The Environmental Impact of Electric Discharge Machining

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Abstract- Sustainable manufacturing aims to use fewer resources and energy, and to produce less environmentally harmful waste and less pollutants. Productive, scientific and research institutions have sought to innovate and develop new production methods that contribute to improved performance, profitability, quality improvement and adherence to sustainable manufacturing requirements. Electric discharge machining is used to machine different types of materials especially hard material with high precision. During EDM wastes and toxic emissions are released to cause negative impact on the environment and operators health. The concentration these undesirable products are affected by several factors, the most important of which is the type of the dielectric or dry EDM or near-dry EDM. In this paper, authors have reviewed studies which most of them focus on two sustainable manufacturing indicators, machining performance and environmental impact of using hydrocarbon based dielectric fluid and compared to bio-dielectric, water, dry, and near-dry. It is concluded from these studies that there are alternatives to EDM, and these alternatives give good machining results and have less impact on the environment. To reduce the risk of the process requires safety measures and some equipment and further researches in sustainable manufacturing using EDM.

Keywords EDM, dielectric fluid, sustainability, bio-dielectric, dry EDM

1. Introduction

Advancement in material science and producing many kinds of hard materials that cannot be machined by conventional machining easily. Also, another technology called non-conventional machining can machine hard materials faster, precisely and more economical has become worldwide recently. Electric discharge machining (EDM) is one these non-conventional metal removal processes [1]. By EDM possible to machine hard materials which is difficult to machine by conventional machining, complex shapes, with micro or macro removal rate, and different type of materials, in addition, many successes have also been achieved to produce macro and micro parts are used in industrial applications [2,3].

EDM was invented by two Russian scientists, B. R. Lazarenko and N. I. Lazarenko during the period between world war I and II. Since 1940 has become possible using EDM to machine hard material, and continued development in EDM processes. The invention of computer contributed solving many mathematical modeling problems related to EDM processes which caused remarkable advancement in EDM. In last fifty years tremendous improvements and development have introduced in EDM such as ultrasonic assisted EDM, powder mixed EDM, dry EDM machining, rotary EDM, micro EDM and Wire Electrical Discharge Machining (WEDM) which contribute performance improvement [4,5]. During 1970s CNC wire-cut EDM machine was introduced and since that time EDM has been contributing effectively in manufacturing [6].

The EDM working process is based on removing and shaping hard material from a part by repeated electrical discharges (spark) between electrode (tool) and the anode (workpiece) in the presence of a dielectric fluid which generates a path for each discharge as the dielectric fluid ionized, heat and pressure rise in the gap between the anode and the electrode. When the potential raises to about 70 V, a discharge occurs and temperature raises of about 8000 to 12000 °C causing a small melt in the surface of the workpiece, within a very short duration (micro second) the voltage drops to 20 V, the discharge stopped, the pressure drops, and the temperature drops which causes bubbles expelled melted material out. This process repeated 20000 to 300000 times per second [7]. Figure 1 illustrates inputs and outputs of EDM process [8]. Discharge current and frequency of discharges are the two main parameters affected on EDM process [9].

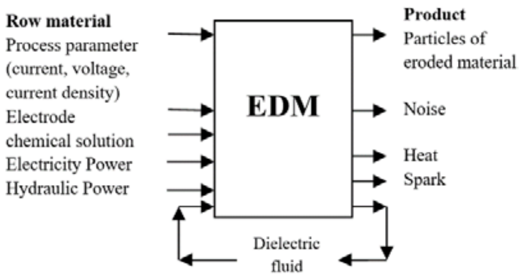

Fig. 1. Inputs and outputs of EDM process [8].

The performance of EDM measures by material removal rate (MMR), electrode wear rate (EWR), total wear ratio (TWR) and surface finish, and these machine characteristics are influenced by material of electrode, dielectric and material of workpiece [10]. The machinability in EDM based on electric conductivity not on mechanical properties, that makes EDM has characteristics to machine materials in different mechanical properties better than traditional machining. Many types of dielectrics are used in EDM.

