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Original Article

Green and Sustainable Experimental Investigations on Superni 909 Using Electrical Discharge Machining

M. Sirisha[1], S. Gajanana[2], P. Laxminarayana[3]

[1,3]*Department of Mechanical Engineering, University College of Engineering, Osmania University, Hyderabad, India.*
[2]*Department of Mechanical Engineering, MVSR Engineering College, Hyderabad, India.*

[1]*Corresponding Author : sirishamidde77@gmail.com*

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Abstract *- Electrical Discharge Machining (EDM) is an unconventional method used for machining superalloys. These alloys have been widely used in nuclear, aerospace, jet, rocket, turbine, and petroleum plants, among other applications. Despite many advantages, the EDM process has a few disadvantages. It consumes a lot of energy, produces hazardous emissions, has a slow material removal rate, generates toxic dielectric, and increases manufacturing costs. To reduce the machining cost and provide a safe environment, this paper reports the study of using different compositions of Al2021 + Cu tool and using used gear oil and vegetable oil as a dielectric medium in the shaping of superalloy superni 909. The results of different input parameters viz., current, pulse-on-time, pulse-off-time, voltage, and tool on responses material removal rate and electrode wear rate are investigated. The result shows that these alternate electrodes and dielectrics could be used for sustainable EDM processes.*

Keywords *- EDM, Dielectrics, Used gear oil, Used vegetable oil, Al2021+Cu tool.*

1. Introduction

Modern manufacturing sectors face numerous obstacles due to sophisticated, challenging-to-cut materials like superalloys, composites, and ceramics to meet the requirements of complicated designs and machining costs [1]. Modern industries are using advanced materials that have high strength, good thermal resistance, and good corrosion resistance. The innovative manufacturing model makes use of unconventional energy sources, such as electrical, thermal, mechanical vibrations, hydraulic, and chemical energy. The combination of these energies can also be used. Non-conventional machining processes do not utilize conventional metal removal tools; they employ different energy sources. EDM has been used to machine advanced materials to the desired shape, size, and accuracy for the past few years. EDM is a thermoelectric machining procedure where electrically conductive materials are machined using a sequence of discrete sparks generated between the electrode and workpiece, which are submerged in a dielectric fluid. It utilizes a thermoelectric energy source for machining hard and exotic materials with complex geometries [2]. High precision and accuracy is a distinguishing characteristic of EDM. A major benefit of EDM is that every electrically conductive substance, irrespective of its hardness or strength, can be machined.

Superalloys are sound metallic materials consisting of at least two elements. They are known for their high strength, heat resistance and corrosion resistance [3]. Superalloys find applications in harsh environments in industry, and they are used in nuclear reactors, gas turbines, aircraft, space vehicles, petrochemical equipment, and submarines. They fit into the following categories: nickel-based, cobalt-based and iron-based. Machining of superalloys is extremely difficult due to their superior properties. Traditional machining cannot be adopted for superalloys. EDM is another method of unconventional machining process which can be adopted to machine superalloys.

The electrode's physical characteristics are the key factor affecting the EDM's machining performance. Good electrical and thermal conductivity, high specific heat, improved machinability, better wear and erosion resistance, and other qualities are desirable in an electrode for an EDM. Copper, brass, graphite, tungsten, and steel are frequently used tool materials in EDM. [4] To reduce the tooling cost in EDM as an alternative, an Aluminium alloy 2021 electrode can be used, which costs much less compared to other conventional electrode materials.

The primary reason for environmental pollution is the machining process incorporated into the manufacturing industry [5]. The initiation of ISO 14000 environmental management system standards made manufacturers worldwide focus on the causes which affect the environment and try to reduce them. It is vitally important for the manufacturing industries to be focused on reducing environmental impact and cost for their products and processes in addition to enhancing the quality [6]. This approach has been used in order to have green manufacturing that is in agreement with ISO 14000 standards to recognize and remove the cause of pollution. In this study used gear oil and vegetable oil are exploited as dielectric fluids. The purpose of using them is to adopt green and sustainable manufacturing [7]. Incorporating these used oils will reduce environmental pollution by mainly a waste-to-use philosophy.

