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A REVIEW ON DIELECTRIC FLUIDS USED FOR SUSTAINABLE ELECTRO DISCHARGE MACHINING

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Abstract- Electro Discharge Machining (EDM) is a thermal energy based non-traditional machining processes. Machining takes place due to continuous recurring of the electrons from cathode to the anode thus leads to melting and vaporization of the material. Dielectric fluid is the most important component in Electro Discharge Machining. It has been found that dielectric fluids have significant effect on the machining characteristics like material removal, tool wear and surface texture of electrode material. Hydrocarbon based oil is the most commonly used in industries as dielectric fluid in EDM. Due to the decomposition of these hydrocarbon oils releases carcinogenic toxic emissions like carbon dioxide, carbon mono-oxide, benzene and polycyclic aromatic hydrocarbons etc. Wide varieties of dielectric fluids (based on water, gas and emulsions) have been used to make the EDM process sustainable. Promising results have been observed by using bio oils/biodiesels as dielectric medium in EDM. In this paper, a comprehensive over view of dielectric fluids used in EDM to make the process sustainable has been reported. Finally, some of the other possible bio oils has reported which can make the process greener and safer.

keywords- EDM, Dielectric fluid, Bio oil, Biodiesel, Sustainable EDM.

I. Introduction

Advancement in the field of materials results into innovation of new engineering materials which are extremely hard and difficult to machine with conventional machining processes. Electro Discharge Machining (EDM) being a non-contact type machining process, can machine any electrically conductive material irrespective of its hardness, strength. Material removal method for non-conductive materials by EDM was also reported [1]. EDM is most commonly used versatile non-traditional manufacturing process that account for about 7% of all machine tools market share in the world [2]. Due to its wide range of acceptance, it has become the 4th most used machining process after milling, turning and grinding [3]. EDM involves a controlled erosion of the work piece by the initiation of rapid and repetitive spark discharges between the tool and work piece [4]. The dielectric fluid present in the inter electrode gap gets ionized by high frequency pulse discharge and form plasma channel. The temperature of the plasma is in the order of 8000-12000K which intern melt and vaporize the any work material [5].

EDM has number of variants like die sinking [6,7], wire cut EDM [8], micro EDM [9], electro discharge boring [10], electro discharge milling [11], electro discharge grinding [12], electro discharge material deposition etc. Electrical discharge machining is the effective process amongst non-traditional machining processes, for machining difficult-to-cut materials such as Titanium [13,14], Inconel [10,15], high speed steel [16] etc. EDM find its unique application to machine super alloys, die and mould manufacturing industries, automobile and aerospace components, surgical and other biomedical parts, etc. [17-19]. Dielectric fluids have significant effect on the surface being produced, productivity, quality and material removal efficiency [20,21]. This work will cover a review of dielectric fluids used based on hydrocarbon, water, gas, bio oil/biodiesel for sustainability of EDM process and suggested some other potential bio oils to be use in EDM.

II. Sustainable EDM

Sustainable manufacturing is a systematic approach that deals with environmental, economic and social aspects of manufacturing activities. Sustainable manufacturing processes are those processes, which can produce which can produce minimum quantity of waste, demonstrate improved environmental performance, minimising manufacturing cost and energy efficiency while providing operation safety and personal health [22]. Sustainability of a manufacturing process is to be evaluated by six criteria via. Personal health, Environmental impact, Manufacturing cost, Energy and material consumption, Waste management and Operational safety [23]. The schematic representation of this six criterias are shown in Figure.1.

Valki et al. [17] have proposed Key Performance Indicators (KPI) to asses the sustainability performance of the EDM process for each criterion of sustainalbe manufacturing is as shown in Table 1. KPI's framed for the EDM process indicates that the dielectric fluid used in the process is one fo the major sources affecting the sustainability of the EDM process.