Dielectric fluid has significant role in EDM performance and EDM environmental impact [11]. MMR, TWR, EWR and surface roughness (Ra) released emissions and wastes during machining are highly affected by type of dielectric fluid. Dielectric fluid effectiveness could be changed or improved by adding some materials, for instant, powder added to the dielectric fluid to improve machining process, its influences depends on type of powder and its concentration [12,13] using air or gases as a dielectric fluid have particular impact on machining process, and salt mixed de-ionized water dielectric and its concentration has significant influence on performance criteria [14].

Industrial processes are the main impact on the environment because of producing pollutants during processing and depletion of resources. As the industry developed, pollutants began to take on other forms. However, EDM has significant environmental impact, during the machining toxic emission is produced due to temperature generated, heavy and poor biodegradable materials are mixed in slurry, electromagnetic radiation, which have negative impact on the environment, in addition to the high consumption of electric power [15]. Figure 2 illustrates the various hazards that may result from the EDM.

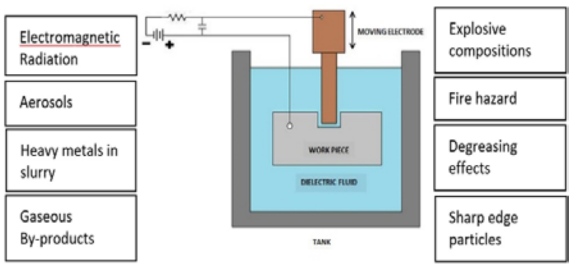

Fig. 2. The possible hazards of EDM [16].

Recently there are many studies have focused on the impact of input parameters on the performance of EDM and using fewer hazardous materials. These included conducting experiments and developing mathematical models that help identify waste and emissions from EDM before to start manufacturing [17,18]. Which in turn supports sustainable manufacturing in terms of achieving better process performance in terms of cost, performance and reducing environmental impact.

2. Environmental Impact and Personal Health

Many manufacturing processes produce industrial waste and environmental effects. As well as machining by EDM produces hazards that harm the operator health at breathing zone such as the emissions of chemical compounds, and environmental impact like non-biodegradable dielectric, toxic dielectric, and non-green products. The quantity of these products depend on inputs of machining process as shown in Figure 1. The undesirable wastes and emissions can be controlled and mitigate their impacts taking practical steps towards environmental improvement [19]. Safety measures are required to prevent fire risk and mitigate dangerous [20].

Abbas et al. reported that the amount of dielectric waste for the process is significant and has an environmental and economic impact. And recommended using EDM with water or dry EDM [21]. Singh et al. hydrocarbon oil such as kerosene decomposes and releases harmful gases during EDM, whereas water as dielectric and dry-EDM give superior performance results and safer and less impact to the environment [22]. Singh et al. mentioned that in EDM, using oil-based hydrocarbon as a dielectric causes damage to the environment. Dry-EDM, near-dry EDM and EDM in water are distinguished by many machining advantages, furthermore their impact to the environment less than oil-based fluids [23]. Chen et al. researched on airborne nanoparticle pollution in a WEDM workshop and possible harm to health and reported that significant harmful gases are generated and polluted atmosphere of a WEDM workshop, and effective measures must be taken to prevent air pollution in the working atmosphere, which causes damage to the health of the workers [24]. Jose et al. have investigated aerosol emissions from EDM using hydrocarbon based dielectric fluid with different process parameters. Figures 3,4,5,6 and 7 show that the concentration of aerosol emissions increased with increase in the peak current, pulse duration and dielectric level and decreased when the flushing pressure was increased, and at higher values of peak current and pulse duration, the concentration of aerosols at the breathing zone of the operator was just above the permissible exposure limit value for respirable particulates (5 mg/m3). Fire or explosion is possible to occur but can be prevented by following safety instructions [15].