2. Experimental Setup and Procedure

2.1. Preparation of the Optimum Composition of Al2021

In this research study, aluminium 2021 was used as the base material for the tool. Table 1 Different material compositions are prepared by varying the proportions of copper, manganese and vanadium. Copper improves strength and facilitates precipitation hardening, reducing ductility. Manganese increases strength and improves strain hardening. Vanadium addition causes significant improvement in mechanical properties. Eight different compositions of tools were prepared using the stir-casting process. Stir casting is a conventional method for commercially producing aluminium composites, wherein reinforced materials such as copper, manganese and vanadium are mixed uniformly within aluminium. Various weight proportions in which copper, manganese and vanadium were added are shown in Table 2. Commercial aluminium wire, copper wire, manganese powder and vanadium powder were the starting materials. Aluminium wire is kept in the electric induction furnace inside a graphite crucible. It is heated to a required superheating temperature of 1070°K until a liquid state is obtained. An amount of 5.8 weight % of Cu, 0.2 weight % of Mn and 0.05 weight % of V, as shown in Table 2, was added to liquid aluminium. The alloy was mixed homogeneously with a graphite stirrer for a period of 15 minutes. The stirrer was kept running at 3000rpm. Particles of impure slag were extracted from the melt, and the molten metal was transferred into the die. After that, the mold was allowed to cool to ambient temperature in the open air without any accelerated and decelerated cooling, and then the cast composites were obtained. This cycle was repeated to get the remaining casting samples, as shown in Table 2**.** The cast samples were machined to the required dimensions and tested per ASTM standard procedure. A full factorial design of experiments is adopted for preparing 8 samples, as shown in Table 2.

The tools prepared are machined to the required dimensions by turning and facing operations. Different tests like hardness and tensile tests were conducted to identify the optimum composition of the tool for machining. Sample 6 of Al2021 with 6.8 wt% Cu, 0.2 wt% Mn and 0.15 wt% V got the highest ultimate tensile strength value of 166.805 N/mm^2 MPa in contrast to other test samples, which is considered the optimum tool composition. Four different tools were prepared by changing the proportion of copper percent by weight in the base aluminium 2021. The composition of copper in tool1 is 6.8%, which has been prepared for high strength. However, as shown in Table 4, other electrodes are prepared by enhancing the Cu% by 13.6%, 20.4%, and 25% to investigate the machining performance.

Table 1. Al2021 compositions

Element	Si	Fe	Cu	Mn	Mg	Zn	V	Al
Composition (%)	0.2	0.3	5.8– 6.8	0.2-0.4	0.02	0.1	0.05-0.15	92.03

Table 2. Metal compositions for the preparation of aluminium2021 tool

S No	Weight % of metals added to aluminium		
	Cu	Mn	V
Sample 1	5.8	0.2	0.05
Sample 2	6.8	0.2	0.05
Sample 3	5.8	0.4	0.05
Sample 4	6.8	0.4	0.05
Sample 5	5.8	0.2	0.15
Sample 6	6.8	0.2	0.15
Sample 7	5.8	0.4	0.15
Sample 8	6.8	0.4	0.15

Table 3. Tensile strength test results of the Al2021 tool

Al2021 Alloy Tool	Tensile Strength N/mm^2
Sample1	141.996
Sample2	142.582
Sample3	136.419
Sample4	107.775
Sample5	106.303
Sample6	166.805
Sample7	154.307
Sample8	143.106

Table 4. Electrode material composition

S.No	Electrode	Cu%
1	T1(optimum composition)	6.8%
2	T2	13.6%
3	T3	20.4%
4	T4	25%

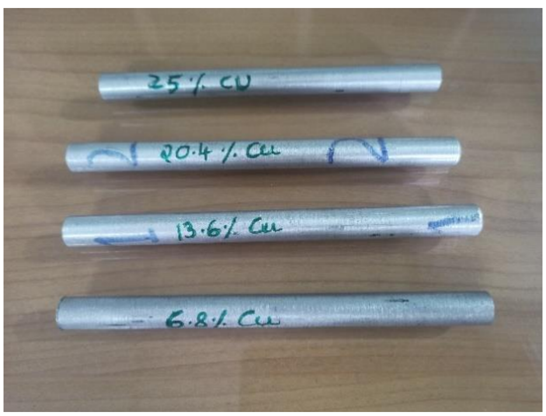

Fig. 1 Al2021 Electrodes with varying % of Cu

In this study, trials were carried out utilizing Die sink EDM, as shown in Figure 3. The experimental architecture was planned as per the Design of the Experiment (DOE) using the Taguchi orthogonal array to optimize the number of runs, time, and resource consumption and gain maximum data from this investigation. Based on the thorough literature review, discharge current (I), voltage (V), pulse-on-time (Ton), pulse-off-time (Toff) and electrode material are identified as the important process parameters, and hence, these are considered for the study. Each parameter varies at four levels, as illustrated in Table 5. Trials were carried out by considering the L16 orthogonal array suggested by Taguchi. Material removal rate (MRR), tool wear rate (TWR), surface roughness (SR) and wear ratio (WR) were studied as responses. Workpiece machining was done for a duration of 10 minutes, and the amount of MRR and TWR was computed by taking the initial weight and the final tool's weight for each trial. The tool and the workpiece were dried, cleaned, and then put through a weighing machine for each experiment. Following each experiment, the instrument was grounded. The precision electronic weighing machine was used to measure the weight of the tool and workpiece. A Mitutoyo talysurf tester with a diamond stylus tip was employed to gauge the machined workpiece's rough surface. The center line average surface roughness value (Ra in micron) was taken straight from the machine's inbuilt tally profile software to ensure precise and efficient measurement. MRR and TWR for each experiment are computed using the following expressions, as seen in Equations (1) and (2), respectively.

