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Research paper

Experimental investigation of EDM process parameters by using Pongamia Pinnata osil blends as dielectric medium

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Abstract

Electro Discharge Machining (EDM) is an incredibly recognizable machining for ticklishness profiles in 'difficult to machine 'materials. In EDM, the material ejection of the cathode is cultivated through exact controlled electric pulse (the flash), which changes the metals of two terminals into dissolve and vaporize, as a result of the breakdown of the dielectric medium. The most commonly used dielectric media are kerosene, paraffin, glycerin, transformer oil, and EDM oil; all are derived from petroleum. These dielectric media undergo pyrolysis and carbon soot formation is deposited on work electrode, and sometimes carbon precipitates into work. To overcome these effects vegetable oils are tried as alternate dielectric media. Pongamia Pinnetta is abundantly available in most countries; and it is cheaper and non-edible. Pongamia Pinnata (PP) oil is extracted from plant seeds, and is blended with EDM oil and several experimentations are done to find its suitability. Operational variables with respect to input and output parameters are identified. Some of these are best EWR, MRR, TWR, and SR with applied current (I), pulse on time (T_{on}), and pulse off time (T_{off}) are the ones picked as the input process factors; because for the industrial application many machinists choose these three as the input parameters; and other is constant and picked under specific requirements only. After the successful completion of this experimentations, Pongamia Pinnata oil blends are fit for the industrial application using technique of order preferancing with similar to ideal solution [TOPSIS]. It is observed that no carbon soot formation takes place in the work component with PP oil as the dielectric fluid.

1. Introduction

Electrical Discharge Machine (EDM) is presently turned into the most vital acknowledged advancements in assembling industry since numerous perplexing 3D shapes can be machined utilizing a basic molded instrument terminal. EDM is an imperative 'non-conventional assembling strategy', created in the late 1940s and has been acknowledged world

wide as a standard handling production of framing instruments to deliver plastics moldings, buzz the bucket castings, manufacturing passes on and so forth. New improvements in the area of material science have prompted innovative designing metallic materials, composite materials, and innovative ceramic production; having great mechanical properties and warm attributes just as adequate electrical conductivity with the goal that they can promptly be machined by start disintegration. Right now, EDM is a far-reaching system utilized in manufacturing for great accuracy machining of a varied variety of conductive materials, for example, metals, metallic combinations, graphite, or even some heat-treated materials, of any hardness. EDM innovation is progressively being utilized in the device, pass on and form making ventures, for machining of warmth treated instrument steels and propelled materials (superalloys, ceramic production, and metal network composites) requiring high accuracy, complex shapes, and high surface completion. Customary machining procedure is regularly founded on the material expulsion utilizing device material harder than the work material and cannot machine them financially.
Working with the advancement of the manufacturing process, the demand for combining materials with high hardness, toughness and effect obstruction is increasing. By and by, such materials are hard to be manufactured by conventional techniques. Subsequently, non-customary machining approaches containing Electro Chemical Machining, ultrasonic machining, and Electrical Discharge Machine (EDM) and so on are linked as hard to machine materials. EDM process with a cathode changes electrical vitality to warm vitality for cutting materials. With this procedure, combination steel, conductive earthenware production, and aviation materials can be machined independently to their hardness and strength. Besides, EDM is equipped for delivering a good, precise, consumption, and wear safe surface. Amid the EDM procedure, the material is disintegrated in front of the electrode and there is no immediate contact between the work piece to the electrode, taking out the mechanical stresses amid machining; along these lines delicate parts can be machined without the danger of harm.
EDM is commonly utilized for form and die making industry and in assembling the car, aviation and careful parts.

