Effect of Dielectric fluids used on EDM Performance: A Review

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Abstract – Electric Discharge machining is a well-known nonconventional machining process. In electric discharge machining Dielectric fluid plays an important role as material removal takes place due to repetitive spark discharge between an electrode and workpiece. The main functions of dielectric are too flushed through the spark gap to remove gaseous and solid debris during machining and to maintain the dielectric temperature by acting as a coolant. Dielectric fluids must have some properties such as low viscosity, good wetting capacity, and high flash point, etc. This paper will present a literature survey on the use of different dielectric and their effect on material removal rate and tool wear rate during EDM. For Gaseous dielectrics such as oxygen, Helium, Argon may also be used as a dielectric. For liquid dielectrics such as graphite and boron carbide powder mixed EDM are also employed in industries urea solution, hydrocarbon oil, and many additives mixed dielectric can be used. The use of vegetable oil-based fluids for industrial applications has a higher sustainability index compared to hydrocarbon and synthetic based fluids. Analysis has been performed for newly proposed Jatropha curcas oil based bio dielectric (Jatropha BD) fluid for material removal rate (MRR), the surface roughness (SR) and surface hardness (SH) in EDM process. The response patterns of Jatropha BD are similar to kerosene which is states that the effect of Jatropha BD is similar to kerosene. It is suggested that Jatropha oil based bio dielectric fluids can be used as an alternative to hydrocarbon-based dielectric for improving the sustainability of EDM process.

Index Terms – Electric Discharge Machining, Surface Hardness, Surface Roughness, Material Removal Rate, Tool wear Rate.

1. INTRODUCTION

Electric Discharge Machining is also known as spark machining or sparks-erosion machining. The EDM process involves a controlled erosion of electrically conductive materials by the initiation of a rapid and repetitive spark discharge between tool and workpiece [1]. The small gap between tool and workpiece is known as a spark gap, and it is about 0.01 to 0.50 mm. This spark gap is filled by dielectric fluid. Various electrode materials used are graphite, copper, copper graphite, tungsten, etc. [2]. The EDM process employs a series of high-frequency electric discharges to cause thermoelectric ionization of the dielectric fluid. The plasma generated during the process raise the temperature on the order of 8000–12,000 K, which into melt and vaporize the work material [3] Dielectric fulfills important functions regarding

Costs, productivity, and quality of workpiece and tool electrode. Health, safety, and environment are also important aspects when the selection of dielectric is chosen. Tool wear and material removal rate are affected by the type of dielectric fluid used for flushing. The EDM process can be classified by dielectric used. In Die sink EDM generally, the hydrocarbon oil is used while in the wire, micro-EDM deionized water is used. Dielectric has certain characteristics such as high dielectric strength, low viscosity, good wetting capacity, high flash point, should not emit any toxic vapors and unpleasant odors. So Many different fluids are used as dielectric fluids. Most of them are hydrocarbon fluids, silicone-based oils and de-ionized water, kerosene oil and water with glycol. The EDM process is mostly used by the mold-making tool and die industries, especially in the aerospace, automobile and electronics industries in which production quantities are relatively low, and the workpiece is very hard. The process also used for machining of superalloys, automotive components, surgical and other biomedical parts, die and mold manufacture industries, etc. [4,5]. Due to its widespread acceptance, it is almost used machining process after milling, turning and grinding [6].

1.1 SUSTAINABILITY CONCERN OF EDM

EDM is a very energy intensive process as shown in Fig. One which consumes 30–50 times more energy than in comparison to the conventional machining process. EDM produces prolonged machining rates (1–200 mm^3/min as against 100–5000 mm^3/min or even more) than conventional machining processes [6]. Disposal of waste generated in the process like debris mixed dielectric fluid, used electrode materials, etc. has serious issues related to recycling, reuse, and non-degradability. Dielectric fluids are highly flammable and volatility which offers concerns relating health and safety issue [8]. The EDM process also concerns with serious health problems and environmental aspects due to the release of toxic and hazardous fumes, gases, volatile agents, odor, smell and micro/Nanoparticles, and continuous longer exposure to the polluted working atmosphere [9]. Sustainable manufacturing processes are those which generate the minimum quantity of wastes, demonstrate improved environmental performance and energy efficiency while providing operational safety and personal health [10]. Increased market competitiveness, go green attitude of consumers, increased social awareness and corporate social responsibility (CSR. Sustainability of a manufacturing process is to be evaluated using six criteria via. Personnel health, operational safety, Environmental impact, manufacturing cost, material, and energy consumption and waste management [11].