$$\text{MRR} = \frac{\text{initial mass of workpiece} - \text{final mass of workpiece}}{\text{machining time}} \tag{1}$$

$$\text{TWR} = \frac{\text{initial mass of electrode} - \text{final mass of electrode}}{\text{machining time}} \tag{2}$$

Table 5. Input parameters and values

Input Parameters	Values
Current(A)	10, 20, 30, 40
Pulse on Time(μs)	250, 500, 750, 1000
Pulse off Time (μs)	100, 200, 300, 400
Voltage (V)	30,40, 50, 60
Electrode	T1, T2, T3, T4

Superni 909 superalloy, based on nickel, is utilized as work material for conducting the experiments. Superalloys maintain superior mechanical qualities at higher temperatures. The superalloys based on nickel show exceptional strength, heat resistance and corrosion resistance at extremely high temperatures.

Superalloy superni 909 was selected as the workpiece for this study due to its tremendous applications in turbines, jet engines, turbochargers, oil, gas, and cryogenic industries. The dimensions of the workpiece used are 66.8mm in diameter and 6mm in thickness. Pictures of the machined workpieces are seen in Figures 2(a-c).

Fig. 2(a)Workpiece operated with EDM oil as dielectric fluid

Fig. 2(b) Workpiece operated with used gear oil as dielectric fluid

Fig. 2(c) Workpiece operated with used vegetable oil as dielectric fluid

The types of dielectric fluids used were EDM oil, used vegetable oil and used gear oil. The properties of the dielectric fluid are shown in Table 6, and samples are shown in Figures 4(a & b). The dielectric tank was emptied and cleaned properly before starting the experiments. The tank was filled with new EDM oil to conduct the experiments. Similarly, the tank was drained and cleaned before using used vegetable oil and used gear oil. The process parameters value taken for the trials are shown in Table 5**.** There were 48 tests conducted in total, 16 runs each with EDM oil, used vegetable oil and used gear oil. Results recorded while machining with three dielectric fluids are presented in Table 7.

Table 6. Physical properties of used dielectric fluids

Dielectric	Density gm/cc	Viscosity poises	Ash content	Carbon residue
Used gear oil	0.8720	9.88	0.10	0.12
Used vegetable oil	0.9153	11.36	0.06	0.09

Table 7. Experimental results of MRR, TWR, SR

S No	T_{on}	T_{off}	I	V	Tool	MRR (gm/hr)			TWR (gm/hr)			SR (μm)		
						EDM oil	Used gear oil	Used vegetable oil	EDM oil	Used gear oil	Used vegetable oil	EDM oil	Used gear oil	Used vegetable oil
1	250	100	10	30	T1	2.82	1.56	4.32	0.54	0.72	0.54	2.896	5.138	4.75
2	250	200	20	40	T2	1.02	3.84	5.4	0.18	0.84	1.08	3.423	4.193	5.315
3	250	300	30	50	T3	3.60	2.1	4.32	0.60	1.32	0.96	3.602	3.003	6.177
4	250	400	40	60	T4	7.32	2.82	5.16	0.78	1.38	1.38	3.987	3.163	6.052
5	500	100	20	50	T4	4.92	3.36	5.28	0.60	0.96	0.72	2.853	3.328	5.535
6	500	200	10	60	T3	2.46	2.64	3.96	0.54	0.78	0.54	3.751	3.75	7.746
7	500	300	40	30	T2	6.12	3.24	7.32	1.32	1.02	0.96	3.556	4.115	4.497
8	500	400	30	40	T1	3.84	3.3	4.68	0.72	0.66	0.96	4.431	4.22	3.59
9	750	100	30	60	T2	5.34	2.4	10.26	0.66	0.78	1.08	4.869	3.74	4.438
10	750	200	40	50	T1	5.52	2.82	7.44	0.78	0.9	0.9	5.011	4.039	4.78
11	750	300	10	40	T4	2.46	2.82	2.82	0.66	1.14	0.72	3.897	3.505	6.153
12	750	400	20	30	T3	5.04	3.48	4.86	1.14	0.96	0.96	3.796	3.323	4.636
13	1000	100	40	40	T3	8.40	9	9.36	0.84	0.78	0.9	3.760	3.867	3.989
14	1000	200	30	30	T4	7.20	7.14	4.68	1.44	0.66	0.78	3.376	3.43	3.735
15	1000	300	20	60	T1	5.70	2.64	5.4	0.54	0.3	0.72	4.664	3.773	4.585
16	1000	400	10	50	T2	6.72	2.76	5.1	0.72	0.18	0.54	3.937	3.123	3.697

Fig. 3 Die-sinking EDM machine

Fig. 4(a) Used gear oil sample

Fig. 4(b) Used vegetable oil sample

2.2. Development of Mathematical Models

Utilizing MINITAB software, a mathematical model was created based on the experimentally observed data, and linear regression analysis was carried out. Considering the data predicted by the regression equation in relation to input parameters, MRR, TWR and SR graphs are drawn.
Equations 3,4, and 5 are developed for EDM oil as dielectric fluid.