EDM process offers some environmental, economic and social concerns like poor material removal rate, electrode wear,

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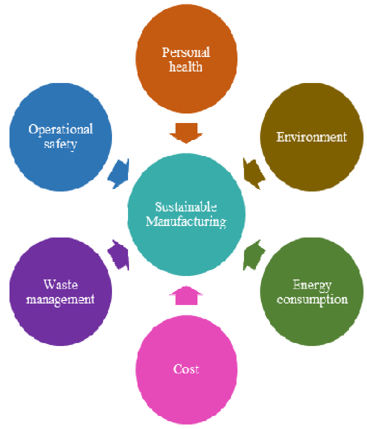

Fig. 1 Criteria of Sustianable Manufacturing

high specific energy consumption, deteriorated surface characteristics, hazardous emissions near operator breathing zone, the possibility of fire explosion and toxic waste and sludge generation [24]. EDM is a very energy intensive process and consumes 30-50 times more energy than in comparison to the conventional machining processes. EDM produces very low material removal rates as compared to conventional machining processes [3]. Different substances emitted from the EDM process will have different effects on operator health. The solidified metallic vapors cause allergic reaction, asthma and lung diseases. Hydrocarbon constituents cause health problems like dizziness, irritations of the skin [25], headache, confusion, memory difficulties etc. [6]. It has been reported that carcinogenic hydrocarbons like carbon dioxide, carbon mono oxide, butyl acetates, benzene and polycyclic hydrocarbons etc., near to machining zone while using hydrocarbon based dialectic fluids [26,27]. Jose et al. [7] have observed that higher values of process parameters increase the concentration of aerosol emissions to beyond permissible limit.

During EDM process Ray [28] has observed various harmful substances released in the form of solid, liquid and gas that result into serious occupational health and environmental issues. Toxic fumes, vapors of the electrode materials and aerosols are observed. Hydrocarbon based dielectrics contain aromatic, paraffinic and naphthenic components. Logesh and Senthil Kumar [29] have investigated the environmental impact minimization on different EDM electrode materials. Due to more wear resistance copper produces less environmental impact compared with the brass, but the emissions produced is more. Compared to copper the emission in the tungsten copper is less. Sivapirakasam et al. [7] have studied the constituent analysis of aerosol generated from die sinking electrical discharge machining process. It was found that 69% of aerosol consists of metallic particles. The remaining portion of the aerosols consisted of carbon dust and unidentified compounds.

III. Literature review

Dielectric fluid plays a major role in the maintenance of stable machining, to achievement of close tolerance and high surface quality. Inadequate flushing can result in arcing, decreased electrode life and increases production time. The main function of the dielectric fluid are

- It should flush the debris particles from the inter electrode gap.
- Provide insulation between the work piece and tool electrode.
- Should be able to cool the surfaces of the both electrodes [4].

1. Water based dielectric fluids

Generally water based dielectric fluids give low material removal rates as compared to hydrocarbon based dielectric oils. Due to lower viscosity of water, it produces less restriction to the plasma channel thus leads to lower energy density and as consequence decreasing in material removal rate [30]. Moreover large amount of energy is require to heat and vaporize water when compared to oil based dielectric fluids which leads to lower gas pressure in the inter electrode gap. Consequently, lower material will be removed per every discharge because of lower pressure created by burst of water. However, the use of water based dielectrics gives more material removal rates in some special conditions [13,31,32].

Erden and Tamel [31] observed higher material removal rate and lower electrode wear when machining steel workpiece with brass electrode in deionized water compared to hydrocarbon oil. Negative polarity was used in this work. At pulse duration of 800µs it was observed that 60% higher material removal rate and 25% lower electrode wear with deionized water. Jilani and pandaey [32] reported that the performance of top water was better than distilled water and hydrocarbon oil when pulse duration less than 500µs pulsed.

Chen et al. [13] have studied the influence of kerosene and distilled water on Ti-6Al-4V alloy in EDM process using copper electrode. A higher electrode wear ratio and a lower material removal rate was observed while using kerosene. Upon decomposition of kerosene, carbon adheres to the electrode surface and forms titanium carbide (TiO_2). It was suggested that due to its high melting point and unstable discharge impulsive forces leads to reduction in material removal rate.

Chow et al. [33] added SiC powder to pure water as the working fluid for micro-slit EDM. The results indicated that the addition of SiC powder would increase electrical conductivity of the working fluid, enlarge the discharge gap between electrode and workpiece, can flush the debris easily, thus results higher material removal rate. In order to increase the performance of water some authors have added organic components with large molecular structures like ethylene glycol, polyethylene glycol 200, polyethylene glycol 400, polyethylene glycol 600, dextrose and sucrose.