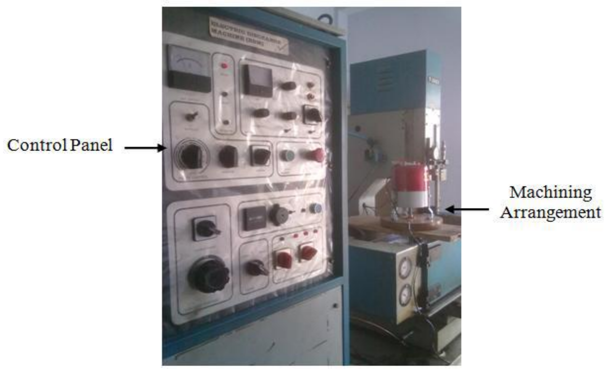

Fig.1. Set up of Electrical Discharge Machining

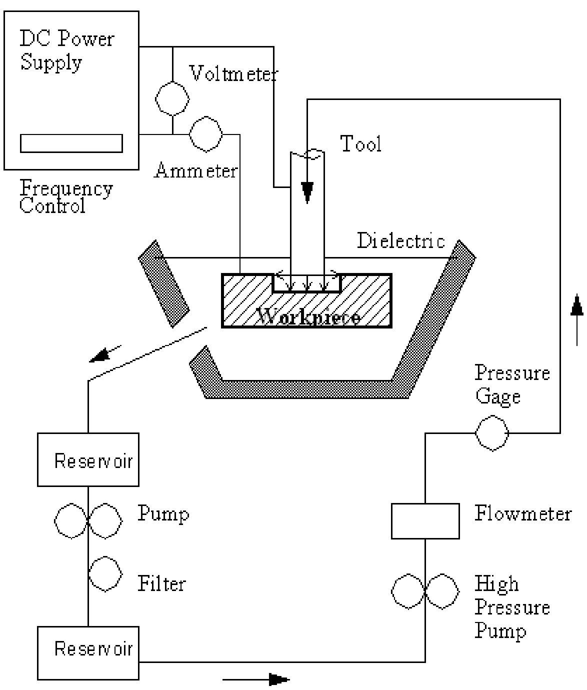

Figure 2 Schematic Diagram of Electrical Discharge Machining

1.2 Effect and Importance of Dielectric Fluids

Minerals oils and Kerosene oil are one of the popular dielectric fluids used in the performance measurement of EDM regarding TWR and MRR. These fluids have very low viscosity and flush easily as shown in Figure 2 of a schematic diagram of EDM. It works as heat transfer medium which controlled electric discharge occur and also works as a quenching medium to cool. Many researchers have observed and studied the effect of dielectric fluids on MRR and TWR during working on EDM machine.

2. LITERATURE REVIEW

2.1 Dry and Near dry wire EDM Process

Dry EDM is an environmentally friendly technique. In Dry electrical discharge machining process, the gaseous dielectric is used replacing fluid dielectric. High-velocity gas is flowing through the spark gap between tool electrode and workpiece. This flow of high-velocity gas into the spark gap facilitate the removal of material and debris particle. Mostly oxygen used as a dielectric. The using of dry dielectric enhance the material removal rate of the process with reducing electrode wear [12]. In the study observed that Dry electrical discharge machining (Dry EDM) has high removal rate and low tool wear ratio, the researchers conducted an experiment with cemented carbide (G5) and copper tungsten was chosen for electrode, and the result was that material removal rate of dry EDM milling is about six times larger than that of hydrocarbon oil EDM milling and tool electrode wear ratio was lowered by one-third [13].Dry EDM is a completely “green” machining process (about health, safety & environmental reasons)

There are found some factors favoring dry EDM are, i.e., No fire hazard, no toxic fumes generated, No need for special treatment for disposal of sludges, dielectric waste, filter cartridges. Another advantage is observed little tool wear rate, Thinner white layer, and lower residual, smaller Heat Affected Zone (HAZ) Narrower discharge gap length, No electrolytic corrosion of workpiece.