$$MRR = -1.89 + 0.00408\ T_{on} + 0.00150\ T_{off} + 0.1050\ I + 0.0099\ V + 0.0487\ Tool \quad (3)$$

$$TWR = 0.457 + 0.000438\ T_{on} + 0.000585\ T_{off} + 0.01185\ I - 0.01365\ V + 0.01181\ Tool \quad (4)$$

$$SR = 1.971 + 0.000847\ T_{on} + 0.001369\ T_{off} + 0.01760\ I + 0.02708\ V - 0.0388\ Tool \quad (5)$$

Equations 6,7, and 8 are developed for used gear oil as dielectric fluid.

$$MRR = 1.93 + 0.00326\ T_{on} - 0.00438\ T_{off} + 0.0648\ I - 0.0567\ V + 0.0942\ Tool \quad (6)$$

$$TWR = 0.633 - 0.000666\ T_{on} + 0.000105\ T_{off} + 0.01035\ I - 0.00105\ V + 0.02320\ Tool \quad (7)$$

$$SR = 6.224 - 0.000472\ T_{on} - 0.001937\ T_{off} - 0.00305\ I - 0.01758\ V - 0.05141\ Tool \quad (8)$$

Equations 9, 10 and 11 are developed using vegetable oil as dielectric fluid.

$$MRR = 3.46 + 0.00202\ T_{on} - 0.00747\ T_{off} + 0.1056\ I + 0.0267\ V - 0.0639\ Tool \quad (9)$$

$$TWR = 0.370 - 0.000258\ T_{on} + 0.000465\ T_{off} + 0.01425\ I + 0.00225\ V + 0.00462\ Tool \quad (10)$$

$$SR = 4.11 - 0.002023\ T_{on} - 0.00059\ T_{off} - 0.0280\ I + 0.0419\ V + 0.0667\ Tool \quad (11)$$

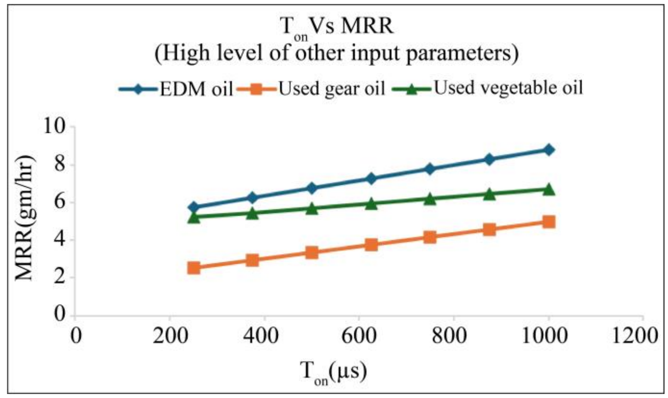

Fig. 5(a) Effect of T_{on} on MRR

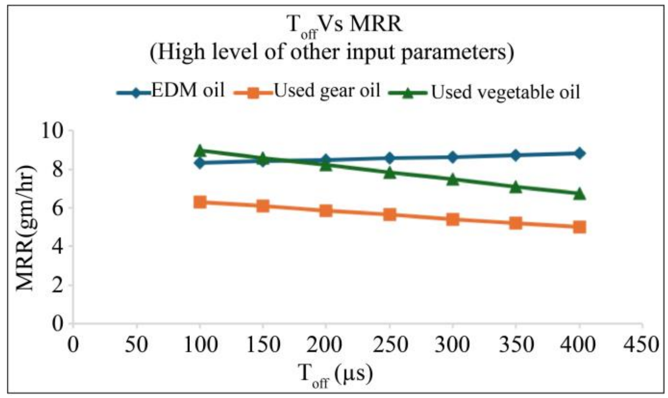

Fig. 5(b) Effect of T_{off} on MRR

3. Results and Discussion

3.1. Influence of control parameters on MRR

The graphic Figure 5(a-e) displays the MRR's reaction behavior when the chosen control parameters are applied. MRR can be defined as the amount of material removed per unit of time. To attain good economic production, a higher MRR is essential. It is a key parameter for this process economy.

From Figure 5(a), a comparative response behavior of the impact of pulse on time on MRR, it can be said that the MRR rises with respect to pulse-on-time for all the three dielectrics used while machining superalloy superni 909. EDM oil shows the highest MRR, while the used gear oil results in the lowest MRR. This is due to EDM oil's lower viscosity and good oxidation resistance contrasted with used gear oil. An effective sparking cycle is maintained due to low breakdown voltage [8]. Increasing the pulse-on-time means maintaining the same temperature for an extended period, leading to more metal melt. The metal is vapourised by the explosion of gas bubbles at high temperatures, causing more metal volume to be removed [9].

Figure 5(b) exhibits the comparative response behavior of the influence of pulse-off time on MRR for all three dielectrics used. The variation of MRR is the same for used gear oil and vegetable oil, whereas the MRR is found to be almost constant for EDM oil. It is observed that the MRR is decreasing for used gear oil and used vegetable oil with increasing value of pulse off time.

