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Experimental investigation of vegetable oil as dielectric fluid in Electric discharge machining of Ti-6Al-4V

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ABSTRACT

Electric Discharge Machining (EDM) is used to machine difficult to cut materials in the area of making dies, mould and tools. Titanium alloy is one of the difficult to machine materials which used in aerospace industries due to its light weight and high hardness value. In this work, titanium alloy (Ti-6Al-4V) is machined using vegetable oil based dielectric fluids and conventional dielectric fluid and their surface roughness values are analyzed. Vegetable oil based dielectric fluids are considered namely, Sunflower, Canola, Jatropha oils and conventional dielectric fluid namely kerosene are used in this investigation. Surface roughness values are measured by talysurf surface roughness tester. The result showed that vegetable oil has similar dielectric properties, erosion mechanism compared with conventional dielectric and it could be effectively replaced as dielectric fluid in EDM process. The proposed vegetable oil based dielectric fluid is biodegradable, eco friendly and thus leading sustainable manufacturing.

1. Introduction

Sustainability in manufacturing as defined by US Department of Commerce "the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers". Industrial pollution caused by both conventional and unconventional manufacturing methods degrades the sustainability of the environment. In EDM process, kerosene is commercially used dielectric fluid and pyrolysis of this dielectric produces some environmental impacts. The continuous usage of dielectric fluid deteriorates and leads to decrease the performance of EDM process [1].

Hydrocarbon based dielectric fluids used in EDM generate harmful elements and affecting environment and operator health and safety. Some of the important functions of dielectric fluid are produce ionization followed by decomposition, flushing out debris, generation of plasma, cool the electrode and work piece. To overcome the environmental issues, some of the steps are taken by researchers to adapt EDM process into a greened process. One of the approaches is dry EDM, which uses gaseous medium as dielectric, but it has limitation of low MRR and debris particle suspended in gaseous medium. Some other approaches such as near dry EDM, water as dielectric, additives added in dielectrics and cryogenic approaches. Few issue to solve on those methods to convert green EDM process. Recently, vegetable oil based dielectric is attempted to attain sustainable idea in EDM process [2,3].

Vegetable oils are classified into edible and non-edible oils and some of the vegetable oils having potential to use as dielectric fluid are Sunflower, Canola, cotton seed, Palm oil, olive and Jatropha oils [4]. Dielectric properties are categorized into electro-chemical properties and electro physical properties. In EDM process, ionization and deionization depends on electro-physical properties such as flash point, fire point, pour point, kinematic viscosity, thermal conductivity and specific heat and electro-chemical properties such as breakdown voltage, dielectric constant, and dielectric dissipation factor, and interfacial tension, water content, acidity value and percentage dissolved gas as [5–8].

Surface roughness measurement is an important performance characteristic in machinability aspect influences functioning characteristics between two mating parts of assembly. Always manufacturing industries give special attention to obtain good surface finish in machining operation. Functional performance of machined surface influences the corrosion resistance, coefficient

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of friction, fatigue strength and wear rate. Low value of surface roughness is desirable for long service life by maintaining lubricated layer between the mating parts [9].

Titanium and its alloys are widely used in aerospace and automobile industries due to their light weight, good strength to weight ratio, thermal stability and high corrosion resistance. These alloys are categorized into difficult to cut materials because of their inherent properties such as low toughness, low thermal conductivity and chemical reactivity. EDM process is preferable for machining of titanium alloy. EDM is energy based machining process in which thermoelectric energy is used to melt and vaporize the material in the form of spark erosion. EDM involves for machining of difficult to cut materials by conventional machining method and can produce complex shapes in such materials. EDM uses series of high frequency current discharge and produce ionization in the dielectric fluid environment [10].