2.2 Water-based dielectrics for die sink EDM

In this category of EDM, water is used as a dielectric. It is more economical, safe and it has no negative impact on the environment, and no toxic fumes are generated. The author conducted experiments and concluded that higher MRR and lower wear ratio could be obtained while machining with distilled water compared to kerosene for high pulse energy range. The performance of plain water regarding material removal rate and electrode wear is lower when compared to that obtained with hydrocarbon oils in die sink EDM [14]. However, the use of deionized water or even tap water may result in higher levels of material removal rate. Hydrocarbon oils are utilized in a wide range of machining operations but the use of plain water results in better performance due to lower viscosity of water [15]. Moreover, the large amount of energy required to heat and vaporize water compared with oil results. Consequently, the molten metal is not removed properly in every discharge, because of the insufficient pressure produced by the burst of water.[16] To improve the performance of deionized water, some additives are added to it such as ethylene glycol, glycerine, polyethylene glycol 200, polyethylene glycol 400, polyethylene glycol 600, such compounds would be decomposed by the sparks producing gases with higher pressure than those produced by the decomposition of pure water[17]. This would improve the removal of the molten metal out from the craters, increasing the material removal rate. In one study, argued that solutions containing organic compounds with larger molecular weights be more efficient for material removal rate [18]. A solution with a high concentration of polyethylene glycol 600 had a performance compatible with Mitsubishi EDF. The best performance regarding productivity and costs was achieved with a solution of glycerine with 87% of concentration. The experimental investigations showed that addition of aluminium metal powder in distilled water results in high MRR, good surface finish, and minimum white layer thickness as compared with pure distilled water [19].The effect of aluminium powder mixed in distilled water on white layer thickness in EDM with W300 dies steel as workpiece and copper as a tool. Experiments were planned using face-centered central composite design procedure, and the empirical model was developed using response surface methodology. The White layer is found to increase with the increase in the current and pulse on time. White layer thickness is found to decrease with the powder concentration at every current level. The further lowest white layer thickness was observed with negative polarity [20].

2.3 Urea solution in water

In one experimental study, workpiece material was a taken of cylinder 6.3 mm diameter, 20 mm high of pure titanium. The electrode was made of copper. For a dielectric solution, the white crystalline granular of urea which readily dissolves in water; it has strong polarizability [21]. This work evaluates the machining performance of EDM by adding urea into the dielectric used in machining for pure titanium metal. Adding urea into the dielectric, MRR and EWR increased with an increase in peak current. Moreover, MRR and EWR declined as the pulse duration increased. This was due to the peak current increase, increasing the discharge energy modification. When the urea was added to the dielectric, the surface roughness deteriorated with an increase in peak current. Since an increase in the peak current increased the discharge energy and the impulsive force, removing more molten material and generating deeper and larger discharge craters. Hence, the surface roughness became coarser. Under suitable machining conditions, the surface modification of pure titanium metals by EDM exhibited improved friction and wear characteristics [22]. In figure 3 shown the SEM micrographs of the machined surface with conventional water dielectric and urea solution dielectric.