From Figure 5(c), the comparative response behavior of the impact of current on MRR, it can be said that MRR rises linearly with increasing current value for three dielectrics used while machining superalloy superni 909. Under the same experimental conditions, the MRR for EDM oil is observed to be higher. This could be explained by the fact that EDM oil's reduced viscosity and higher breakdown voltage result in an arduous ionized state that lasts longer and results in increased MRR [10]. The rise in metal removal rate is because of the reason that the spark discharge energy is enhanced to improve melting and evaporation and promote the impulsive force in the spark gap. Greater current values lead to high thermal loading on a workpiece and result in higher metal removal rates.

Figure 5(d) reveals the comparative response behavior of the influence of voltage on MRR for all three dielectrics used. It is noticed from the figure that MRR is almost constant with an increment of voltage for EDM oil and used vegetable oil, while MRR decreases with an increasing voltage value for used gear oil. Because of inadequate work material cooling, an increase in voltage causes an undesirable concentrated discharge, which lowers MRR.

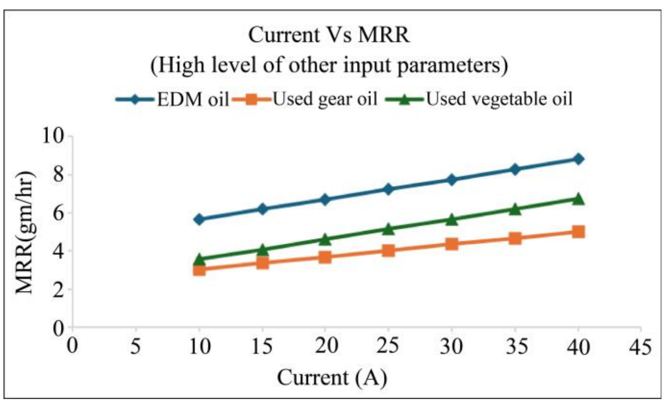

Fig. 5(c) Effect of current on MRR

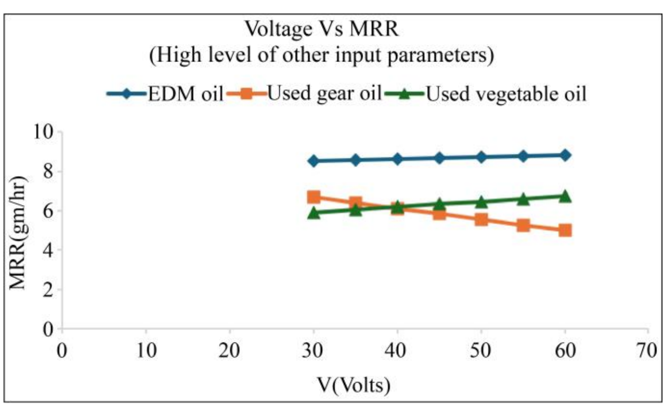

Fig. 5(d) Effect of voltage on MRR

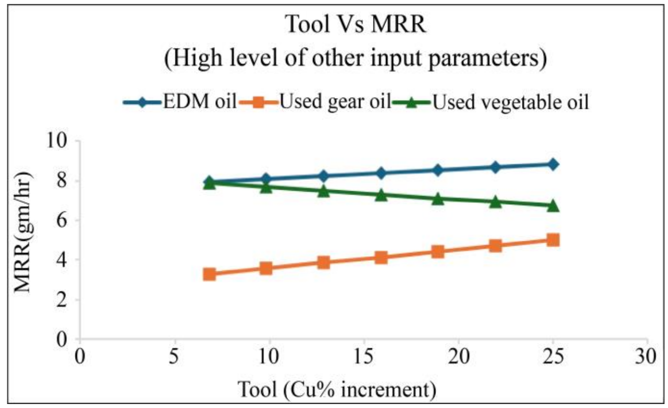

Fig. 5(e) Effect of the tool on MRR

Figure 5(e) exhibits the comparative response behavior of the influence of increment of Cu% in the Al2021 tool on MRR for all three dielectrics used. It is noticed that MRR rises with increasing the composition of copper in the AL2021 tool for EDM oil and used gear oil, whereas, for used vegetable oil, the variation of MRR is inverse to the increase in the percentage of copper addition to the Al2021 tool.

As the copper percentage increases, the thermal conductivity of the tool also increases. This means that during machining superalloy superni 909, the heat generated at the electrode-workpiece interface can be dissipated more efficiently. As a result, more metal removal rates are observed.

3.2. Influence of Control Parameters on TWR

Electrode erosion occurs when high-speed electrons from the electric spark produced in the EDM process impact a softer electrode surface [11]. The electrode's dimensions and shape, as well as the cavity that is formed, are altered by this erosion.

Hence, to obtain better geometry and dimension, a minimum TWR is desired. Also, due to erosion, the electrode needs to be dressed regularly, which further depreciates the electrode and hence impacts the price of the electrode. Figure 6(a-e) shows the response behavior of TWR with the influence of control parameters.

