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Pongamia pinnata Plant Seed Oil as Dielectric Fluid for Electro Discharge Machining Process

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ABSTRACT

Electro Discharge Machining (EDM) is a noticeable machining practice among created unconventional machining procedures for intricate, complex profiles in "hard to machine" materials, similar to heat-treated steels, composites, superalloys, ceramics, composites, carbides, and so on. In EDM, the material expulsion of the cathode is accomplished through precise controlled electric discharge (the spark), which transforms the metals of two electrodes into melt and vaporize, and due to the breakdown of the dielectric medium. In this research work, the suitability of non-edible plant seed oils from *Pongamia pinnata* as a dielectric fluid in the EDM process was investigated. Also, the suitability of EDM oil as an alternate dielectric fluid for industrial application was studied. Electrode Wear Rate (EWR), Material Removal Rate (MRR), Surface Roughness (SR), and Tool Wear Rate (TWR) are the key performance features of EDM. The principal goal of EDM is to get higher MRR alongside accomplishing the sensibly good surface quality of the machined workpiece. The parameters that accomplish the most astounding MRR depend on the machining surface, which is related to the workpiece and tool. Dielectric is the most significant variable for obtaining excellent results for the above-stated key features. These investigations showed that *Pongamia pinnata* oil is a suitable dielectric media; the results are satisfactory comparing with that of EDM oil. The effect of topography of the workpiece and carbon particles dissolving is also checked with SEM analysis for any deviations on work surface.

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1. INTRODUCTION

Ancient mechanical processing techniques have been developed, mechanized, automated and computer controlled. In EDM procedure, the material is expelled from the workpiece due to disintegration brought about by quickly repeating electrical sparks between the workpiece and the cathode with a little gap between them while both are submerged in dielectric fluid (EDM oil, deionized water, and Kerosene oil). This productive technique is based on the repetitive waste management of controlled discharges. Because of its nature of contact, it became a general production process like, efficiency of machining materials, molding, instruments industry, precision industry, consumer industry, and medical field, regardless of their hardness and its specific surface design.

Moghaddam et al. [1] studied the effect of input EDM parameters on the surface quality of 2312 hot worked steel. The experimental result for the optimal setting have shown that there is considerable improvement in the surface roughness; therefore, the proposed approach is quite capable in predicting and optimizing EDM process output. Dastagiri et al. [2] studied the four info process parameters picked as a part of this strategy as discharge current (IP), pulse on time (T_{on}), Discharge voltage (V) and Inter-Electrode Gap

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(IEG). These parameters will be analyzed at three distinct dimensions. By considering MRR, SR, and TWR as yield and estimated for each investigational run. Concentrating on demonstrating MRR is increasing, SR as lower and parallel to lesser TWR of the terminal. Hence, the Heuristic strategy along these lines has been received to conjecture the outcomes referenced. Lin et al. [3] studied Copper tool as diameter of 8 mm was utilized for an anode to disintegrate a workpiece of SKD11 die steel with a thickness of 8 mm. The workpiece and terminal were isolated by a moving dielectric liquid of kerosene oil and an added substance (Aluminum powder and Aluminum Oxide powder) utilized as the dielectric liquid was utilized to improve the machining execution for 18 trial runs. Dastagiri et al. [4] examined the effect of WEDM parameters on EN-31 (DIN 100Cr6 | AISI 52100) tool steel, and the results show that SR and MRR is impacted on a very basic level by the current, voltage and T_{on}. Kumar et al. [5] made an endeavor on machining the EN-19 (AISI 4140 | DIN 42CrMo4) alloy steel by utilizing U-molded copper cathode execution on EDM. The examination shows that MRR expanded with the release current (Ip). As the beat span expanded, the MRR diminishes monotonically.

2. EXPERIMENTATION

2. 1. Selection of Tool and Workpiece The tool material (electrode) used for this experiment is copper with 10 mm diameter, and the workpiece is taken as harden steel EN-31 (DIN 100Cr6). The mechanical properties of EN-31 are displayed in Table 1.

EN-31 composition of C-1.5, Mn-0.52, Si-0.22, Cr-1.3, S-0.05, P-0.05 weight percent respectively, with thermal conductivity of 46.6 W/m.k.