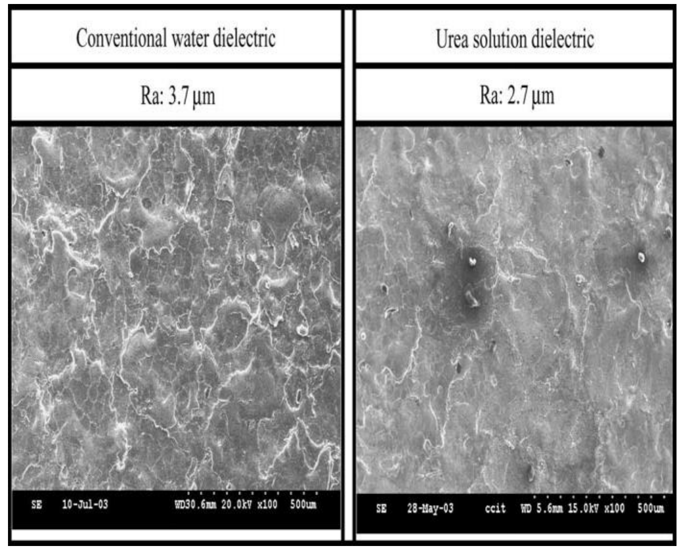

Fig. 3. SEM micrographs of the machined surface with different dielectrics [22]

2.4 Silicon Mixed Kerosene Solution Dielectric

In another [23] experiment study to evaluate the performance of Silicon powder mixed with kerosene servo them dielectric medium in EDM of Monel 400 is analyzed and the optimum range of Silicon powder. In this experiment, four different dielectric combinations are obtained by mixing the kerosene. In the study used with 6g graphite powder and 2g, 4g, 6g and 8g silicon powder respectively. The 10-mm diameter and 6 mm length of the copper tool electrode were prepared, and performance of the same was investigated in EDM of Monel 400 with a different combination of the dielectric medium. With keeping machining parameters constant such as machine voltage, current parameters, etc. The Variation of MRR and TWR with a diverse range of silicon mixture as depicted in Figure 4 and Figure 5.

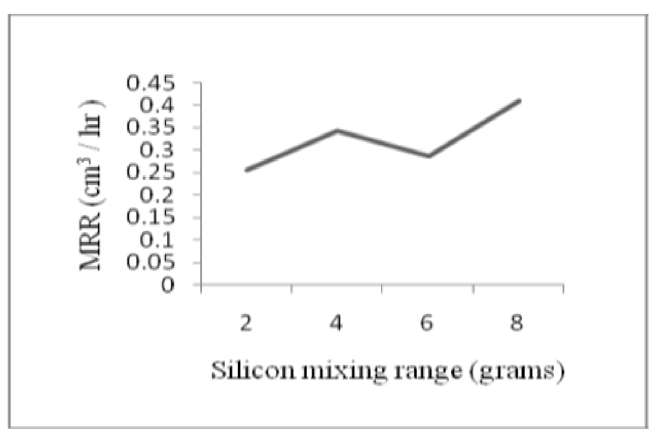

Fig.4.Variation of MRR with Silicon mixing range (grams) [23]

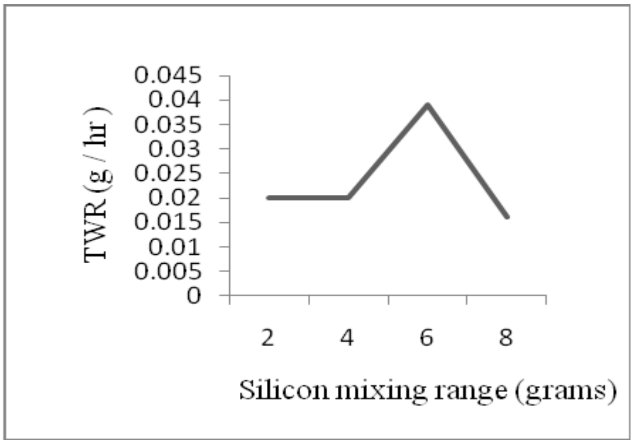

Figure 5. Variation of TWR with different range of silicon mixing range (grams) [23]

The conclusions of this experiment were summarized as followed by 8 and 6g of silicon and graphite powders are mixed with kerosene-servo them (75:25) gives better results of MRR, TWR, and OC. The kerosene servo them of 8g silicon mixed dielectric medium gives better result on surface smoothness and overcut accuracy.The experimentally observed performance of kerosene-servo them of different proportion of silicon powder found that better machining output in EDM of Monel 400.