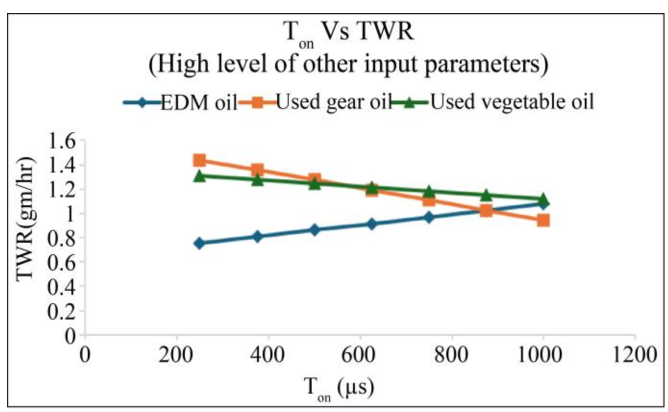

Fig. 6(a) Effect of T_{on} on TWR

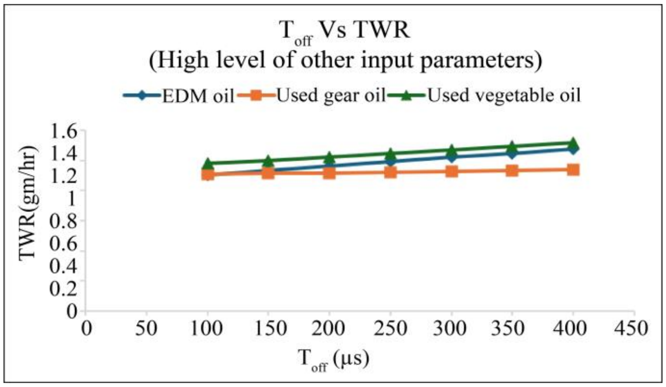

Fig. 6(b) Effect of T_{off} on TWR

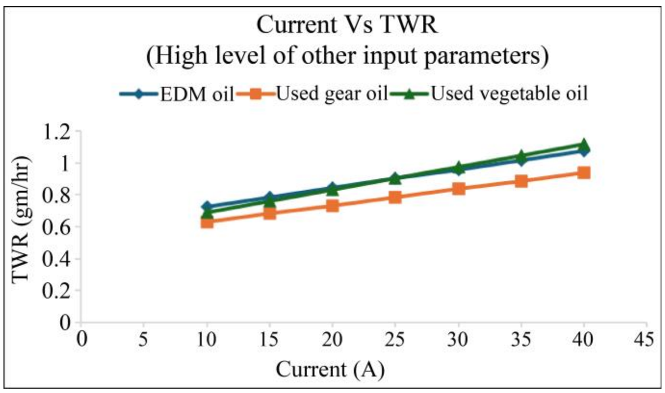

Fig. 6(c) Effect of Current on TWR

Figure 6(a) reveals a comparative response behavior of the effect of pulse on time on TWR for three dielectrics used while machining superalloy superni 909. It is observed that the TWR is decreasing with respect to pulse-on-time for used gear oil and used vegetable oil, and it is increasing with respect to EDM oil. TWR values when EDM oil is used are lower, and TWR values when gear oil is used are highest, while TWR values when used vegetable oil is used are in the middle. With the rise in pulse on time, the machining rate is accelerated, which leads to higher TWR.

Figure 6(b) exhibits the comparative response behavior of the influence of pulse-off time on TWR for all three dielectrics used. The change of TWR is the same for all the dielectrics used and is found to be almost constant. Pulse-off time does not have a considerable impact on TWR.

From Figure 6(c), the comparative response behavior of current influence on TWR, it can be said that the TWR increases linearly with increasing current value for dielectrics used while machining superalloy superni 909. As the discharge current increases, spark energy increases, generating more heat over the electrode, which is the main cause of electrode erosion [12]. The figure shows that the TWR is less for the used gear oil and almost the same for EDM oil and vegetable oil used while machining the superalloy superni 909. A good conductive discharge channel leads to lower TWR for used gear oil.