In addition of organic compound attributes to increase of viscosity which lead to effective restriction to plasma channelTable1. Key performance indicators for Sustainable EDM [17]

Sr. no	Sustainability criteria	Key performance indicators for EDM
1	Personal health	Emissions of organic and inorganic compounds in the form of gases, molten vapour and solid particulate concentraion in the operator breathing zone Exhaust ventilation in the operator breathing zone to keep harmful concentraions blow specified limits
2	Environmental impact	Biodegradability of dielectric fluid Non-toxicity of dielectirc fluid Green manufacturing practices index
3	Energy consumption	Use of minimum amount of dielectric for the same amount of material removed Recondition, recycle and reuse of used dielectric
4	Manufacturing Cost	Minimum deterioration of metallurigical structures of tool-work materials Minimum amount of post material removal operations, rework and defective parts produced Lean manufacturing measures
5	Waste management	Recyclability and reusability of waste dielectric, sludge and used electrode Ensure minimum spillage Minimum hazardless inde of waste
6	Operational safety	Minimum fire risk for dielectrics Prevention of vapour accumulation zones for fire risk mitigation

thus leads to higher material removal rates [30]. Konig et al. [34] observed that water based dielectrics are suitable for both roughing and finishing machining with a glycerin concentration ranging from 50 to 60%.

2. **Gaseous dielectric fluids**

In Dry EDM gaseous dielectric fluid is used instead of liquid dielectric whereas in Near-Dry EDM uses gas-liquid mixture as the two-phase dielectric fluid and has the advantage the concentration of liquid and properties of dielectric fluid to meet desired performance responses. High-pressure gas or air is supplied through the pipe. The role of the gas is to remove the debris from the gap and to cool the inter electrode gap. The technique was developed to decrease the pollution caused by the use of liquid dielectric which leads to production of vapour during machining and the cost to manage the waste.

Kunieda et al. [35] observed that the performance of EDM using gas (air and O2) can be better than that with a dielectric liquid under some especial situations i.e., the use of a tubular electrode with very thin wall (<0.3 mm), negative polarity of the electrode, rotation/planetary motion of the electrode and high speed gas flow. Material removal rate achieved with oxygen was higher than that achieved with air and EDM oil. The greatest advantage of EDM in gas is the very low level of electrode wear (almost zero), which was reported to be independent on the pulse duration. The material removal rate of EDM with gas can be improved using ultrasonic vibrations of the workpiece, as it helps the flushing of the molten metal from the craters.

Yu et al. [36] have machined cemented carbide by using copper tungsten as tool electrode in dry EDM milling process. Material removal rate observed with dry EDM was six times larger than with conventional hydrocarbon oil EDM and tool wear was lowered by one third.

Pattabhiraman et al. [37] have investigated atomized dielectric spray based Electric Discharge Machining (spray-EDM) for Sustainable Manufacturing. Spray EDM involves the application of dielectric to the machining zone in the form of droplets that are several micrometers in size. The use of a thin film of dielectric not only reduced the quantity used during the process but also resulted in better machining performance compared to conventional wet and dry EDM techniques. The discharge energy in the spray-EDM process was 37% higher compared to conventional wet-EDM and dry-EDM processes. The volume of material removed in the spray EDM process was 78% higher than those observed during wet-EDM and dry-EDM. The tool wear in spray-EDM was significantly lesser than dry EDM due to the better heat removal capability of the flowing liquid film and comparable to that observed in conventional wet-EDM.

Dhakar and Dvivedi [16] investigated on near-dry electro discharge machining using glycerin-air mixture as dielectric medium. Copper tube was used as electrode with external diameter 5.6 mm and internal diameter 3mm to machine High Speed Steel (T2 grade) workpiece. In this investigation, highest material removal rate (MRR) 8.99 mm^3/min was measured at parameter setting of current 15A, duty factor 0.80 and flushing pressure 80 psi. However, Dhakar and Dvivedi [38] reported that MRR obtained at same parameter setting with water-air dielectric medium was 3.29 mm^3/min. It was revealed that combination of glycerin-air dielectric medium produces approximately three times higher MRR than water-air dielectric medium.