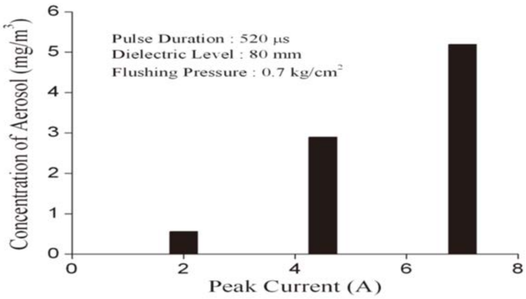

Fig. 3. The impact of peak current on concentration of aerosol at the operators breathing zone [15].

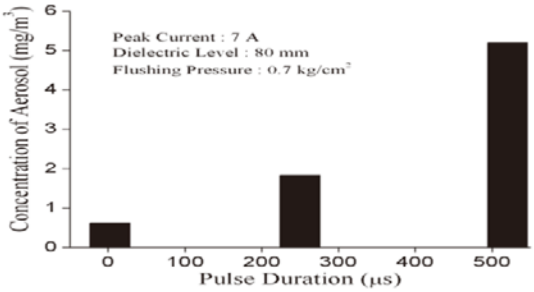

Fig. 4. Pulse duration impact on concentration of aerosol at breathing zone of the operator [15].

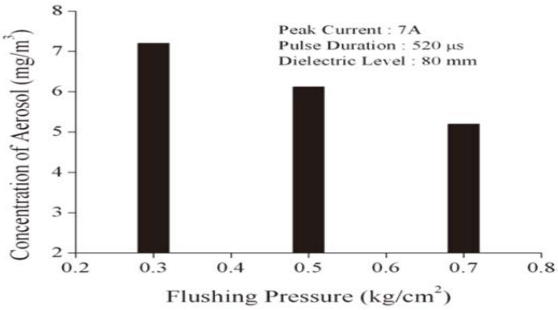

Fig. 5. The impact of flushing pressure on concentration of aerosol at the operators breathing zone [15].

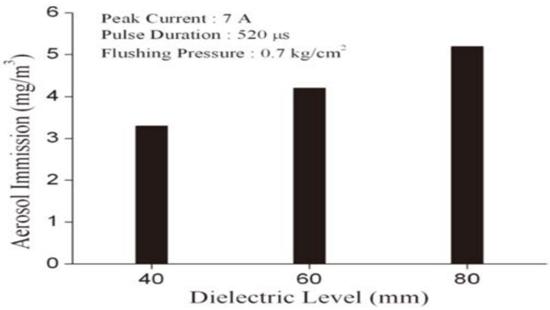

Fig. 6. The effect of dielectric level on concentration of aerosol (respirable) at breathing zone of the operator (At high discharge energy) [15].

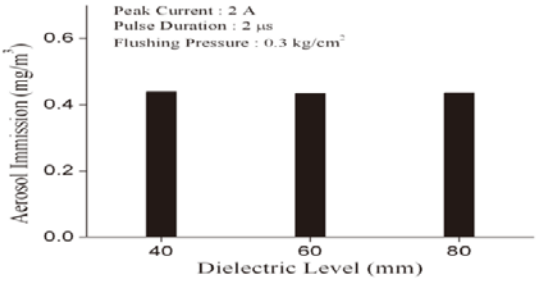

Fig. 7. The impact of dielectric level on concentration of aerosol the operators at breathing zone (At low discharge energy) [15].

Sapkale et al. reviewed the effect of dielectric fluid in EDM and mentioned that hydrocarbon oil gives better machining performance results in die sinking EDM but releases toxic emission products affect environment and health of the operator. Some experiments were carried out with water-based fluids such as distilled or deionized water, tap water etc. they were better MRR, less TWR and better surface finish, but recast layer and micro-cracks are produced. adding powder additives to dielectric fluid the results were better than original fluid. But it gives more aerosol emissions which are harmful to the environment as well as health of the operator. Experiments has done with using vegetable oil gave better performance results than hydrocarbon oil. Vegetable oils are biodegradable, environment friendly and do not negative effect to the health of operators, therefore can be an alternative solution to hydrocarbon dielectric fluids. However, studies in this area are insufficient and require further study [25].