2. 2. Selection of Dielectric Kunieda and Yoshida et al. [6] studied the EDM with gaseous dielectrics (air and O_2) performance is higher than the dielectric fluid underneath certain special situations, EDM's highest advantage in gas is that electrode wear (almost zero) is too low, which is said to be self-ruling during pulse.

TABLE 1. Mechanical properties of EN-31 [4]

Properties	Values
Density	7.8 Kg /m^3
Elongation	0.3
Hardness	63 HRC
Modulus of elasticity	215 GPa
Reduction of Area	0.45
Tensile Strength	750 MPa
Yield Stress	450 MPa

Generally, usage dielectric fluids for EDM are Mineral oils, pure water; additives are added in Water, Kerosene, EDM oils, and transformer oils. Mineral oils are generated from hydro carbon based paraffin crude oils of fossil fuels. [6] As the mineral oils are extracted from hydrocarbon molecules with different molecular structure which is resists degradation behaviors of mineral oil. Due to such phenomenon several researchers used vegetable oils as a liquid dielectric in transformers. Among the attractive factors of vegetable oil, the non-toxicity and highly biodegradable features which ensure low risk to the environment if there is a spillage. The high flash and fire points of vegetable oil ensure more in-service operation safety than mineral oil [7]. Again selection of edible and non-edible alternate oils, edible oil usage generates an issue which rises of food security, so the better option is selecting the non-edible oil as alternate dielectric fluid. In this research work to examine, whether *Pongamia pinnata* oil (*Karanja* oil) is suitable for EDM or not?.

Pongamia pinnata seeds are shown in Figure 1. Table 2 summarized the physico-chemical properties of *Pongamia pinnata* oil and EDM oil. *Pongamia pinnata* is a type of family *Leguminasae*, local in tropical and calm Asia including some portion of India, China, Japan, Malaysia, and Australia. Blooming begins from 4-5 years onwards. Cropping of pods and single almond sized seeds can happen by 4-6 years and yields 9-90 Kg's of seed per tree, *Pongamia pinnata* seed is shown in Figure 1. The yield potential per hectare is 900 to

Figure 1. *Pongamia pinnata* Seeds

TABLE 2. Physico-chemical properties of *Pongamia pinnata* – oil and EDM oil

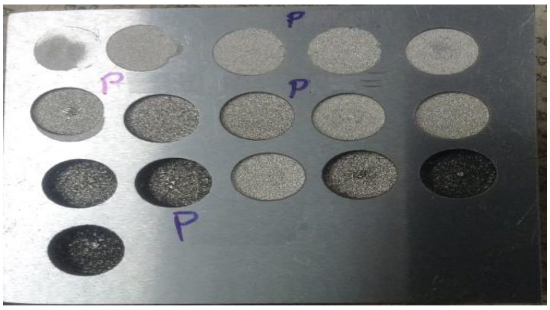
Property	Unit	Pongamia Pinnata oil	EDM oil
Color	-	Yellowish red	No color
Odor	-	odd odor	No odor
Density	kg/m^3	924	820 at 15°C
Flash Point	°C	225	155
Fire Point	°C	230	170
Dielectric strength	kV/mm	24	15

9000 kg/hectare. According to statistics available *Pongamia pinnata* oil has a capability of 135000 million tons for every annum and just 6% is being used [8]. *Pongamia pinnata* oil extractor is shown in Figure 2.

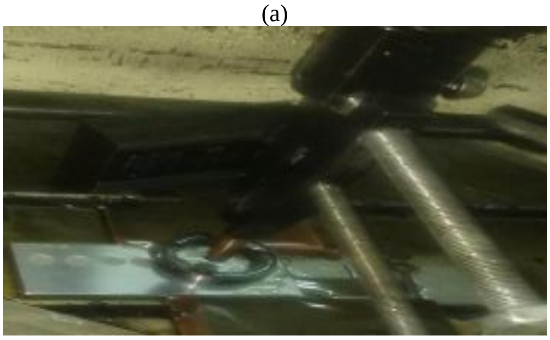
3. DESIGN OF EXPERIMENTS

There are so many input process parameters to be available for EDM process. In this investigation three components are picked. The analysis has 3 factors at 4 distinct levels. A full factorial examination would require 4^3=64 investigations [3, 4]. The directed Taguchi explore different avenues regarding a L16 orthogonal exhibit (16 tests, 3 factors, 4 levels) appears in Table 3. I, T_{on}, T_{off} as input parameters resulted better in MRR, TWR, EWR and SR.