3. Emulsion based dielectric fluids

Some of the authors have studied the influence of emulsion as dielectric fluids from the last decade. Most commonly, water and oil is used to prepare the emulsion to grab the advantages of both the liquid properties. Compared with kerosene, emulsion is more efficient, economical, and environmentally friendly but less stable.

Liu et al. [39] investigated an emulsion for die sinking EDM. The anionic compound emulsifier (ACE) is made of sodium petroleum sulfonate and triethanolamine oleate. Emulsion-1 was 95 wt.% distilled water+ 5 wt.% emulsified oil with 25 wt.% ACE and 75 wt.% machine oil. Emulsion-2 was 95 wt.% distilled water +5 wt.% emulsified oil with 25 wt.% ACE, 1 wt.% OP-10, and 74 wt.% machine oil. The reason for this is that OP-10 molecule can insert into the saturated adsorption layer formed by ACE. It can improve the adsorption action and decrease the van der Waals force between the hydrophobic groups, so the surface tension decreases very slowly with increasing OP-10. In comparison with kerosene, emulsion-1 and emulsion-2 used in EDM show high MRR, low surface roughness, high discharge gap, and good working environment. The electrode wear ratio in emulsion-1 is lower than that in kerosene. The electrode wear ratio in emulsion-2 is higher than that in kerosene. In comparison with emulsion-1, emulsion-2 used in EDM shows high MRR, low surface roughness, low discharge gap, and high electrode wear ratio. Experiment results show that when using emulsion-1 and emulsion-2 as the machining fluid in EDM, negative polarity for the tool electrode should be used.

Zhang et al. [40] investigated the die sinking EDM in water-in-oil (W/O) emulsion. W/O emulsion was prepared using, for the oil phase, 66 vol.% of machine oil and, for the water phase, 34 vol.% of de-ionized water. In order to stabilize the emulsion, 2.5 wt.% of Span80 was added to the oil phase. It was suggested that the MRR of the W/O emulsion was higher than the conventional EDM dielectric kerosene. Since the discharge crater was larger, the surface roughness value obtained in W/O emulsion is slightly higher than that of kerosene. Relative Electrode Wear Ratio (REWR) was higher when using W/O emulsion as the dielectric fluid than when using kerosene.

Zhang et al. [20] has investigated die-sinking electrical discharge machining with oxygen-mixed water-in-oil emulsion working fluid. The emulsion and oxygen were premixed before compelled into the gap through the flushing hole in the center of the copper electrode. The average diameter of the water droplets in emulsion was about 8–10μm. It has been reported that the material removal efficiency highly improved by mixing oxygen into the emulsion. Since the melted material was effectively removed, the recast layer of the machined surface was much thinner with the oxygen-assisted EDM. Experimentation result when using other gases is shown in Fig.3.

Zhang et al. [21] investigated the influence of the dielectrics on the material characteristics of EDM to machine mild steel 8407 by using steel needle with the help of 5 different dielectrics namely Oxygen, air, kerosene, de-ionized water and water oil emulsion. Pulse on time was the only parameter considered over a long range starting from 52 to 840μs. It was found thatthere was a huge difference of the geometry shape of the craters formed in different dielectrics

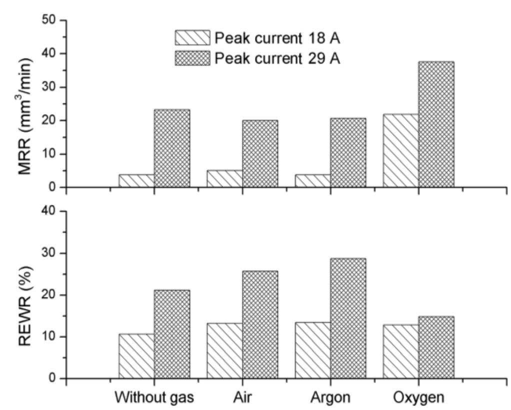

Fig. 2 Comparison of the type of the mixed gases on MRR and REWR [20]

even with the same experiments conditions. In water in oil emlsion high pressure can sustain for a much longer time than that in kerosene and deionized water due to the extremely high viscosity of the water-in-oil emulsion. It was suggested that higher material removal is possible by water in oil duet to its high pressure at dischargespot.

