes. Besides, conventional machining is inefficient in machining hard materials like ceramics and composites. The demand for high-dimensional accuracy also sometimes creates hindrances during traditional machining. Again, during the machining process blank is affected severely by cutting forces, as a result, more stress is induced in the blank. To overcome such problems, new methods of machining such as modern or unconventional machining process have come in use. In current times, the process has been used by the manufacturing industry to manufacture automotive, aerospace, tool and die and forging machine tool parts.

The electric discharge machining is an electrothermal unconventional spark erosion machining process in which no chattering and vibrations are associated as those happen during conventional machining. The process is useful to cut difficult to cut materials for those having optimum hardness and toughness. The process with negligible distortion and stress concentration can easily machine high and superalloys. In the EDM device, electrical current is used to generate spark between electrode and workpiece. The electrode is in a fixed position maintaining a small distance from the workpiece and both submerged in a dielectric. A pulsating DC power supply is used to generate voltage pulses between electrode and blank. The gap between the workpiece and electrode is maintained by a servo-controlled unit mechanism, which is being incorporated with the EDM machine. When the current starts to flow through the electrode to workpiece, high heat is generated and spark is established. It heats the local area without affecting the other part of the workpiece (Fig. 1).

Recent advancement of EDM leads to the development of powder mixed EDM (PMEDM) where powders are mixed in the dielectric. There is a little modification in the traditional EDM system, and a submerged pump is installed with the system to inject powder mixed dielectric fluid on to the cutting zone. The objective to mix the powder with dielectric is to diminish the insulating strength of the dielectric and

Fig. 1 EDM machine

Fig. 2 PMEDM setup



to decrease the gap between work and electrode. Thus, the process becomes more stable, and good MRR value is obtained with relatively good surface finish (Fig. 2).

2 History

In 1970, the English scientist Priestely first found the erosive effects of electrical discharge on metals. Later, 1943 soviet scientists, Lazarenko developed a controlled method of metal machining. Now improved version electric discharge machine tools are used with various cutting modes such as EDM and PMEDM. EDM process has found ready application in machining titanium alloys, tungsten carbides, and any other hard steels. The process is useful to any electrically conductive materials where mechanical properties such as toughness, hardness, strength, and microstructures are not barriers to its application. Slender and fragile jobs can be machined easily as there is no contact of the cutting tool with the workpiece. Though EDM is a thermal erosion process, there is no heating in the bulk of the material because of dielectric uses. Accurate profile with minimum dimensional deviation can be easily achieved with a little attention of the operator.

In recent past, PMEDM has emerged as one of the suitable techniques to enhance the efficiency, surface quality, and mechanical properties of the recast layer. The added powder affects the performance of the process. Powder mixing techniques increase the spark gap distance and reduce the insulating strength between the tool electrode and workpiece. As a result, the process becomes more stable, hence the MRR increased significantly (Fig. 2).

3 Methodology

Recent advancement of EDM led to the development of powder mixed EDM (PMEDM) where powders are mixed in the dielectric. These powders are known to improve many output parameters. Because of these powders, the insulating strength of the dielectric decreases and the spark gap between tool electrode and workpiece increases, which leads to the process more stable, and ultimately results in improved MRR values and a relatively good surface finish [1–4]. Proper discharge parameters are the most criteria while machining workpieces as the study shows that machining efficiency and SR can be improved [5]. There are many methods to machine exotic alloy, namely conventional and non-conventional processes. Although conventional techniques have been employed to machine such alloys, the non-conventional techniques, especially electric discharge machining (EDM), is the best suited for machining hard alloys. In EDM, the material removal process is achieved by a series of continuous electric discharges between the workpiece and the electrode in the presence of a dielectric fluid [6]. So this unconventional technique is highly successful in its ability to machine and manufacture incredibly hard material and geometrically complex shapes with razor-sharp precision [7, 8]. While machining, there are numerous options for selecting the dielectric fluid but it has been found that the use of water as a dielectric instead of oil-based dielectrics significantly improves the material removal rate (MRR). Moreover, water-based dielectrics are more eco-friendly [9]. EDM is a well-researched technique. Research shows that the main reason behind the continuous EDM is the result of the formation of the pyrolytic carbon layer on the ceramic surface due to the cracked carbon dissipated from the carbonic dielectric [10]. While machining with EDM, the formation of the white recast layer (WRL) cannot be ignored. High pulse current and pulse on duration are found responsible for increasing the thickness of this WRL [11]. This increases with increasing the surface roughness (SR) but on the other hand increases the hardness of the surface of the workpiece. Tool wear rate [TWR] is one of the major disadvantages of this technique.