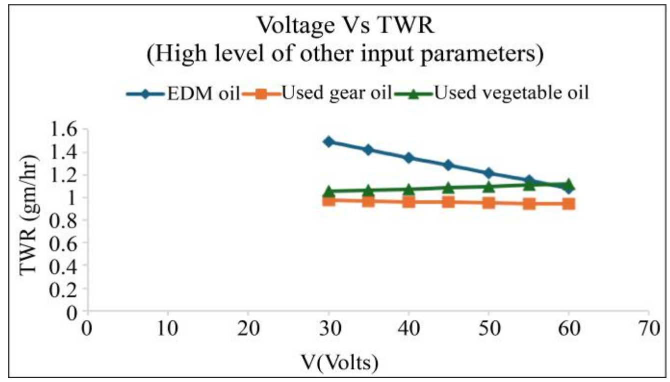

Fig. 6(d) Effect of voltage on TWR

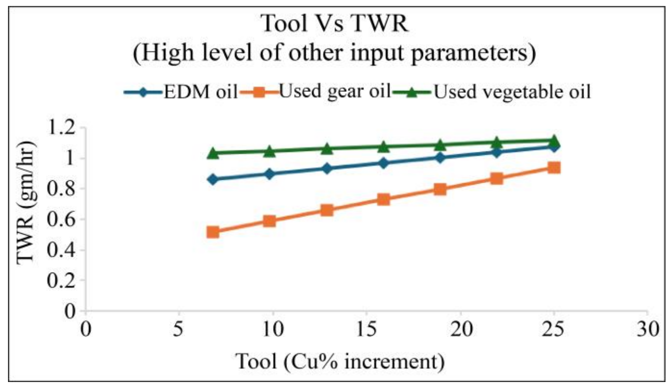

Fig. 6(e) Effect of the tool on TWR

Figure 6(d) exhibits the comparative response behavior of the impact of voltage on TWR for all three dielectrics used. It is observed from the figure that TWR is almost constant with an increase of voltage for used gear oil and used vegetable oil while TWR is decreasing with increasing value of voltage for EDM oil. Voltage does not have a considerable impact on TWR.

Figure 6(e) conveys the comparative response behavior of the influence of increment of Cu% in the Al2021 tool on TWR for all three dielectrics used. It has been noticed that TWR is increasing with the increase in the composition of copper in the AL2021 tool for all three dielectrics used. The graph indicates that TWR is less for the used gear oil and high for the used vegetable oil while machining superalloy superni 909. TWR values for EDM oil were shown in the middle of used gear oil and vegetable oil.

3.3. Influence of Control Parameters on SR

The machined components on EDM contain thousands of tiny pits and bumps formed due to continuous spark discharges on the machined surface. The automotive and aerospace industries have a high demand for good surface-finished products. Hence, the surface texture of the machined component is a crucial performance metric in the EDM method. Figure 7(a-e) conveys the response behavior of SR with the influence of control parameters.

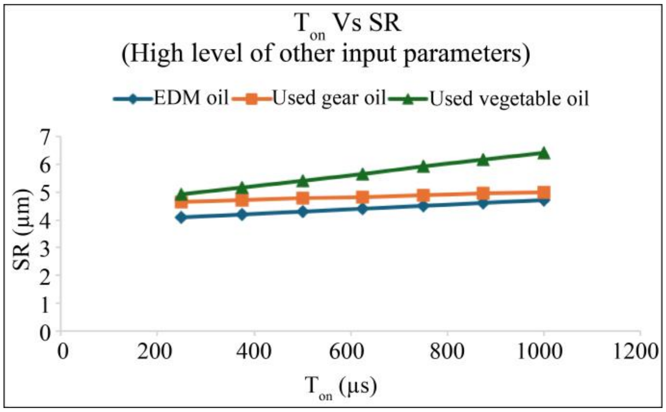

Fig. 7(a) Effect of T_{on} on SR

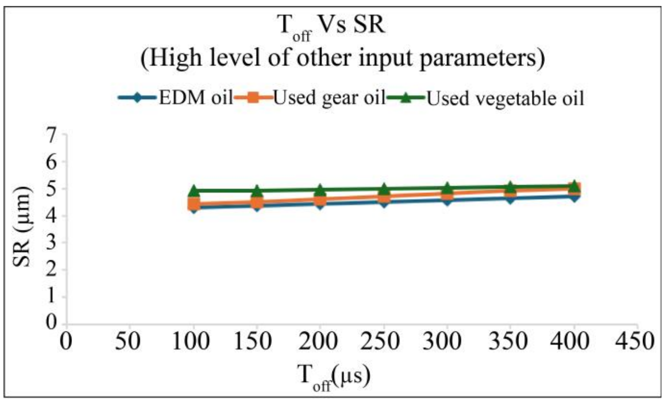

Fig. 7(b) Effect of T_{off} on SR

From Figure 7(a), a comparative response behavior of the impact of pulse-on-time on SR, it can be said that the SR rises with pulse-on-time for all the three dielectrics used. As the pulse increases over time, the spark energy rises, which causes more metal to melt and evaporate, forming thousands of tiny pits on the surface and increasing the irregularities of the machined component [13]. The plot shows that SR is less for the EDM oil and higher for the vegetable oil used while machining superalloy superni 909. SR values for used gear oil are in the middle of EDM oil and used vegetable oil. When vegetable oil is utilized, a concentrated plasma channel is formed due to higher viscosity, which increases surface texture, while EDM oil has a weaker plasma channel and smoother surface.

Figure 7(b) reveals the comparative response behavior of the influence of pulse-off time on SR for all three dielectrics used. SR variation is the same for all the dielectrics used and is found to be almost constant. It can be concluded that pulse-off time does not contribute much to the variation of SR.