2. Literature review

Gohil and Puri [10] used statistical approach for the analysis of EDM performance of titanium alloy. In their work, Taguchi orthogonal array, signal-to-noise ratio and Analysis of Variance (ANOVA) were used to analyze the experimental results. The result indicated that peak current and pulse on time are influenced parameters on surface roughness. Ramanuj Kumar et al. [11] investigated and optimized process parameters in EDM process on machining of titanium alloy. In their work, the effect of input parameters such as current, voltage and pulse on time on Material Removal Rate (MRR) and Ra were analyzed using grey relational analysis. Surface morphology also analyzed using machined surface microstructure. The result concluded that machining performances were directly proportional to discharge current. Shabgard and Khosrozadeh [12] investigated the effect of carbon nano tube added on dielectric fluid in EDM process of titanium alloy. They have analyzed that the effect of nano particle added dielectric fluid on Tool Wear Rate (TWR) MRR and Ra. The result revealed that machined surface micro cracks and surface roughness were reduced due to reduced spark energy and uniform distribution of nano particle added dielectric fluid. Jabbaripou et al. [13] investigated the effects of process parameters on titanium alloy in EDM process. They have considered MRR, TWR, and different aspect of machined surface parameters such as crack formation, white layer thickness and micro hardness. Main effects of plot and Analysis of Variance (ANOVA) were used to investigate the results. Pulse current and pulse on time were the important process parameters on machined surface related issues.

Ng et al. [4] investigated vegetable based dielectric in EDM process for sustainable enhancement. The effects of Canola and Sunflower based bio diesel dielectric in conventional dielectric EDM process. The result concluded that MRR value was increased with canola and sunflower oils are dielectric at both low and high energy settings. They have pointed out and also suggested about further research work are required about TWR in EDM process, because of TWR value was decreased with low energy settings and increased with high energy settings. Result indicated that EDM process will be more cleaner and sustainable if vegetable oil as dielectric. ANOVA concept was used for the effect of process parameters on output parameters. The result of ANOVA stated that low energy settings play significant effect than higher energy setting parameters with vegetable oil as dielectric. Also, they point out about future work is required in the area of different vegetable oils are dielectric and large amount of dielectric must be present during machining process. Valaki et al. [14] investigated the feasibility for utilization of used vegetable oil as alternative of conventional dielectric fluid like hydrocarbon oil, kerosene in EDM process. The result indicated that used vegetable oil could act as an alternative dielectric fluid for EDM process. Valaki et al. [15] investigated sustainability analysis in EDM using biodiesel (jatropha oil) as dielectric and compared with kerosene dielectric. In their work, the effect of input parameters (current, gap voltage, pulse on time and pulse off time) on MRR, SR and surface hardness were studied. The result concluded that enhanced machining performance as observed using vegetable oil based dielectric fluid.

Amanullah et al [5] were analyzed the electro-chemical characteristics of vegetable oils to find out substitute to mineral oil-based dielectric fluid. The various chemical properties such as break down voltage test, dissipation factor test, acidity number, interfacial tension on mineral oil, Canola oil, Sunflower oil, Olive oil, Grape seed oil, peanuts oil. They concluded that considered vegetables could be used as dielectric fluid as an alternative for mineral based oils. Amanullah et al [6] were analyzed the physical characteristics of vegetable oils as an alternative to mineral oil-based dielectric fluid. The various physical properties considered in their study such as flash point, fire point, pour point, specific gravity, viscosity, moisture content on mineral oil, canola oil, sunflower oil, olive oil, grape seed oil, peanuts oil. They concluded that considered vegetables could be a potential dielectric fluid as an alternative for mineral based oils. Abdullahi et al [7] were tested the potentials of Palm oil as a dielectric fluid. Petroleum and mineral based fluids have some drawbacks such as low flash point, fire point and have low dielectric breakdown voltage. They are not biodegradable and spillage takes long time to decompose naturally. For these reasons Vegetable oils are the alternative source for mineral based dielectric fluids. They were tested for the properties of palm oil in comparison with mineral oil such as turbidity, dielectric breakdown voltage, fire point, plash point, smoke point, relative density, viscosity, thermal conductivity, thermal diffusivity and moisture content percentage. They concluded that the considered oil had a very good potentiality to use as dielectric fluid. Amanullah et al. [8] were analyzed the evaluation of several techniques and additives to de-moisturize vegetable oils and bench mark the moisture content level of vegetable oil-based dielectric fluids. They have noticed that mineral based dielectric fluids are not friendly to the environment where as vegetable oils friendly to the environment. The drawback of vegetable oils is high moisture content. High moisture content is not suitable for power and distribution transformers. The reduction of moisture content in vegetable oils to an acceptable level and safe working level is one of the major developments of vegetable based dielectric fluids.