Valaki et al. have investigated the hazardous impact of wet EDM, dry EDM, and near dry EDM and reported that wet EDM has a higher environmental impact, operators' health and operational safety requires because of harmful chemical released to the operators breathing zone, sludge, and poor biodegradability of dielectric fluid. Dry EDM has minimal impact to environmental and personal health compared to wet EDM. But it provides some concerns to the operations zone since the concentration of toxic gaseous, harmful aerosols, that impact on operators' health near operator breathing zone. Near-dry EDM provides high concentrated mixture of hazardous gaseous, solid metallic particles, vapors, and liquids, require strong safety measures to prevent any risk of fire and explosion [26].

Satyrthi et al. have studied different types of EDM and concluded that the EDM generates harmful substances and the green processing would be a better option for manufacturing by EDM process [27]. Valaki et al. have mentioned that machining using waste vegetable oil (WVO) dielectric provides MRR, TWR, and EWR results like using hydrocarbon-based dielectric (kerosene). Also, WVO less environmental impact, cleaner, greener, and its emissions less hazardous compared to hydrocarbon-based dielectric. So, WVO is a possible alternative dielectric fluid to hydrocarbon oil (kerosene). Using WVO dielectric fluid in EDM is a contribution towards sustainable manufacturing, that because of the results that have been achieved to improve the impact on workers' health as well as on the environment. The widespread adoption of ISO 14000 and increased awareness of environmental impacts also supported sustainable manufacturing [28]. Amanullah et al. reported that vegetable oil-based dielectric fluid is high biodegradable, nontoxic, has very low impact on operator's health and environment friendly [29].

Abbas et al. have reviewed previous studies and explained different methods and the development in EDM and mentioned that using water as a dielectric in EDM process is safe and environmentally friendly [4]. Goh and Ho, reported about the influence of dielectric fluid on operators' skin and mentioned that the skin irritation is as a result of prolong and frequent contact to the dielectric fluid which contain hydrocarbons produced from petroleum. Following safety instruction and personal hygiene prevent irritant contact [30].

Sivapirakasam, et. al. have conducted experiments on sinking EDM using hydrocarbon dielectric fluid and reported that the pulse duration and the peak current have the most influence on aerosol generation and concentration on the breathing zone. An analysis of aerosol resulted the presence in about 69% spherical shape metal particles with an average volume of 20-29 nanometer, and approximately 20 different hydrocarbons with 12.2%. And the respirable particulates concentration was greater than the safe exposure limit values at higher values of pulse duration and peak current. The compositions of aerosol generated are affected by the composition of the electrode materials, the boiling point of its constituents, and the presence of toxic particles is influenced by the presence of these particles in the alloy is expected whenever alloy containing that material is machined. It also recommended a set of measures limiting the damage caused using EDM such as choosing proper material, dielectric and process parameter, ventilation and dust extraction, filtering dielectric fluid, and wearing safety gears [31].

Singh and Sharma have mentioned that in EDM the aerosol concentration can be considered as the more significant environment polluting factor and is highly affected increasingly by the increase in current, pulse-on time, and dielectric fluid level. These aerosols affect the health of operators and may cause them some health problems such as, skin infections and respiratory diseases. To reduce the influence of these hazardous, safety procedures must be taken to prevent harmful effect, as well as, EDM equipment must be kept in good working condition [32]. Paramashivan et al have concluded that dielectric has a significant role in condensing most of emissions. In addition, peak current and pulse duration have crucial influence on emissions concentration, and any increase in peak current cause increase in emissions concentration [11].

Thiyagarajana et al, have stated that MRR and variation of hazard materials released affected by constituents of workpiece and their melting and vaporization temperatures. The melting point of the metal has a significant impact on emissions. Materials with a low melting point release more emissions concentration. Reducing the risk of these chemical emissions requires a range of procedures, commitments and equipment, such as providing the workplace with ventilation systems as well as fume extraction systems [33]. Singh et al. have compared dry-EDM to EDM and mentioned that one of the most important advantages of dry-EDM is eco-friendlier compared to the EDM since dry-EDM produce less harmful emissions and waste and no risk about fire [34].