The experimental test plain is shown in Table 4 which is generated by using Minitab-16 as per Table 3 is taken as input, and the output values of MRR, TWR, EWR and SR are shown in Figures 3 to 6 respectively for *Pongamia pinnata* oil and EDM oil as dielectric fluid.



(a)



(b)

Figure 2(a). EN31 specimen used for *Pongamia pinnata* oil **(b)**. EN31 specimen used for EDM oil

TABLE 3. EDM process 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

TABLE 4. EDM process parameters test plan

Sl No.	Current (I)	T_{on}(μs)	T_{off} (μs)
1	9	100	100
2	9	200	200
3	9	500	500
4	9	900	900
5	12	100	200
6	12	200	100
7	12	500	900
8	12	900	500
9	15	100	500
10	15	200	900
11	15	500	100
12	15	900	200
13	18	100	900
14	18	200	500
15	18	500	200
16	18	900	100

Reduced weight of workpiece MRR and average value of SR for machined surface are measured in every experimental trail. The MRR, TWR are by the loss in weight is measured by a measuring balance with least count of 0.001 mg. It is then divided by the density of workpiece 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 typical machining time with lowest MRR was observed for 10 min. The average SR of the machined workpiece is assessed by the Talysurf Roughness Checker. The estimation of SR parameter Ra in micron for each exploratory run was gotten specifically from the Talysurf programming incorporated with the Talysurf. The machined workpiece with *Pongamia pinnata* oil and EDM oil are shown in Figures 2(a), 2(b), respectively.

4. RESULTS AND DISCUSSIONS

TOPSIS method [2, 4] is applied for the experimental machine responses to find out the best response of all experimental trails. *Pongamia pinnata* oil and EDM oil are used for each experiment, where 16 trail runs are taken. For the first run the current, T_{on} and T_{off} are 9A, 100 μm and 100 μm, respectively. The T_{on} and T_{off} have the same values. Due to this the MRR of *Pongamia pinnata* oil value is slightly less than EDM oil. At trail 3 the *Pongamia pinnata* oil MRR is less than EDM oil T_{on} and T_{off} is 500 μm. For trail 11 *Pongamia pinnata* oil

MRR is less than EDM oil slightly with 15A, 500 µm, and 100 µm. For 14th trail also the 18A, 200 µm, 500 µm the MRR value is slightly less than EDM oil values. These values are shown in the graph of Figure 5, all the MRR values of *Pongamia pinnata* is nearer or lie along the pure EDM sample values. It is also observed that 16 experimental trail runs with 4 levels, at I = 9A the first level of 1- 4 trail runs, the first three trail runs MRR is increased and at 4th run the MRR is reduced. The second level of experimentation at I = 12A, 5th, 6th, trail runs MRR is increased, 7th trail run MRR is reduced slightly and at 8th trail run MRR is higher than the old one. The third level at I = 15A, 9th and 10th trail run MRR is slightly reduced and greatly increased in 11th trail run, slightly increased in 12th trail run. The fourth level at I = 18A, 13th, 14th trail run MRR is increased and reduced in 15th trail again increased in 16th trail run. It is observed that the current is significantly showing the effect on material removal during the machining process.

For TWR, EDM oil experimental values are as per the graph shown in Figure 4 are greater than that of Pongamia Pinnata oil, this leads to more amount of Tool Wear is occurred with EDM oil used as dielectric fluid. Due to this, more amount of time is required to tool making, rises its making charges and which leads to increases the machining lead time, raises the overall cost of the product.