Figure 7(c) shows the comparative response behavior of the influence of current on SR for all three dielectrics while machining superalloy superni 909. It is observed that as the discharge current is raised, the surface finish of the machined component is reduced for EDM oil and used vegetable oil, and it is almost constant for used gear oil. Higher SR reported with used vegetable oil could be a result of the plasma channel's high energy density [14]. A higher discharge current generates high spark energy, resulting in the deeper metal being removed from the workpiece, forming an uneven surface of the machined component [15].

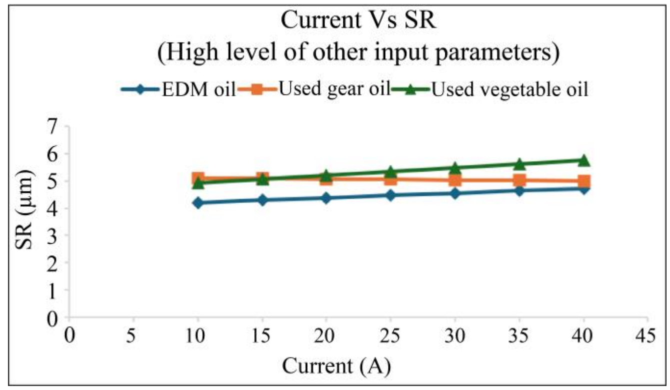

Fig. 7(c) Effect of current on SR

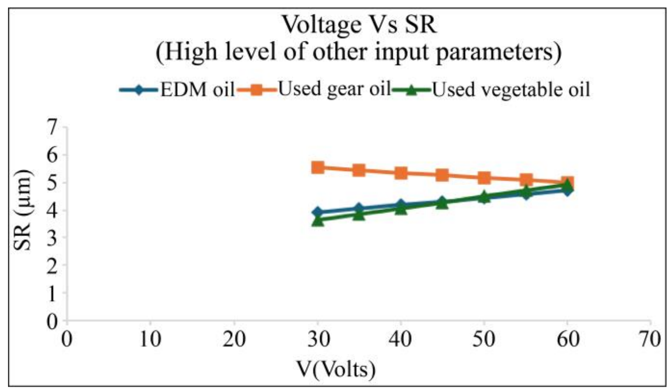

Fig. 7(d) Effect of voltage on SR

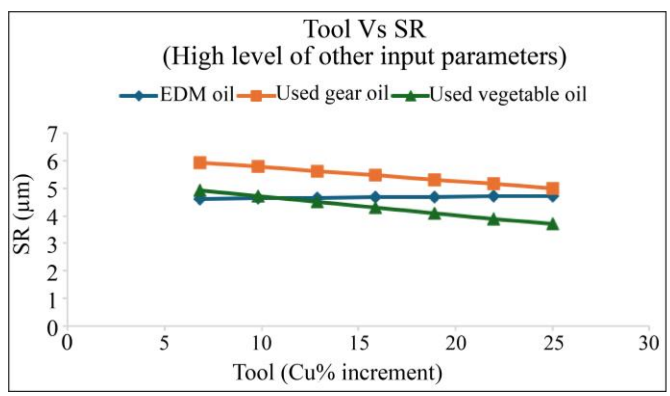

Fig. 7(e) Effect of the tool on SR

Figure 7(d) reveals the comparative response behavior of the impact of voltage on SR for all three dielectrics used. It is noticed from the figure that SR increases with the increase of voltage for EDM oil and used vegetable oil, while SR decreases with the increasing value of voltage for used gear oil.

Figure 7(e) shows the comparative response behavior of the influence of increment of Cu% in the Al2021 tool on SR for all three dielectrics used. It has been noticed that the surface quality of the machined component is increasing with the increase in the composition of copper in the AL2021 tool for all three dielectrics used. From the plot, it can be observed that gear oil showed the least performance concerning the quality of the machined component compared to EDM and vegetable oil. The vegetable oil machined component used has a good surface finish. The surface finish of the component superalloy superni 909 is between the used gear oil and the used vegetable oil.

4. Conclusion

In this present work, the machinability of the superalloy superni 909 workpieces is explored to fulfill the requirement of sustainable EDM manufacturing. This work helps achieve optimal circumstances for machining, improve productivity, and create a good working environment to meet the needs of green manufacturing. The feasibility of using gear oil and chip oil as a dielectric is studied in this work.

- The pulse on time and discharge current remarkably impact the MRR of superalloy superni 909 in EDM. Al2021 electrode with 25% copper gives better MRR during EDM of superalloy superni 909.
- The comparative analysis of the dielectrics infers that EDM oil possesses more MRR.
- The pulse on time and discharge current are the main determining elements for TWR. Utilization of used gear oil is found to be the best among the other two with respect to TWR.
- Pulse on time and Al2021 tool with varying copper percentages are identified as significant factors for surface quality in EDM of superalloy superni 909. EDM oil has the best surface quality of the superalloy superni 909 among the three dielectrics.
- During EDM of superalloy superni 909, a smaller discharge current value might result in a precise and accurate cut. Al2021 electrode with 25% copper enables the production of exact components.

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