2. Experimentation

Electronica make sinker type EDM, the equipment that was chosen to carry out the research, is presented in Fig. 1.
The electrode used for this experiment was pure copper with 10 mm diameter and work component is EN 31 of 70×70×10 mm size is chosen. Electrical insulation materials, which will keep the stream of flow in an electrical circuit, are being utilized since the earliest starting point of the science and innovation of electrical wonders. Dielectrics are protecting materials that show the property of electrical polarization, along these lines they change the dielectric capacity of the vacuum. The dielectric fluid functions act as a medium for meticulous discharge, temperature transmission agent to engross and transfers the hotness created by the spark between work part to the electrode, quenching medium and strainer system for debris Chakraborty S [1].
Generally, usage dielectric fluids are Mineral oils, pure water, and additives that were added to water. Leao and Pash [2] by originating certain investigations considered the possibility of combining organic compounds such as ethylene glycol, polyethylene glycol 200, 400, 600, dextrose and sucrose to increase the recital of demineralized water. EDM with gaseous dielectrics (air and O_2) performance is higher than the dielectric fluid underneath certain special situations.

Fig. 1. Electronica make sinker EDM machine.

Based on Kunieda and Yoshida [3], EDM's highest advantage in gas is that electrode wear (almost zero) stays too little, which is said to be self-ruling during the pulse [2] Kerosene, EDM oils, and transformer oils. PP oil blends are used for this experimentation. Insulation fluids are specifically founded on their chemical arrangement and properties (e.g. aromatic hydrocarbons, cryogenic fluids, mineral, micro-organisms, mixed insulating fluids, silicon, vegetable oils, liquids) [4-6]. Mineral oils are commonly utilized in electrical transformers as insulating fluids and as a dielectric fluid in the EDM process. They are treated with petroleum distillation and sulfuric acid refinery. Vegetable oils are customary ester molecules with a triglyceride arrangement, beginning as of the compound bond of three unsaturated fats to one glycerol molecule. These oils have for the most part fantastic imperviousness to fire and biodegradability [6-10].

Bradshaw [8] expressed that 4.8:1 molar proportion of methanol to vegetable oil prompts 98% transformation. This proportion is more noteworthy than 5.25:1 meddled with gravity partition of the glycerol and added pointless cost to the detachment. Freedman, et al. [9] considered the impact of the molar proportion of methanol to oil and impact of changes in convergences of tri-, di-and monoglyceride on ester yield. Freedman et. al. [10] got the outcomes for methanolysis of sunflower oil, in which the molar proportion shifted from 6:1 to 1:1 and reasoned that 98% change to ester was grown at a molar proportion of 6.1. Bio-oil from Karanja oil demonstrates no erosion on cylinder metal and cylinder liner while biodiesel from Jatrophacurcas has an insignificant destructive impact on cylinder liner [11].

2.1. Pongamia Pinnata – oil

In this research, Pongamia Pinnataoil is chosen as the dielectric fluid to carry out the research. Pongamia Pinnata oil is mixed with EDM oil and different blends are taken to run the experimentation. PP is a type of Leguminasae family. Figs. 2-3 show PP tree and seeds respectively, that are local in tropical and calm Asia including some parts of India, China, Japan, Malaysia, and Australia. Blooming begins from four to five years onwards. Cropping of pods and solo almond estimated seeds can happen by 4-6 years and yields 9-90 kg's of seed. The harvest possible for each hectare is 900 to 9000 Kg/Hectare [4].

According to statistics, accessible PP lubricant has a capability of 1,35,000 million tons per year and just 6% is being used, and its properties are mentioned in Table 1.

The dielectric test is conducted on the liquid. The dielectric test set with an electrode gap is 2.5 mm as per IEC – 60156 standards as shown in Figs. 4 –6, and the flash and fire point test is conducted as shown in Figs. 7-8; whileits respective values are tabulated and shown in Table 2.

Fig. 2. Pongamia Pinnata tree with fruits.

Fig. 3. Pongamia Pinnata seeds.

Table 1. Physico-chemical properties of PP – oil and EDM oil.

Property	Unit	PP oil value	EDM oil value
Color	-	Yellowish red	no color
Odor	-	odd odor	no odor
Density	gm/cc	0.924	0.820 at 150^0C
Flash point	^{0}C	225	155
Fire point	^{0}C	230	170
Dielectric strength	KV/mm	24	15

Fig. 4. Liquid dielectric test apparatus for breakdown measurement.

Fig. 5. Electrode gap is 2.5 mm as per by IEC-60156 standard.