2.5 Boron Carbide Mixed into Dielectric Fluid

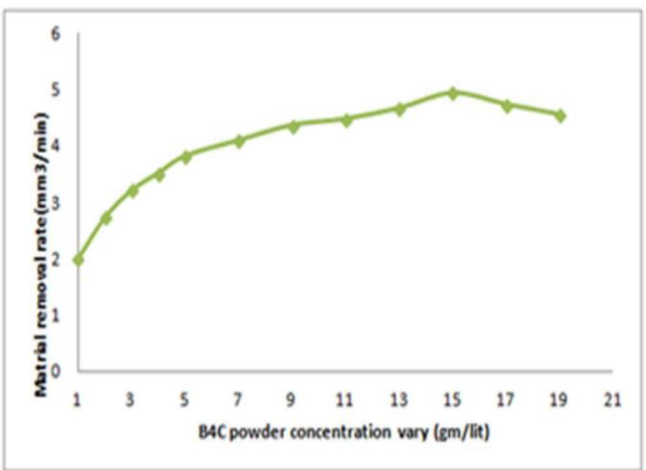

Figure 6. variation between MRR and B_4C powder concentration [25]

The experiment performed on Formatics EDM 50 die sinking, The electrolytic copper having dimensions of 14mm and 70mm length selected for the electrode. Moreover, the workpiece was of 100 mm length,50 mm width and 5 mm thickness made of Ti-6Al-4V alloy. For dielectric, spark erosion 450 EDM oil and Boron Carbide (B_4C) powder particles are used as the dielectric fluid for machining.Boron carbon powder is added in a certain amount into dielectric fluid because the conductivity of dielectric fluid increases with B_4C powder concentration [24] and continuously stirred to maintain a uniform distribution.The influence of B_4C powder addition to dielectric fluid on material removal rate [MRR], tool wear rate, surface roughness was investigated, and conclusions were drawn as followed the mixing B_4C powder into dielectric improved electrical discharge density and improved the MRR [25] as shown in Figure 6.

The tool wear rate increases with the increase in B_4C powder concentration and at 1gm/lit lower tool wear rate resulted. [26]. Surface finish can be improved by adding the B_4C powder in the dielectric fluid.

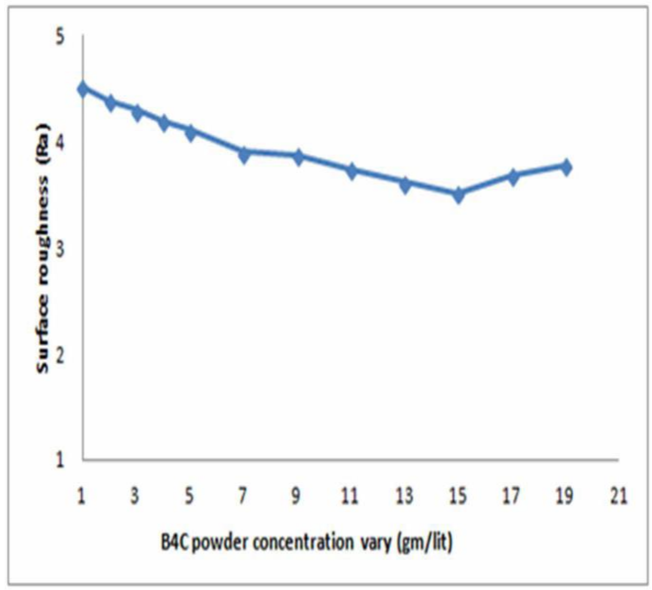

Figure 7. Effect of B_4C powder concentration on surface roughness [26]