From the previous work, the limited literatures are involved in the area of vegetable oil as dialectic in EDM process. Particularly, in manufacturing practice, environmental issues, personal health and operator safety are the important elements. This work focuses sustainability in EDM process with different vegetable oil as a dielectric in EDM process. Also, studies are required for machining of titanium alloy and its machined surface to explore the machinability. Hence, an effort has been made for machining of titanium alloy with vegetable oils.

3. Experimental procedure

The experiments are performed on EDM machine is shown in Fig. 1. In this work, titanium alloy with grade 5 (Ti-6Al-4V) is selected as work piece materials. Electrode materials are selected as copper, brass and tungsten copper with 12 mm diameter. The input parameters considered are pulse on time, pulse off time, current and voltage. These parameters are selected based on literature study and some preliminary tests. Dielectric fluids used are Kerosene, Sunflower oil, Canola oil and Jatropha oil. . Three sets of energy levels are used in experiments they include low level (Pulse

Fig. 1. EDM Machine.

Fig. 2. Talysurf surface roughness tester.

on time = 400 μs; Pulse off time = 200 μs), medium level (Pulse on time = 600 μs; Pulse off time = 400 μs) and high level (Pulse on time = 800 μs; Pulse off time = 600 μs). The voltage, current and machining times are kept as constant and the values are 55 V, 8 Amps and 40 min respectively.

Surface roughness of the machined components is analyzed by talysurf surface roughness tester (Fig. 2). The measurements are repeated three times in a machined sample and the average values are considered. Table 1 shows the results of experiments conducted. In surface roughness measurements, various parameters are referred by researchers and industries such as arithmetical average surface roughness (Ra), average peak to valley height (Ry) Ten spot average roughnesses (Rz) and roughness maximum (Rt) and root mean square roughness. The parameter (Ra) is selected in this work, which is the area between the roughness profile and its centre line during the measurements. Also, Ra can be indicated that integral of the absolute value of the roughness profile height over the evaluation length [Fig. 3]. These Ra measurements are measured using ISO 4287:1997 with a cut-off length of 0.8 mm and sampling length of 5 mm.

Hence, the Ra is denoted by

$$R_a = \int_0^L |Y_x dx| \tag{1}$$

where, Ra = average surface roughness from the mean line, L = sampling length; Y = ordinate profile curve. Table 1 shows the experimental results. Fig. 4 shows the machined samples [9].

4. Results and discussions

In this investigation, titanium alloy is machined with EDM process using conventional and vegetable oil based dielectric fluids.

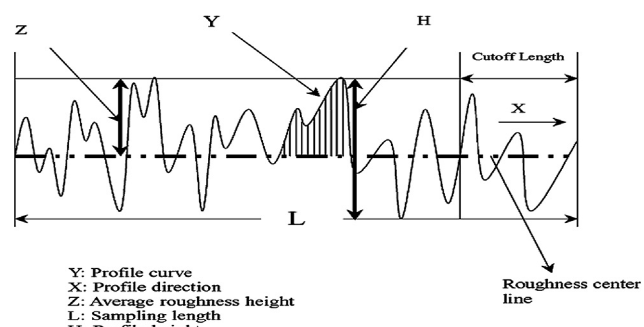
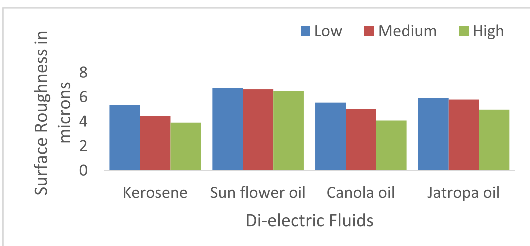


Fig. 3. Surface roughness profile. (Ref.9).