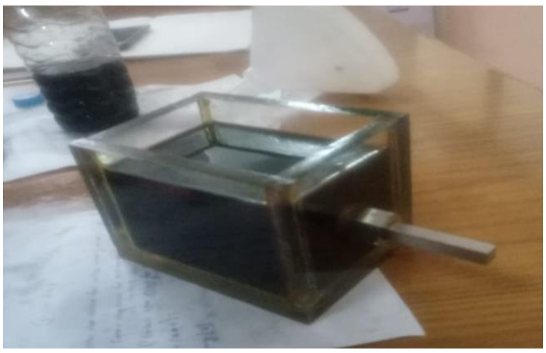

Fig. 6. Oil chamber for breakdown voltage measurement with sample oil.

Fig. 7. Saybolt viscometer apparatus while conducting experimentation.

Table 2. Dielectric strength, flash and fire points of EDM oil, PP oil and its blends.

Sl No	Oil description	Dielectric strength KV/mm	Flash point ^{0}C	Fire point ^{0}C
1	PP90-10	22.5	165	190
2	PP80-20	22	160	180
3	PP70-30	21	155	180
4	PP60-40	21	160	170
5	PP50-50	23.3	135	160
6	PP40-60	21	160	175
7	PP30-70	22.3	160	170
8	PP20-80	19	160	185
9	PP10-90	18.5	160	185
10	EDM oil	15	155	170

Table 3. EDM parameters with its levels.

Parameters	Level-1	Level-2	Level-3	Level-4
Current (I)	9	12	15	18
T_{on} (μs)	100	200	500	900
T_{off} (μs)	100	200	500	900

Fig. 8. Cleaveland flash & fire point apparatus during conducting of experimentation.

2.2. Orthogonal array

In this investigation three factors are chosen, 4 levels of full factorial examination is taken, i.e.4^3=64 investigations [5, 7]. The directed Taguchi explored different avenues regarding an L16 orthogonal exhibit (16 tests, 3 factors, 4 levels); appeared in Table 3. I, T_{on}, T_{off} as input

parameters resulted in better MRR, TWR, EWR, and SR.
The reduced mass of work part MRR and SR for machined surface are measured in every experimental trial. are measured in every experimental trial. The MRR, TWR are measured by the loss in weight and a weighing scale with least count of 0.001 mg. It is then divided by the density of work material and tool respectively in order to convert it into volumetric term and is further divided by the actual machining time to obtain the MRR and TWR in terms of mm^3/min. The machining time for each trail is for 10 minutes. The TalySurf Roughness tester assesses the SR (Ra) of the work part

3. Results and discussion

For comparing the experimental investigations Technique of Order Preference with Similar to Ideal Solution (TOPSIS), a multiple attribute decision criterion technique is employed in the present work.
TOPSIS method [5-11] is applied for the experimental machine responses to find out the best response of all experimental trails. The PP oil and EDM oil mixed with different proportions were used for each experimentation, consisting of 16 trial runs. In this experimentation, PP oil is blended with EDM oil with a volume as PP90-E10, PP80-E20, PP70-30, PP60-40, PP50-50, PP40-60, PP30-70, PP20-80, PP10-90, and E100 are of total 10 number of experimentations were conducted; i.e. with each blend, each blend with again experimentation of L16 trails, the output as MRR, TWR, EWR, and SR were taken. The performance of bio-dielectric blends was checked with TOPSIS [12]. The experimental trails of all PP oil and its blends outputs of MRR values are shown in the graph of Fig. 9. The MRR values of PP oil and its blends are close to that of the pure EDM oil. The PP oil properties are better than that of EDM oil that shows a good impact on the TWR, EWR, and SR.
The Tool Wear Rate values of EDM oil experimental values that are shown in Fig. 10 are greater than that of pure PP oil and its blends, which leads to more amount of tool wear that will occur with EDM oil. Due to this, more amount of time will take to reshape the tool for the multiple numbers of times, which raises the tool making cost.

Electrode Wear Rate is the ratio of wear weight of the tool to the wear weight of the work piece; the values of EWR is compared with EDM oil and pure PP oil as is exposed in graph Fig. 11 and its blends values are greater and on it of EDM oil.
While the SR value is compared with EDM oil to pure PP oil and its blends, all values are less than that of EDM oil value. In any manufacturing processes the crucial objective is less surface roughness and more MRR; hence the pure PP oil and its blends got good results in comparison to EDM oil as shown in Fig. 12.