A study shows that when aluminum powders are mixed with IPOL oil to machine AISI D3, high MRR, low TWR, and low SR are achieved [12]. Gudur et al. studied that when aluminum and silicon powders were mixed with various dielectrics, MRR was found to increase and TWR was decreased compared to conventional EDM process [13]. Hastalloy steel is nickel molybdenum–chromium superalloy and has substantial corrosion resistance in several environments. Singh et.al tried to machine the metal by EDM and found maximum MRR of 0.063 gm/l at aluminum powder concentration of 6 gm/l in EDM oil. Further, the MRR decreased to 0.06 gm/min at a concentration of 12 gm/l. The experiment also reveals that fine grains of aluminum powder give less MRR results than the medium-sized grain powders. This is because of less suspended particles found in EDM oil than the medium-grain particles. Again suspended coarse grain size aluminum powder in a dielectric with little density bridges the gap between electrodes and leads to short-circuiting. As a result, MRR becomes less than MRR yields with pure EDM oil. It can be said to be an ideal EDM process if the electrode erodes maximum materials from the workpiece than its self-erosion. In this verse, the paper states that minimum TWR is found with fine grain powder particles. However, TWR is more with pure EDM oil followed by coarse and medium grade particles. The surface roughness of 3.4 μm found at the machining surface of Hastalloy steel using fine grain aluminum powder, which is maximum as compared to medium and coarse grain powder SR results. EDM with pure EDM oil also produces more roughness value than the surface produced with fine-grained particles. Again, the concentration of powder has also a significant effect on SR. The value is inversely proportional to the amount of powder concentration in EDM oil. The powder concentration of 9 gm/l exhibits a good SR value of 2.85 μm and then the roughness increased [14].

Researchers have developed several ways for machining hard metals by the EDM process. The rotary tool EDM process is a recent development in which the electrode tool rotates at the desired speed. Patel et al. used a rotary tool in the PMEDM process to machine Inconel 718. Inconel 718 is a high-performance alloy and used for turbine components, cryogenic storage tanks, jet engine parts, rocket motors, nuclear fuel element spacer, and for hot extrusion tooling. They added aluminum oxide (Al_2O_3) powder with a concentration of 0.5–1.5 gm/l into the dielectric fluid. The rotary tool shows better MRR results than the fixed electrode tool. It also reveals that peak current (Ip) takes prime responsibility to increase the MRR of Inconel 718 steel. MRR result shows low results at 9 A and higher at 28 A. MRR shows lower at pulse ON time 50 μs and minor increment at 150 μs. Hence, pulse ON time has less significance in the rotary EDM process. Duty cycle has no significance on MRR. However, Ip has a significant role on TWR. TWR is lower at 9 A and higher at 28 A. TWR is also a function of T_{on}. Higher TWR shows at 50 μs and a minimum at 100 μs. The most effective parameter also found for SR is I_p. Minimum SR is evidenced at 9 A and maximum at 28 A. Topography study of Inconel 718 EDMed surfaces by SEM analysis reveals that aluminum oxide (Al_2O_3) powder particles are deposited on the EDMed surface. [15]. When the performance of different powders like aluminum, silicon and silicon carbide were compared, aluminum powder gave the highest MRR. However, overall better machining performance was obtained from silicon powder [16]. Another study showed that when the aluminum powder was mixed with distilled water; a green dielectric to machine W300 die steel, a high MRR, good surface finish, and a minimum white layer thickness was reported [17].

A similar study showed that out of six parameters chosen, namely nozzle flushing, grain, the concentration of powder, pulse OFF time, pulse ON time and peak current, and nozzle flushing did not show any effect on MRR [18]. In another study, when SiC was mixed with a dielectric fluid to machine premium stainless mold steel, a reduction of machining time was reported [19]. Graphite is another such powder which is known to improve the MRR. When 4 g of graphite powder was mixed with kerosene, MRR was found to increase by 60% and TWR by 15% [20]. Another research in micro-EDM showed that when graphite powder was introduced in the dielectric, the machining time reduced by 5 times and when workpiece vibration was employed to the machining process the machining time was found to get reduced by 3 times [21]. Tungsten powders have also shown improvements in MRR when mixed with pure kerosene [22].