High concentration levels of B_4C powder resulted in the good surface finish, fewer craters, and cracks. Dielectric fluid with B_4C powder added 1.0 gm/lit significantly affected by the recast layer thickness. Jatropha curcas, a perennial plant grown in tropics and subtropics is popularly known for its potential as a biofuel. The plant is reported to survive under varying environmental conditions having tolerance to stress and ability to manage pests and diseases. Out of various non-edible oil resources, Jatropha curcas oil is considered as future feedstock for biodiesel production. Jatropha-based bio dielectric fluid resulted in increased production rate, better surface finish, and increased surface hardness. Some of the main outcomes of this research study are listed in the study [27]. Jatropha BD resulted in 38%, 26%, 28% and 15% higher MRR than kerosene under the influence of process parameters such as current, gap voltage. It indicates that higher production rate can be achieved using Jatropha BD. The researchers observed that in 23%, 13%, 18% and 6% lower SR than kerosene for current, gap voltage. Improved surface finish is an indication of the better tribological performance of the surfaces generated by the increased life of dies, punches and another tooling. They found in 6%, 7%, 6% and 5% higher SH than kerosene for current, gap voltage. Higher surface hardness obtained for Jatropha BD is an indication that life of dies, punches and another tooling can be enhanced using Jatropha BD due to improved wears resistance through high surface hardness. EDM process. Jatropha BD resulted in better performance for MRR, SR, and SH compared to kerosene dielectric for EDM process. Moreover, the process behavior and response trends obtained with Jatropha BD are similar to that achieved in the case of kerosene. Results obtained in this research indicate that Jatropha BD is operationally feasible and better dielectric than kerosene for EDM process [28].

2.6 Powder Mixed Dielectric in EDM

The surface characteristics and material migration properties during surface modeling in EDM process, while machining dies steels (H11 and AISI 1045) with silicon, graphite and tungsten powder. Graphite, tungsten-copper and brass tools are used for machining. Powder mixed in dielectric along with its concentration, current, and pulse on time are identified as significant factors for surface finish, while powder and its concentration, current, pulse on time and electrode are found significant for microhardness (MH). Powder addition improves finish while the increase in current and pulse on time decreases finish [29]. The effect of process parameters and mechanism of material deposition rate in powder mixed EDM on dying steel materials was investigated by some researchers. Samples were analyzed by X-ray diffraction (XRD) followed by microstructure analysis using a Scanning Electron Microscope (SEM). Surface modification was measured regarding the MH, and results showed that there was almost 80 % increase in MH after powder mixed EDM and the results also showed a significant material transfer from the electrode as well as powder [30]. Current, powder and interaction between workpiece and electrode affected the MH significantly. The copper electrode was found best for EN31, and H11 die steel, whereas tungsten-copper electrode was better suited for steel to achieve higher MH value. Graphite powder was found to be more suitable compared to aluminium in improving the MH of all three materials. Highly amorphous structure because of high temperature coupled with rapid cooling was observed [31]. The optimization of powder mixed electric discharge machining using dummy treated experimental design with analytic hierarchy process with seven different process parameters, i.e., workpiece (HCHCr, Hot Die Steel, EN31), dielectric (kerosene and EDM oil), powder (copper, tungsten), electrode, pulse on and pulse off time and current with L27 array for optimization of MRR, TWR and SR. The process conditions that affected the three responses were identified and optimized together using AHP for HCHCr, EN31, and HDS workpiece. Addition of powder in the dielectric improved MRR as well as SR. Three factors, current, electrode material, and pulse-on time were found to be the most significant factors affecting MRR [32]. Electric current, powder and electrode material was significantly affected the TWR. It observed that kerosene as dielectric was observed to be a superior alternative than EDM oil. moreover, tungsten-copper tool electrode worked best for HDS as they globally optimize the three output variables. Arcing was observed at high current settings with a low pulse on time during the addition of more electrically conductive copper powder. Current and pulse-on time influenced the SR of the finished work surface. [33] studied the nano-powder-mixed sinking and milling micro-EDM of tungsten copper (WC-Co (10 % Cobalt)) workpiece with tungsten electrode and Total FINA ELF EDM 3 oil as a dielectric fluid. It was concluded that spark gap increases with increase in powder concentration producing an excellent surface finish up to a limit but poor surface finish after that, because after a limit when the powder is added, it leads to increase in series discharges producing a rough surface. MRR was found to increase with an increase in powder concentration. For all the concentration levels, powder-mixed milling micro-EDM was found to provide lower SR, higher spark gap, and lower TWR compared to powder mixed sinking micro-EDM. The studied about accuracy improvement in micro-EDM with nano graphite powder-suspended dielectric fluid with the silver-tungsten workpiece, tungsten electrode, and kerosene as a dielectric. In transparent dielectric fluid, since there are no disturbances at the detection of the first discharge, the machining depth ultimately is accurate. It was observed that the presence of nano graphite powder in the dielectric fluid increases the machining gap creating an early detection from discharge pulse [34]. It was observed that introduction of nanographite powder in dielectric reduces machining time by 35 %. The addition of nanopowder to a dielectric fluid also improved surface quality by eliminating micro-cracks in the surface machined and produced a high sparking gap size, which led to a reduction of electric discharge power density, hence low in explosion force due to the nanographite powder size. [35] described the effect of the micro-powder suspension of dielectric fluid in the μ-EDM process by using Taguchi Approach. The results showed that the introduction of MoS2 in the dielectric fluid in ultrasonic vibration significantly increase the MRR and improves surface quality by providing a flat surface free of black carbon spots. The studied about MRR and TWR in the powder mixed EDM of cobalt-bonded tungsten carbide (94WC-6Co) with copper electrode (negative polarity) and aluminium powder being mixed in mineral oil (TOTAL EDM44) as dielectric and observed that by using dielectric fluid with conductive aluminium powder can effectively disperse the discharging energy dispersion in order to improve the machining performance [36]. The MRR was found to increase up to a certain maximum value with the increase in the amount of aluminium powder and after that MRR reduced.