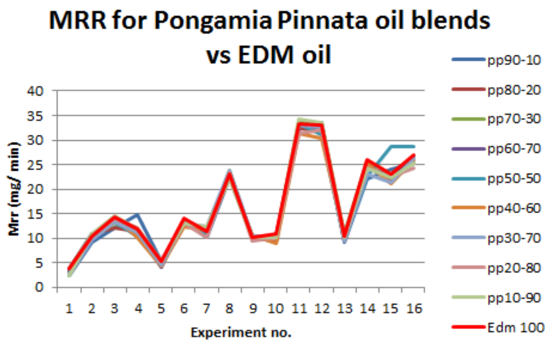

Fig. 9. Material Removal Rate for PP blends with EDM oil vs. EDM oil.

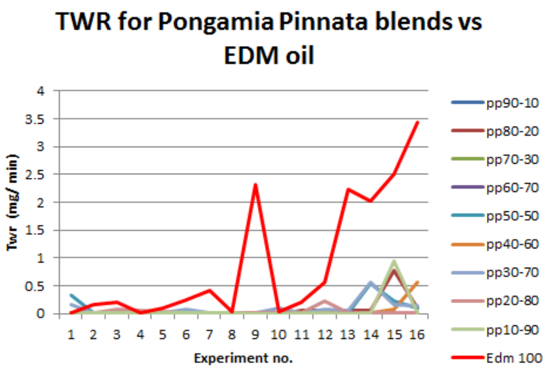

Fig. 10. Tool Wear Rate for PP blends with EDM oil vs. EDM oil.

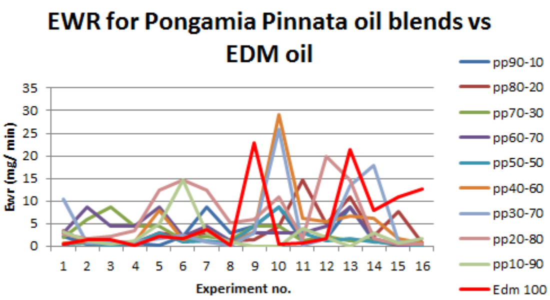

Fig. 11. Electrode Wear Rate for PP blends with EDM oil vs. EDM oil.

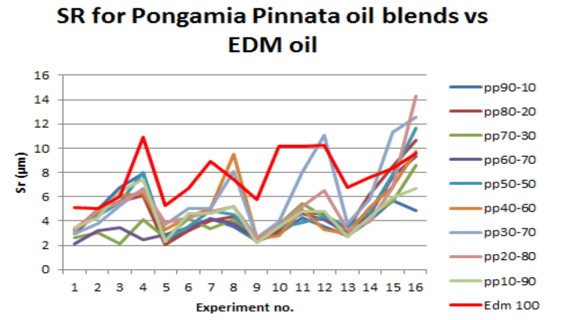

Fig. 12. Surface Roughness for PP blends with EDM oil vs. EDM oil.

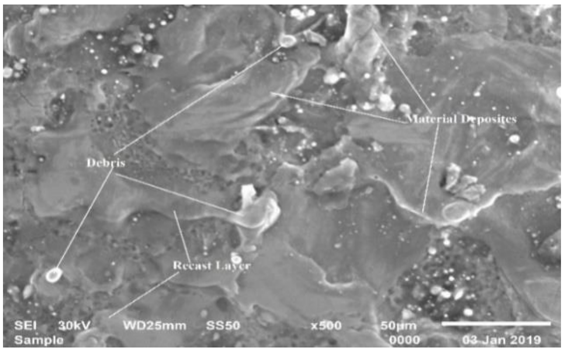

Fig. 13. PP 30-70 SEM image of experiment trail No. 1.