Mohal et al. used Al 6061 reinforced with 10% silicon carbide particle as workpiece material. Multiwall carbon nanotube (MWCNT) mixed dielectric fluid and copper tool with –ve polarity is used for the EDM process. The experiment reveals that MRR increases with increasing CNT powder concentration. This is because of the high thermal conductivity of CNT particles. Thus, high electric current flows to the workpiece, as a result, more MRR is achieved. But the concentration of CNT equal or more than 8 gm/l increases derbies at the discharge gap makes the machining process unstable; as a result, MRR is reduced. It is found again from the experiment that the concentration of CNT powder plays a vital role in SR value apart from electrical parameters. The addition of CNT powder helps to establish more dissipation of discharge energy, which in turn minimizes the crater size. On the other hand, surface roughness increases by increasing CNT powder concentration to 0.4 gm/l in dielectric fluid. This is because at a very high concentration of CNT in dielectric loses its ability to distribute the powder particles uniformly. Again, machined surfaces are analyzed by SEM and found that larger craters are noticed at the machined surface as compared to CNT as additive [23].

Patel et al. compared machining characteristics of aluminum, silicon and silicon carbide powder and found aluminum powder has the highest MRR and silicon powder has better overall results among the three [24]. In another PMEDM process titanium, nanopowder is mixed with dielectric. The study revealed that the EDMed surface morphology of D_2 steel was improved. Low height ridges, shallower crater, and fewer voids were found at the machined surface. Furthermore, a very less amount of Ti nanopowder welded at the EDMed surface [25]. When mixing chromium powders with commercial grade EDM oil to machine H-11 die steel, the surface texture was improved with increasing powder concentration. A remarkable improvement in increasing micro-hardness was recorded by increasing I_p even at a constant C_p [26]. Similarly, when graphite was mixed with kerosene to machine Inconel 625, there was a reduction in surface tensile stress, which helped to enhance its fatigue strength [27]. Another advantage of the PMEDM process is during machining, and there is a scope of surface modification due to the transfer of suspended particles from dielectric to work surface. In this verse, Kumar et al. found that a significant amount of tungsten carbide powder transferred to the machined surface and welded on it, as a result surface defect diminished. Besides, hardness at EDMed surface enhanced due to the deposition of carbon. The negative polarity of the electrode, shorter $T_{on,}$ longer T_{off}, and low discharge current are the considerable factors for metal transfer in which I_p is more significant [28]. Another research shows biomedical grade titanium alloy, when machined with nanoscaled aluminum powder, imparted high surface finish and enhanced surface morphology showing minimum voids, cracks, and craters [29].

EN-19 is known for its high tensile strength. This property of this alloy along with good ductility and shock resistance has it very popular in the automotive industry. Also, its extremely precise machining property has led its use in the oil and gas sector. However, one downside to this alloy is its low wear resistance and hence leads to a shorter service life [30]. It is reported that optimized process parameters by Taguchi method for maximum MRR to cut EN 19 are 24 A, pulse OFF time of 2300 μs, pulse ON time of 400 μs, and a voltage of 40 V. But the process parameters for EN 41 are 40 V, 24 A, pulse ON time of 400 μs, and pulse OFF time of 2100 μs [31]. Kolli et al. used the Taguchi method to optimize the graphite powder concentration and machining surface characteristics of Ti-6Al-4V. Their detailed investigation revealed that an improvement in MRR and reduction in TWR, SR, and WLT is noticed by using mixing graphite powder with dielectric. MRR increased in increasing C_p from 4 to 6 g/l and again decreased beyond 6 g/l [32]. Taguchi's L_{27} orthogonal array was employed to machine H-11 die steel taking copper as an electrode material and SiC as powder material. The experiment revealed that maximum surface roughness, cracks, pores, and holes were found by machining without powder; whereas, substantial improvement in surface topology was seen while adding powder with dielectric. Higher MRR with improved micro-hardness at EDMed surface and lower surface roughness and cracks were found at higher C_p [33]. Kansal et al. investigated that when Si powder was mixed with dielectric higher MRR and surface finish were reported. Further, it was observed that I_p and C_p are the most significant parameters which affect MRR and SR [34].

4 Conclusion

From the above evidential study, it can be concluded that EDM and its novel method PMEDM are suitably found more efficient to cut hard alloys, where a conventional process fails to do so. Good MRR value and complex geometry with tight accuracy can be obtained by PMEDM. But still researchers are troubled to explore the optimum parameters as the process is concerned to many complex activities. Therefore, more research is required to explore all angles of the process.

5 Future Scope

In this discussion, it is clear that many researchers are showing their interest and have been working in improving MRR, surface finish, strength, and recast layer integrity. They also worked to reduce tool wear rate and white layer thickness. They do not have any adequate control over spark density and its interface area. If we would control the spark density and its interface area, then we could use a standard electrode for cutting different dimensions of different alloys. Further, electrode manipulation is restricted in the process. Hence, a great scope lies in this process for further research. Still, many things are to explore for optimizing the process parameters. Moreover, EDM is a gray area for researchers, and the process holds a bright future for the manufacturing industry [35].

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