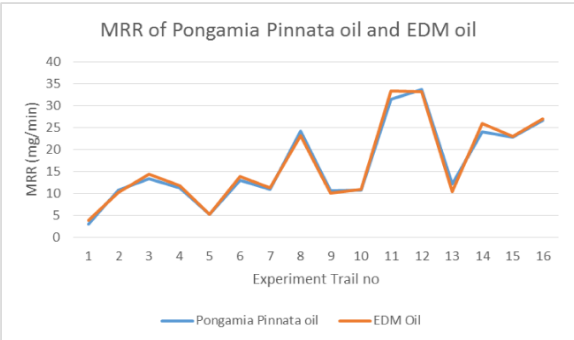


Figure 3. MRR for *Pongamia pinnata* vs. EDM oil

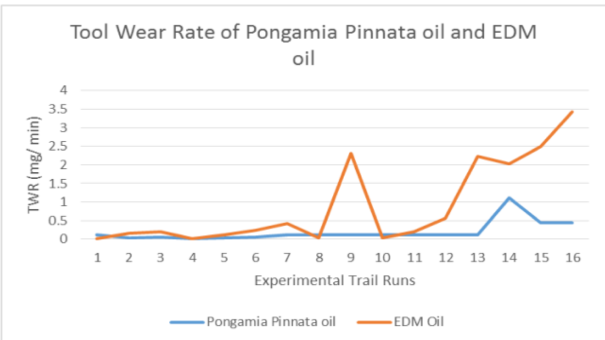


Figure 4. TWR for *Pongamia pinnata* oil vs. EDM oil

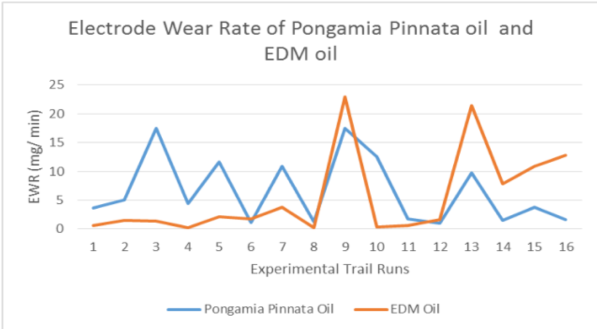


Figure 5. EWR for *Pongamia pinnata* oil vs. EDM oil

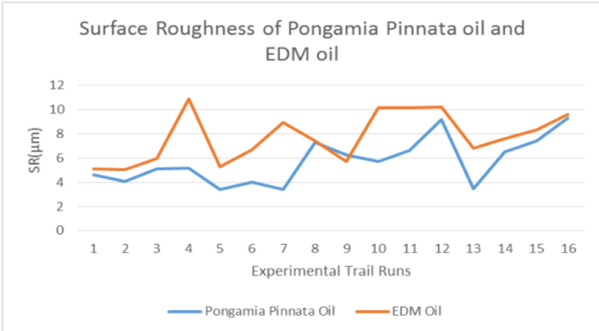


Figure 6. SR for *Pongamia pinnata* oil vs. EDM oil

EWR is ratio of wear weight of the tool to the wear weight of the workpiece, compared with EDM oil to Pongamia Pinnata oil EWR value got greater than the EDM oil from graph as it is shown in Figure 5.

Figure 7 shows the impact of current (I), T_{on} and T_{off} on MRR. The MRR value is increased at higher rate from 9A to 12A, from 12A to 15A increasing rate is slightly lesser and from 15A to 18A, it increasing rate is high. As the current value is increases MRR also increases, from the Figure 7 it made clear that current is directly proportional to the MRR values. T_{on} value is gradually increased from 100 µs to 900 µs, which is directly proportional to MRR value, if T_{on} increases the MRR will also increase. T_{on} is showing greater impact

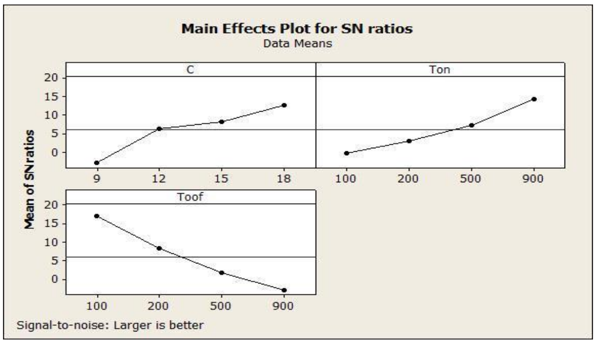


Figure 7. Minitab graph for (I), T_{on} and T_{off} Vs. MRR for *Pongamia pinnata* oil