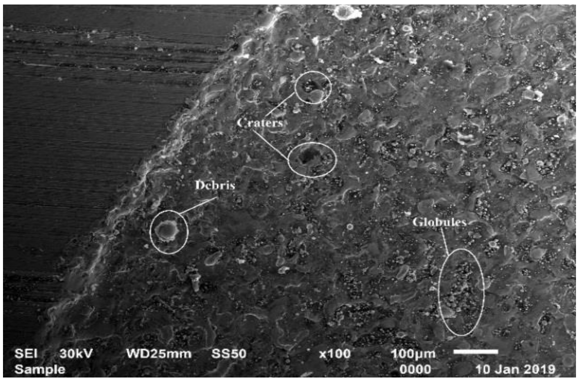

Fig. 14. PP 50-50 SEM image of experimentation trail No.1.

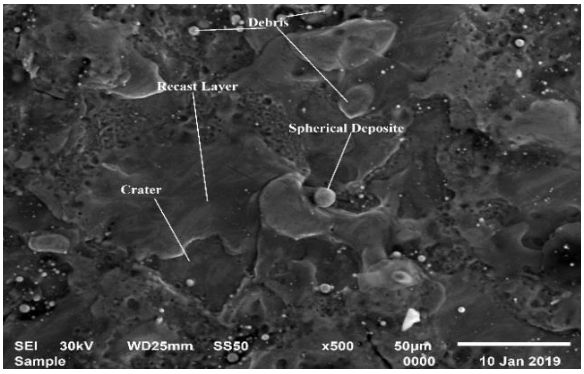

Fig. 15. PP 50-50 SEM image of experimentation No. 1.

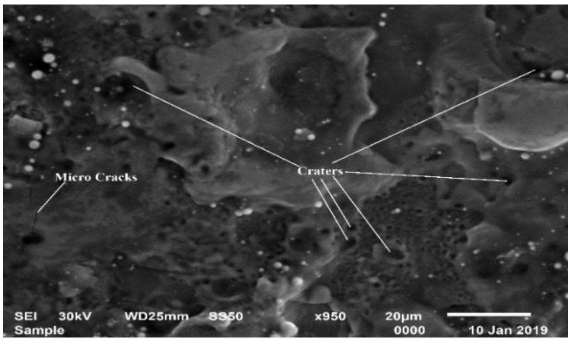

Fig. 16. PP 50-50 SEM image of experimentation No. 1.

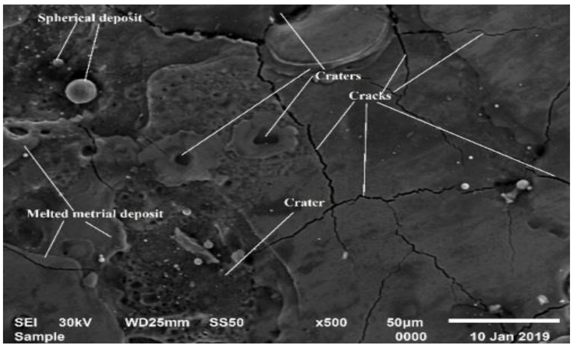

Fig. 17. PP 90-10 SEM image of experimentation No.1.

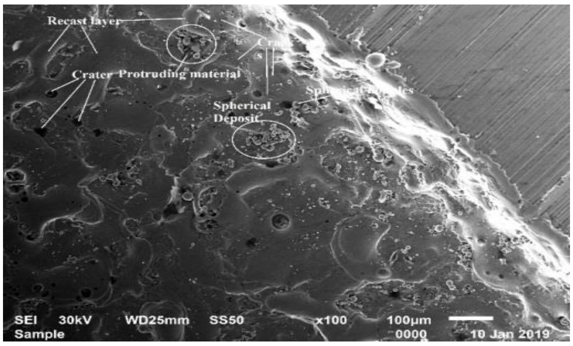

Fig. 18. PP 90-10 SEM image of experimentation No. 1.

4.1. SEM Analysis

Fig. 13 is the SEM micrographs and Fig. 14 is the SEM image observed at 100X magnification with debris, cracks, globules [13-16] at Pulse on time = 100 µs, pulse off time = 100 µs, and peak current = 9A, Ra = 3.312 µm, 3.347 µm, 3.083 µm sample of 3 values measured through Talysurf.