4. Bio oil/Biodiesel based dielectrics fluids

Shah et al. reported that vegetable oil based esters have dielectric properties comparable to hydrocarbon and synthetic oils. Bio oils/bio diesel generate no fumes, environment friendly and efficient compared to hydrocarbon oils. The use of bio based oils in EDM have given more material removal rates [15,17,18,24,41], high electrode wear rates[15,24,41] and high surface roughness [15,17]compared to hydrocarbon oils.

Valaki and Rathod [41] were investigated the feasibility of Waste Vegetable Oil (WVO) as bio dielectric fluid for sustainable EDM. Cold worked plastic mould steel has been machined by using 99.73% carbon electrode as tool in the presence of esterified WVO and kerosene to investigate MRR, Electrode Wear Rate (EWR) and Tool Wear Ratio (TWR). The comparative results obtained in this research show that from the operational feasibility point of view, WVO dielectrics can be used as an alternative to hydrocarbon-based dielectric fluid, i.e. kerosene. Trends of response parameters, i.e. MRR, EWR and TWR, obtained using WVO indicate similarity with results of kerosene.

In continuation to the previous work [41], Valaki and Rathod [24] investigated feasibility of EDM by newly proposed vegetable oil based green dielectric fluids, Jatropha oil (BD1) and waste vegetable oil (BD2). Comparative analyses for BD1, BD2 and kerosene have been studied to assess the performance in terms of MRR, EWR and relative wear ratio (RWR). It has been observed that under the influence of current, BD1 and BD2 produced 38% and 165 % improvement in MRR respectively. In addition, BD1 and BD2 resulted 100% & 275% higher EWR than kerosene. Moreover, BD1 and BD2 resulted 30% higher and 7% lower RWR, respectively under the influence of pulse duraiton.

Mali and Kumar [15] investigated feasibility of Waste Vegetable Oil (WVO) derived from Pongamia Pinnata and Blended Used Vegetable Oil (BUVO) out of castoff edible vegetable oil has been used as dielectric for sustainable EDM process. Inconel 718 workpiece has been machined by using copper tool electrode. WVO results in 32% higher and BUVO results in 10% lower MRR as compared to Conventional Hydrocarbon Oil (CHO). EWR obtained while machining with WVO is 40% higher compared to CHO while BUVO results in 8% lower EWR.

Valaki et al. [17] studied the feasibility of Jatropha Curcas oil based bio dielectric fluid for sustainable EDM. Jatropha resulted in 38%, 26%, 28% and 15% higher MRR and 23%, 13%, 18% and 6% lower surface roughness than kerosene under the influence of process variables vis. current, gap voltage, pulse on time and pulse off time, respectively. Ng P.S et al. [42] reported the feasibility of canola and sunflower biodiesels as dielectric fluids for sustainable EDM.

Sadagopan and Mouliprasanth [18] examined the influence of different types of dielectrics in EDM. Biodiesel, transformer oil and kerosene was used to machine Aluminum alloy 6063 by using copper tool electrode. Biodiesel was derived from palm styrene with lower viscosity and higher flash point. It has been observed that in the case of biodiesel as dielectric, the MRR is much higher compared to transformer oil and kerosene whereas the EWR with biodiesel is slightly less in comparison with transformer oil and kerosene. It was suggested that MRR and EWR are mostly affected by peak current followed by pulse on time.

IV. Future Scope

It has been reported that dielectric fluid used in EDM should have higher flash point [43,44] excellent biodegradability [44], higher oxygen content [45], low carbon atom chain [45], nontoxic, higher breakdown voltage [43,46], higher viscosity, lower toxic emissions and lower volatility [46]. Dielectric strength and viscosity are the most important as these are attributed to higher material removal. Any bio oil consisting of these properties can be promising results in EDM. Abeysundara et al. [47] coconut oil as an alternative to transformer oil due to its superior properties and characteristics than conventional hydrocarbon and mineral oil. Karaosmanoglu et al. [48] have reported the fuel properties of cottonseed oil. Sekhar et al. [49] have produced biodiesel from neem oil by esterification. These bio oils have properties in the same range of conventional hydrocarbon oil. Hence, the feasibility of these oils have to be investigate for Electro Discharge Machining.

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