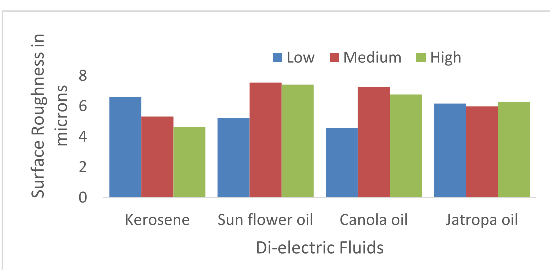
Table 1
Experimental Results.

Types of dielectric fluids	Energy settings	Surface roughness in microns		
		Copper electrode	Brass electrode	Tungsten copper alloy electrode
Kerosene	Low	5.36	5.06	6.60
	Medium	4.47	5.40	5.32
	High	3.90	4.73	4.02
Sunflower oil	Low	6.75	8.50	5.22
	Medium	6.63	9.32	7.55
	High	6.48	9.1	7.42
Canola oil	Low	5.55	9.56	4.56
	Medium	5.03	8.89	7.27
	High	4.89	9.12	6.77
Jatropha oil	Low	5.92	8.82	6.18
	Medium	6.81	7.22	5.99
	High	4.97	9.12	6.28

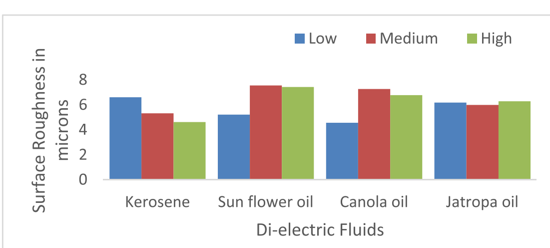
Fig. 4. Machined samples with copper electrode.



a. EDM machining of Titanium alloy with copper electrode



b. EDM machining of Titanium alloy with brass electrode



c. EDM machining of Titanium alloy with Tungsten copper electrode

Fig. 5. A–c Effect of different dielectric fluid on surface roughness of the machined titanium alloy.

Three types of electrodes are used on each dielectric fluid. These studies are involved considering conventional dielectric (Kerosene) and three types of vegetable oil (Sunflower, Canola and Jatropha oils) based dielectric fluid in machining are used. Three set energy settings are selected to conduct experiments and the surface roughness of the machined components are analyzed. Surface roughness of the component influences the accuracy, tribological properties and enhances service life. Fig. 5a–c shows the effect of dielectric on surface roughness of the machined titanium alloy.

Pulse on time influences SR, as the vaporization and melting increases at higher pulse on time causes deeper craters having more width leading to higher SR. Minimum debris solidification followed by lower SR value is observed in few cases due to dielectric properties of dielectric fluid and selected process parameters. Pulse off time has marginal effect on SR as re-ionization takes place for subsequent spark cycles and reduced sparking time create smaller and shallow crater surfaces [14,15].

In order to achieve cleaner, greener and sustainable EDM, vegetable oils can be used as dielectric fluid. It must have dielectric properties namely electro-chemical properties and electro- physical properties for finding the suitability of vegetable oils as an alternative to conventional dielectric. The use of vegetable based dielectric in EDM solve the above problems and also leads to the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers. The advantages of vegetable oil based bio dielectric fluids are that, they do not contain halogens, polynuclear aromatics, volatile or semi-volatile organics, or other compounds that can be present in mineral oils or other dielectric fluids.

5. Conclusions

Vegetable oil based dielectric fluid are attempted in EDM process for machining of titanium alloy and the inference from the experiments can be written as following conclusions are obtained

- In EDM process, vegetable oils are successfully employed as dielectric fluids and they are having similar dielectric properties and erosion mechanism compared to conventional dielectric fluid.
- The proposed EDM machining having vegetable oil based dielectric fluid is showing higher SR than conventional dielectric. Lower surface roughness value is observed in few cases due to dielectric properties of vegetable oils and selected process parameters. More studies are required for enhancing dielectric properties thereby improving machinability aspect.
- In any manufacturing practice, environmental impact, personal health and operator safety are important concern to make it as a green process. This work is imposed about the sustainability in EDM process through vegetable oil as dielectric in EDM process.

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