It was found from SEM micrographs in Figs. 14 and 15 that fewer craters and no micro-cracks were molded at low peak current 9A and T_{on} 100 µs. Due to the low peak current and T_{on}, the work surface is imposed with less intensive discharge. [17-19] High peak current and low T_{off} increased the debris in the spark gap, which leads to abnormal arcing. From Figs. 6-10 in all experimental images, no carbon content ingredients are dissolved in the work component. Fig. 17 is the observation from SEM picture at 500X magnification with Spherical deposit, debris, material deposition, crater, [20-23] cracks at higher T_{on} = 900 µs, T_{off} = 100 µs and I = 18 A, Ra = 4.886 µm, 4.650 µm, 4.911 µm. Fig. 18 is the SEM image observed at 100X recast layer, crater, spherical deposit, spherical globules, and protruding material.

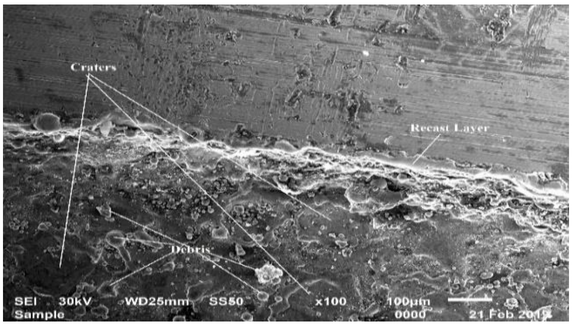

Fig. 19. EDM oil SEM image at X100 magnification for experimentation No. 1.

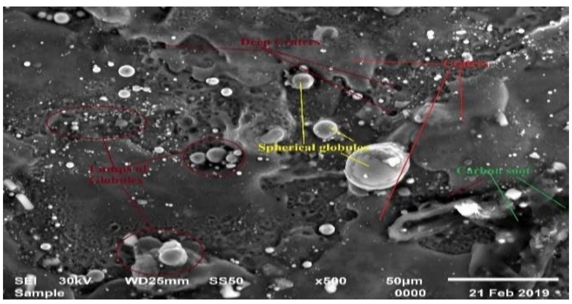

Fig. 20. EDM oil SEM image at X500 magnification for experimentation No. 1.

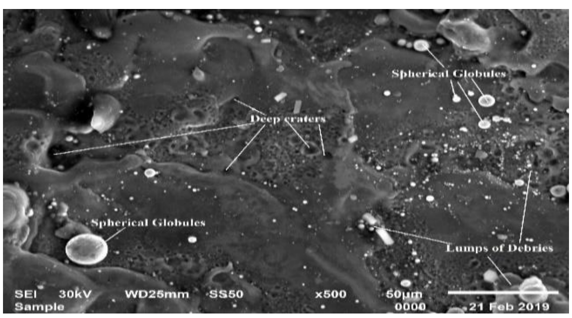

Fig. 21. EDM oil SEM image at X500 magnification for experimentation No. 1.

Fig. 19 image observed at X 100 magnification with lumps of debris, spherical globules, craters, deep craters. It was detected from SEM micro graphs Fig. 20 that craters, spherical globules, debris, and recast layer, carbon soot were molded at current 9A and T_{on} 100 µs.

Fig. 21 SEM micrographs observed at 500X magnification with Spherical globules [24-30], lumps of

deposit, debris, material deposition, the crater at higher T_{on} = 100 µs, T_{off} = 100 µs and peak I= 9 A, Ra = 5.099 µm, 5.254 µm, 5.111 µm at X 500 magnification.

For the most part by utilizing ordinary hydro carbon-based paraffin crude oils as dielectric liquids, because of high vitality will breaks the dielectric quality around then some measure of carbon will separate in the mean time the work material goes disintegrate amid this time the disseminated carbon particles will blend in to the workpiece frames carbon soot, to check this effect by utilizing bio-oils like PP oil blends as dielectric liquid no carbon soot development is watched from Figs. 13 to18 and in with using of EDM oil carbon soot is observed in Fig. 21.