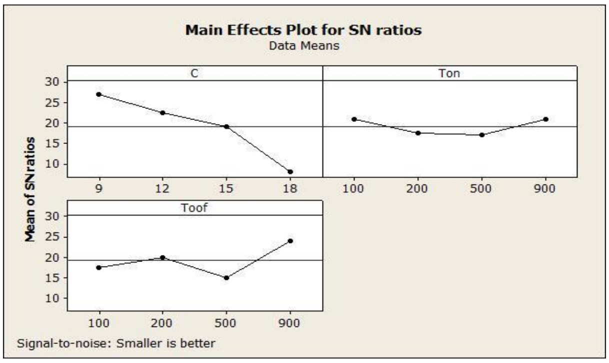


Figure 8. Minitab graph for (I), T_{on} and T_{off} Vs. TWR for *Pongamia pinnata* oil

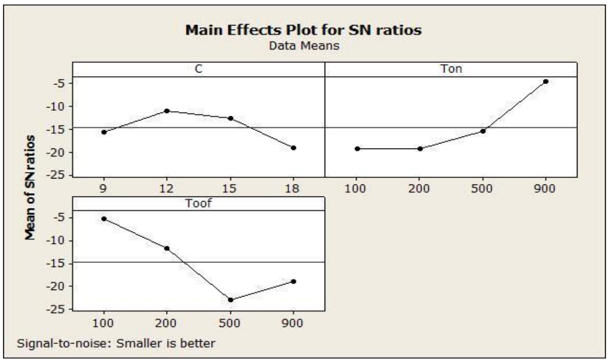


Figure 9. Minitab graph for (I), T_{on} and T_{off} Vs. EWR for *Pongamia pinnata* oil

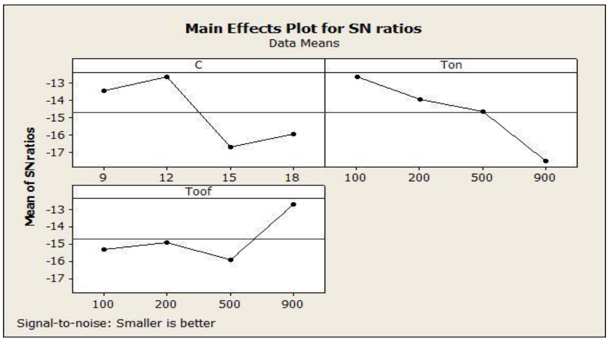


Figure 10. Minitab graph for (I), T_{on} and T_{off} Vs. SR for *Pongamia pinnata* oil

on MRR. T_{off} value is reduced from 100µs to 900µs, where T_{off} increases MRR decreases. From the results considering the MRR all blends including *Pongamia pinnata* oil will alter the requirements of EDM oil. So by increasing Current, T_{on} More MRR will occur along with decrease in T_{off}.

Figure 8 shows the relation between I, T_{on} and T_{off} with TWR. TWR is gradually reduced from 9A to 15A, where at higher current 18A the TWR is too lesser than 9A, 12A and 15A. By this, the impact of current on TWR is indirectly proportional to the current value. T_{on} is gradually reducing at 100µs to 200 µs, the least value of TWR obtained at 500 µs than the remaining all values, again at 900µs the TWR is slightly increased but value is less at 100 µs. As T_{on} is increasing the TWR is reduced up to the 500µs after that TWR is slightly increased at 900µs i.e T_{on} is showing impact on TWR. T_{off} value is increased at 100 µs to 200 µs and decreased at 500µs again increased at 900µs. T_{off} is minimum at 500µs.

From Figure 9, the current is increased from 9A to 12A EWR is increased, and EWR is decreased from 12A to 18A. As current is increased EWR is reduced. T_{on} is increased from 100µs to 900 µs EWR is also increased. At starting EWR is decreased and increased slightly at T_{off} is 100µs - 500µs and 900µs. While the surface roughness value compare with EDM oil to *Pongamia pinnata* oil, the SR value of *Pongamia pinnata* oil is lesser than that of EDM oil values as shown in Figure 8. From Figure 10 the current value increased from 9A to 12 SR value increased and from 12A to 18A SR reduced and slightly increased. As the current increases the SR value will be reduced. SR is gradually reduced with increased T_{on} from 100µs to 900µs. By increasing T_{off} the SR value is reduced and increased at 200µs and 900µs. In any manufacturing processes the ultimate aim is lesser surface roughness, more MRR, hence the *Pongamia pinnata* oil got better results than that of EDM oil.