3. Productivity of EDM Performance

Recent years have witnessed the development of the technique of EDM use in metal cutting, as well as many types. Each type has its disadvantages and characteristics in terms of performance and impact on the environment. Researchers have worked hard to improve the performance of this technique and reduce its risks to the environment and humans [5]. EDM productivity is assessed by MMR, EWR, and TWR, but some of researchers consider surface textures too. Figures 8, 9, 10 and 11 show performance of EDM operations.

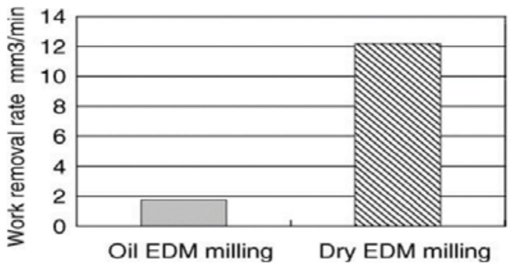

Fig. 8. Comparing work removal rate of oil EDM milling to dry EDM [35].

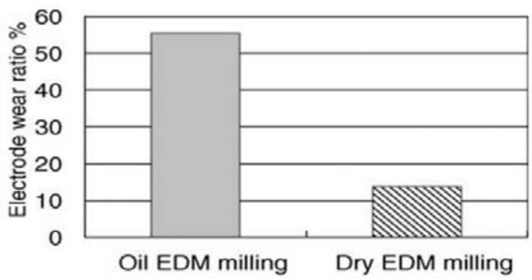

Fig. 9. Comparing electrode wear ratio of oil EDM milling to dry EDM [35].

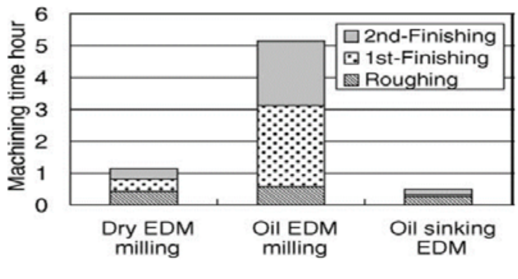

Fig. 10. Comparing machining time of oil EDM milling to dry EDM [35].

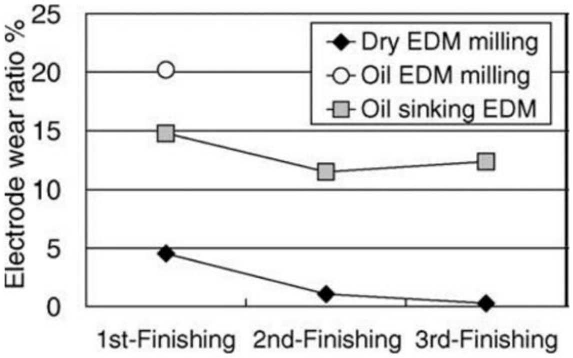

Fig. 11. Comparing electrode wear ratio [35].

Yu et. al. have experimented and summarized the results of cemented carbide machining using dry EDM and oil EDM. Dry EDM milling provide higher machining rate and lower EWR than oil EDM milling, whereas, machining time was longer by using dry EDM compared to oil die sinking EDM. Considering the required time to produce electrodes for oil die sinking, dry EDM becomes more beneficial in manufacturing [35].

Singh et al. have compared dry-EDM to EDM. In dry-EDM the EWR is lower and surface roughness is better. Machining cost in EDM higher than in dry-EDM because of EWR is higher and cost of dielectric fluid. MRR in dry-wire EDM is lower as comparing with wire EDM, but in dry wire EDM milling MRR is higher in EDM [34].