4. Conclusions

- The PP oil properties are like flash point, fire point and dielectric strength are greater than the EDM oil.
- Carbon content dissolving in to the work material is not found with PP oil as a dielectric medium.
- Material Removal Rate values of PP oil and its blends are nearer and greater than EDM oil values.
- Surface roughness values of PP oil and its blends values are less than that of EDM oil, which is a great requirement for the machining process.
- The cost analysis of EDM oil, Mineral oils, etc. are costlier than the PP oil.
- The mineral oils were obtained from crude oil, the crude oil reserves are depleting fast, may not be available after some time.
- Crude oil sources are the non-renewable source of energy after exhausting of these reserves so definitely need to choose for an alternate source of oils i.e. bio-oils.
- Usage of EDM oils, Kerosene, mineral oils causes dissolving of carbon content into the work surface, which leads to the change of material property.

Hence from these, it is concluded that PP oil and its blends can be used as an alternate to commercial EDM oil or mineral oils as a dielectric fluid.

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References

[1] S. Chakraborty, V. Dey and S. K. Ghosh "A review on the use of dielectric fluids and their effects in electrical discharge machining characteristics". *Precis. Eng.*, Vol. 40, pp. 1-6, (2015).

[2] F. N. Leao and I. R. Pashby. "A review on the use of environmentally-friendly dielectric fluids in electrical discharge machining". *J Mater. Process. Technol.*, Vol. 149, No. 1-3, pp. 341–6, (2004).

[3] M. Kunieda and M. Yoshida, "Electrical discharge machining in gas". *Ann CIRP*, Vol. 46, pp.143–6, (1997).

[4] S. N. Bobade and V. B. Khyade, "Detail study on the Properties of Pongamia Pinnata (Karanja) for the Production of Biofuel", *Res. J. Chem. Sci.*, Vol. 2, No. 7, pp. 16-20, (2012).

[5] M. Dastagiri, P. Srinivasa Rao and P. Madar Valli, "Optimization of EDM process parameters by using heuristic approach", *Mater. Today: Proc.*, Vol. 5, No. 13, pp. 27036-27042, (2018).

[6] I. Fofana, "50 Years in Development of Insulating Liquids", *IEEE Elect. Insul. Mag.*, Vol. 29, No. 5, pp. 13-25, (2013).

[7] A. A. Pollitt. "Mineral Oils for Transformers and Switchgear", *IEEE Elect. Insul. Mag.* Vol. 89, No. 20, pp. 15-22, (1942).

[8] Z. H. Shah and Q. A. Tahir, "Dielectric Properties of Vegetable Oils", *Jsr Journal of Scientific Researchs*, Vol. 3, No. 3, pp. 481-492, (2011).

[9] A. A. Abdelmalik, J. C. Fothergill and S. J. Dodd, "Electrical Conduction and Dielectric Breakdown Characteristics of Alkyl Ester Dielectric Fluids obtained from Palm Kernel Oil", *IEEE Elect. Insul. Mag.*, Vol. 19, No. 5, pp. 1623-1632, (2012).

[10] M. Augusta and G. Martins, "Vegetable oils an Alternative to Mineral Oil for Power Transformers-Experimental Study of Paper Aging in Vegetable Oil Versus Mineral Oil", *IEEE Elect. Insul. Mag.*, Vol. 26, No. 6, pp. 7-13, (2010).

[11] M. P. Dastagiri, S. Rao and P. Madar Valli. "TOPSIS, GRA methods for parametric optimization on wire electrical discharge machining (WEDM) process." *All India Manuf. Technol. Des. Res. Conf. (AIMTDR–2016)* College of Engineering-India, PP 497-504, ISBN: 978-93-86256-27-0, (2016).

[12] P. Govindan and S. S. Joshi, "Analysis of micro-cracks on machined surfaces in dry electrical discharge machining". *J. Manuf. Proc.*, Vol. 14, pp. 277–288, (2012) .

[13] B. Ekmekci, O. Elkoca, A. E. Tekkaya and A. Erden, "Residual stress state and hardness depth in electrical discharge machining: de-ionized water as dielectric liquid". *Mach. Sci. Technol.*, Vol. 9, No. 1, pp. 39–61, (2005).

[14] M. Dastagiri and A. H. Kumar, "Experimental Investigation of EDM Parameters on Stainless Steel & En41b" [J]. *Procedia Eng.*, Vol. 97, pp. 1551–1564, (2014).