4. 1. SEM Analysis *Pongamia pinnata* oil used workpiece SEM topology is shown in Figures 11 and 12. Figures 11 and 12 SEM image are observed at X300 and X800 magnification shows lumps of debris, recast layer, craters, lumps of spherical globules, and deep craters produced at experimental trail no 5 at T_{on} = 100 µs, T_{off} = 200 µs, and I = 12A, as input values and obtained output SR = 3.431 µm is average SR value of three sample readings (where SR = 3.382 µm, 3.483 µm, 3.422 µm of 3 sample readings of Talysurf roughness tester).

Figures 13 and 14 SEM micrographs observed at 500X magnification with spherical globules, lumps of

Figure 11. SEM image at X300 magnification for *Pongamia pinnata* oil workpiece

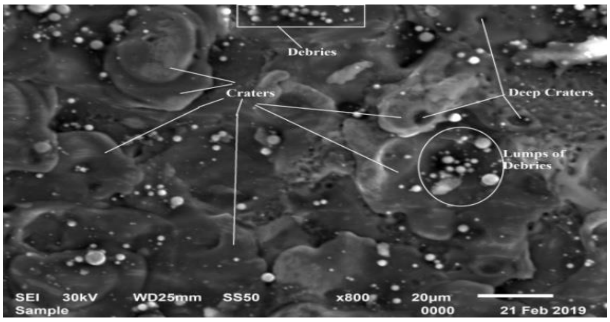


Figure 12. SEM image at X800 magnification of *pongamia pinnata* oil workpiece.

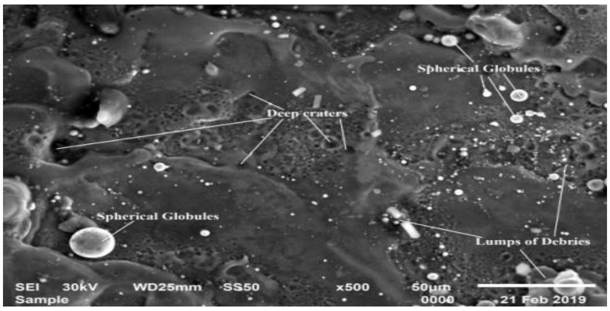


Figure 14. SEM image at X500 magnification for EDM oil workpiece

deposit, debris, material deposition, crater, recast layer were found at higher T_{on} = 100 µs, T_{off} = 100 µs and I = 9 A, as input values and obtained output SR = 5.154 µm (where SR = 5.099 µm, 5.254 µm, 5.111 µm of 3 sample readings average is taken) of workpiece where EDM oil used as dielectric fluid.

By increasing the pulse on time, the amount of heat transfer to the machined surface will be increases and subsequently high amount of material yield to melts. The surface roughness will turn out worst if the liquefy material is not brushed appropriately from the surface by the dielectric liquid which solidifies during the cooling process on the machined surface and forms a recast layer (also known as a white layer).

To cut the materials as fast as could reasonably be expected while the rough cuts, high current and long pulse on time sets are used. The longer pulse on-time and higher current associate to greater thermal energy in the spark consequently vaporizing and liquefying a greater amount of the workpiece material. This outcomes in larger craters left in the surface of the workpiece, and a thicker recast layer. It ought to be noticed that the extents of the craters are influenced by the amount of current that is permitted to go through each of the sparks, and thusly these pictures are just a portrayal of surmised size and shape [9].