TWR was observed to show exactly the opposite trend to that of the MRR, i.e., TWR value was found to decrease with the aluminium powder concentration down to a minimum value after which it tends to increase. The effect of surfactant (polyoxyethylene-20-Sorbitan monooleate) on the powder mixed EDM with aluminium powder mixed in the dielectric and its effect on surface finish [37]. Surfactant retarded agglomeration of aluminium particles and well distributing them reducing the recast layer thickness. For this purpose, positive polarity, lower peak current and lesser peak duration were preferred. It optimized powder mixed EDM by response surface methodology using EN-31 tool steel as workpiece in kerosene dielectric with silicon mixed powder. Variables like pulse-on time, peak current, duty cycle and concentration of silicon powder in dielectric were selected for measurement of MRR and SR. It was concluded that addition of silicon powder in dielectric increases MRR and gives better surface finish. MRR was observed to increase with increase in concentration of silicon powder improving surface finish as well. Concentration and peak current individually affect the MRR and SR as well as their combination was also significant. In the paper [38] investigated the effect of the addition of fine graphite powder into kerosene oil. It was reported that addition of 4 gm/l of fine graphite powder increased the interspaces for electric discharge initiation and lowered the breakdown voltage. It was found that the added powder improves the breakdown characteristics of the dielectric fluid. It was further observed that the machining rate increases with increase in the concentration of the added powder. The effect of the addition of powder particles in EDM using AISI H13 steel as workpiece with electrolytic copper as an electrode in the dielectric fluid as Castrol SE fluid 180 with Silicon powder of 99.5 % purity. The analysis was carried out by varying silicon powder concentration and flushing flow rate over a set of different parameters [40].

3. CONCLUSION

From the literature review, with the help of gaseous dielectric mediums like oxygen, air, argon, helium, we can reduce the environmental pollution and also the machining time is reduced, the surface roughness of the workpiece material is increased. Some commercial water-based fluids have performance similar or higher than that of hydrocarbon oils. Gaseous dielectrics such as air and oxygen can provide higher material removal rates than that with a hydrocarbon oil, under some extraordinary machining conditions. Water-based dielectrics can replace hydrocarbon oils as they have higher performance and are more environmentally suitable.

4. FUTURE SCOPE

Many types of research and experimental work have been carried out contributes to the use of different dielectrics and mixture of additives which improve the performance of dielectrics which are cheaper and eco-friendly and have quite impressive Material removal rate. The literature review shows that dry EDM can be a substitute for hydrocarbon oil based EDM due to low cost, simple operation and no pollution. So, more research is needed for powder mixed EDM regarding using essential alloying elements such as manganese, molybdenum, vanadium, etc. in the form of powder for machining of materials which have not been tried yet. Effect of size, shape, and concentration of powder particles on the performance of EDM can also be investigated. More Research work is needed in the field of sustainable manufacturing and sustainable EDM processes.

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