[15] A. Kumar, V. Kumar and J. Kumar, "Microstructure Analysis And Material Transformation Of Pure Titanium And Tool Wear Surface After Wire Electric Discharge Machining Process" *Mach. Sci. Technol., Taylor & Francis Group*, LLC ISSN: 1091-0344 print/1532-2483 online.

[16] A. Kumar, V. Kumar and J. Kumar, "Multi-response optimization of process parameters based on response surface methodology for pure titanium using WEDM process". *Int. J. Adv. Manuf. Technol.*, Vol. 68. No. 9, pp. 2645-2668, (2013).

[17] A. Hascalik and U. Caydas, "Electrical Discharge Machining of titanium alloy (Ti-6Al-4V)". *Appl. Surf.*

Sci., Vol. 253, No. 22, pp. 9007–9016, (2007).

[18] S. H. Lee and X. P. Li, "Study of the surface integrity of the machined work piece in the EDM of tungsten carbide". *J. Mater. Proc. Technol.*, Vol. 139, No. 1-3, pp. 315–321, (2003).

[19] T. Sultan, A. Kumar and R. Dev Gupta, "Material Removal Rate, Electrode Wear Rate, and Surface Roughness Evaluation in Die Sinking EDM with Hollow Tool through Response Surface Methodology", *Int. J. Manuf. Eng.*, Vol. 2014, Article ID 259129, 16 pages.

[20] C. H. C. Haron and A. Jawaid, "The effect of machining on surface integrity of titanium alloy Ti-6Al-4 V". *J. Mater. Proc. Technol.*, Vol. 166, No. 2, pp. 188–192, (2005).

[21] T. Sultan, A. Kumar and R. Dev Gupta, "Material Removal Rate, Electrode Wear Rate, and Surface Roughness Evaluation in Die Sinking EDM with Hollow Tool through Response Surface Methodology", *Int. J. Manuf. Eng.*, Vol. 2014, Article ID 259129, 16 pages.

[22] B. Freedman, E. H. Pryde and T. L. Mounts, "Variables affecting the yield of Fatty Esters from Transesterified Vegetable Oils"; *J. Am. Oil. Chem. Soc.*, Vol. 61, No. 10, pp. 1638 – 43, (1984).

[23] B. Freeman, R. O. Butterfield and E. H. Pryde, "Transesterification Kinetics of Soybean Oil", *J. Am. Oil. Chem. Soc.*, Vol. 63, No. 10, pp. 1375-1380, (1986).

[24] M. J. Haas, K. M. Scott and W. N. Marmer, "In situ Alkaline Transesterification: An Effective Method for the Production of Fatty Acid Esters from Vegetable Oils", *J. Amer. Oil. Chem. Soc.*, Vol. 81, No. 1, pp. 83-89. (2004)

[25] S. A. H. Rizvi and S. Agarwal. "An investigation on surface integrity in EDM process with a copper tungsten electrode." *Procedia CIRP*, Vol. 42, pp. 612-617, (2016).

[26] M. Antar, P. Hayward, J. Dunleavey and P. Butler-Smith, "Surface integrity evaluation of modified EDM surface structure." *Procedia Cirp*, Vol. 68, pp. 308-312, (2018).

[27] M. A. Younis, M. S. Abbas, M. A. Gouda, F. H. Mahmud and S. A. Abd Allah, "Effect of electrode material on electrical discharge machining of tool steel surface." *Ain Shams Eng. J.*, Vol. 6, No. 3, pp. 977-986, (2015).

[28] M. A. R. Khan, M. M. Rahman, M. S. Rahman and M. D. Saifur Rahman. "Optimal set-up and surface finish characteristics in electrical discharge machining on Ti-5Al-2.5 Sn using graphite." *Perspect. Sci.* Vol. 8, pp. 440-443, (2016).

[29] C. Mascaraque-Ramirez and P. Franco. "Experimental study of surface finish during electro-discharge machining of stainless steel." *Procedia Eng.*, Vol. 132 pp. 679-685, (2015).

[30] F. Klocke, S. Schneider, L. Ehle, H. Meyer, L. Hensgen and A. Klink, "Investigations on surface integrity of heat treated 42CrMo4 (AISI 4140) processed by sinking EDM." *Procedia CIRP*, Vol. 42, 580-585, (2016).

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