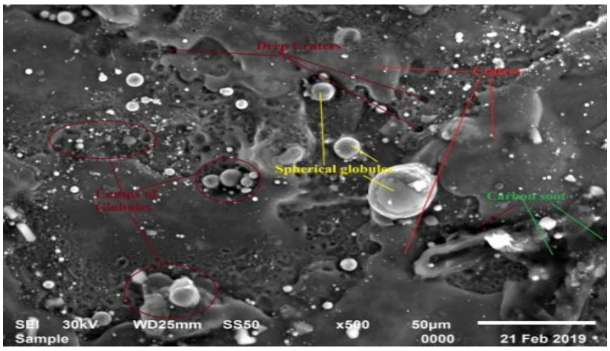


Figure 13. SEM image at X500 magnification for EDM oil workpiece

By applying high energy electrical pulse, which loses its dielectric strength of hydrocarbon based paraffin crude oils at the same time some amount of carbon will dissociate, and simultaneously the workpiece goes erode during this time the dissipated carbon particles will mix in to the workpiece forms carbon soot, to check this impact by using bio-oils like *Pongamia pinnata* oil as dielectric fluid no carbon soot formation is observed from Figures 11 to 12 and in with using of EDM oil carbon soot is observed in Figure 13.

5. CONCLUSION

The following conclusions are made by using sinker EDM machine with EN 31 workpiece and Copper as electrode, by using *Pongamia pinnata* oil and EDM oil as dielectric fluid.

- Dielectric fluid contamination after machining is lower than commercial EDM oil as the *Pongamia pinnata* oil is more cleaner after usage.
- The machined surface output is more cleaner and more finer surface finishing is obtained compare to EDM oil.
- The material removal rate (MRR) of *Pongamia pinnata* oil is equal to EDM oil, in view of this, it can be a good alternate dielectric fluid and also it has high sustainability as it is obtained from plants. Whereas commercial EDM oil is obtained from petroleum refining process.
- The surface roughness values of *Pongamia pinnata* oil shows better performance than the EDM oil.
- The Tool Wear Rate is also less in *Pongamia pinnata* oil, which reduces the tool making cost and setup time, increases the machining time.
- The workpiece surface is more cleaner and no carbon soot is obtained on workpiece.
- *Pongamia pinnata* oil is an eco-friendly, bio-degradable, lesser in cost and generates lesser fumes during machining compared with EDM oil, hence it is operators friendly as it is harmless.

Hence from these, it is concluded that *Pongamia pinnata* oil can be used as alternate to commercial EDM oil.

6. ACKNOWLEDGEMENT

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TOPSIS

چکیده

ماشینکاری تخلیه الکتریکی (EDM) یک عمل ماشین کاری قابل توجه در بین روشهای ایجاد شده ماشینکاری غیر متعارف برای پروفایل های پیچیده در مواد "سخت به ماشین" است ، مشابه فولادها با گرما ، کامپوزیتها ، فوق آلیاژها ، سرامیکها ، کامپوزیتها ، کاربیدها و غیره. در EDM ، خروج مواد کاتدی از طریق تخلیه الکتریکی دقیق کنترل شده (جرقه) انجام می شود ، به دلیل خراب شدن محیط دی الکتریک فلزات دو الکترود را به مذاب و بخار تبدیل می کند. در این کار تحقیقاتی ، مناسب بودن روغنهای دانه گیاهی غیر خوراکی از *Pongamia pinnata* به عنوان یک مایع دی الکتریک در فرآیند EDM مورد بررسی قرار گرفت. همچنین ، مناسب بودن روغن EDM به عنوان یک مایع دی الکتریک متناوب برای کاربردهای صنعتی مورد بررسی قرار گرفت. نرخ پوشیدن الکترود (EWR) ، میزان حذف مواد (MRR)، زبری سطح (SR) و سرعت پوشیدن ابزار (TWR) از ویژگی های اصلی عملکرد EDM هستند. هدف اصلی EDM ، دستیابی به MRR بالاتر در کنار دستیابی به کیفیت سطح حساس سطح قطعه کار ماشین کاری شده است. پارامترهایی که حیرت انگیز ترین MRR را به دست می آورند به سطح ماشین کاری بستگی دارند که مربوط به قطعه کار و ابزار است. دی الکتریک مهمترین متغیر برای بدست آوردن نتایج عالی برای ویژگی های کلیدی فوق است. این تحقیقات نشان داد که روغن *Pongamia pinnata* یک رسانه دی الکتریک مناسب است. نتایج در مقایسه با روغن EDM رضایت بخش است. اثر توپوگرافی قطعه کار و حل شدن ذرات کربن نیز با تجزیه و تحلیل SEM برای هرگونه انحراف در سطح کار بررسی گردید.

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