Valaki et al have experimented Jatropha carcass oil-based bio dielectric (Jatropha BD) fluid for (EDM) and compared to hydrocarbon-based dielectric. And the result was; higher material removing rate, smoother surface, and improved surface hardness in Jatropha BD compared to hydrocarbon-based dielectric. Considering Jatropha BD is friendly environment substance, and gives high performance, consequently Jatropha BD can replace hydrocarbon-based dielectric [20].

Leão and Pashby have reported that many studies evident in die sink using hydrocarbon-based dielectrics are more efficient to deionized or distilled water. Whereas in some conditions deionized water mixed with organic compounds, and some gaseous such as oxygen and air produce higher material removal rate (MMR) by 2-3 times, and the cost per part is lower compared to hydrocarbon-based dielectric. Also, carbon concentration in steel workpiece machined by water less than that machined using hydrocarbon-based dielectric. Moreover, workpiece surface resulted from deionized water is smoother than that of hydrocarbon-based dielectric. In addition, water is more environmentally friendly and good alternative for hydrocarbon-based dielectrics [36].

Valaki and Rathod have studied the performance of EDM using vegetable oil based green dielectric fluids biodielectric1 (BD1) and biodielectric2 (BD2) and comparing the results with hydrocarbon-based dielectric(kerosene). Using bio-dielectric for die sinking EDM, the MRR was higher compared to hydrocarbon-based dielectric. There for machining cost is lower. On the other hand, the EWR using bio-dielectric higher than machining with hydrocarbon-based dielectric, and this disadvantage impacts on the shape and the accuracy of the dimensions of the workpiece, the cost electrodes consumption is higher, and productivity of electrodes is less. However, in general the results of EWR, MRR, RWR for dielectric fluids bio-dielectric and hydrocarbon-based dielectric are similar, as a result bio-dielectric could be alternate hydrocarbon-based dielectric [37].

Islam et al. have investigated using air and oxygen as dielectric fluids and compared the results with previous results on oil EDM. Using oxygen and air gave three times and two times respectively better MRR than using oil. Besides less environmental impact [38]. Skrabalak and Kozak, have reported that MRR in dry EDM higher than using kerosene dielectric, whereas electrode tool wear was less in dry EDM [39]. Kunieda and Furuoya, have experimented supplying oxygen into the gap between the electrode and the workpiece in presence water-based dielectric in EDM. And concluded that the MRR was higher compared to conventional EDM and discharge energy was lower [40].

In addition to previous studies in the field of electrolytic operation. There is still scope for studies and research to reach results that lead to realize sustainable environment. Studying the gaseous emitted and its concentration in the machining area resulting from using bio-dielectric fluids, water, dry, and near-dry to machine different materials, and their effect on the workers' health and the environment. Studying purification and reuse of bio-dielectric fluids and their effectiveness.

4. Conclusion

According to the presented studies, which dealt with the subject of EDM and compared machining using different dielectrics and without dielectric fluids and the extraction of results. Most of studies compared between the use of hydrocarbon-based dielectric and vegetable oil, water, dry or near-dry in terms of machining performance. As well as focus on the emissions, pollutants and waste resulting from the machining and its impact on the environment and workers and summarize these results in the following.

Machining with using vegetable oil, water, dry or near-dry give good performance and close results in trends of EWR, MRR, TWR, and surface textures to machining with hydrocarbon-based dielectric. All EDMs release emissions and waste of harmful substances and affect the environment and health of operators. These damages vary according to the machining process and the inputs parameters, but the hydrocarbon-based dielectric has the worst effect on the environment and the operator's health. Using vegetable oil, water, dry, and near-dry can be considered a right step to sustainable environment.

Vegetable oil, water, dry, and near-dry are suitable alternative to hydrocarbon-based dielectric. Reducing aerosols concentration possible by controlling dielectric level, peak current, and pulse duration. Employee awareness of the risks of the EDM and how to deal with inputs and outputs and all components of machining process.

Furthermore, safety measures must be considered which mitigate and avoid releasing unfriendly environment contaminants during machining.

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