Investigations on Performance Enhancement of Eco-Friendly Electrical Discharge Machining using oil based bio dielectric fluid of Oil Hardened Non-Shrinkable Steel – A Review

Ajay K. Pathak[1], Dr. D. M. Patel[2]

Assistant Professor, Department of Mechanical Engineering, D. Y. Patil College of Engineering, Akurdi, Pune, Maharashtra, India[1]
Professor, Department of Mechanical Engineering, D.N.Patel College of Engineering Shahada, Maharashtra, India[2]

ABSTRACT

OHNS (Oil Hardened Non-Shrinkable Steel) is widely used in range of application in tool and die making industries. OHNS steel is a general purpose steel that is generally used in applications where alloy steels cannot provide sufficient hardness, strength and wear resistance. The electric discharge machining is categorized as thermoelectric process in which the heat energy generated by spark is used to erode material from work piece. In this process, high-frequency electric sparks cause decomposition of the dielectric media, which eventually generates intense temperatures of the order of 8000–12,000 K to melt and vaporize the work material. Uniqueness of the process lies in the fact that the material is removed accurately and precisely at extremely high temperature. Controlled material erosion makes it possible to generate dimensionally and geometrically accurate profiles on difficult-to-cut materials. The present work is about analysis of performance comparison of the electric discharge machining of OHNS steels using Hydrocarbon based oil and eco-friendly bio dielectric. With the consideration of influencing parameters, experiments are conducted with the copper electrode used as the tool and OHNS as the work piece in the machining process. The combination of the gap voltage, gap current settings are selected for maximum material removal rate (MRR), surface roughness (SR), surface crack density, white layer thickness etc. Finally the optimum cutting condition is said to be obtained.

Keywords: *EDM, MRR, SR, SH, OHNS, Bio-dielectric.*

---

1. Introduction

Electric discharge machining (EDM) is the most widely practiced non-conventional material removal process and rules significant market share of worldwide sales of total machine tools. In this process, high-frequency electric sparks cause decomposition of the dielectric media, which eventually generates intense temperatures of the order of 8000–12,000 K to melt and vaporize the work material. Various work pieces are machined by EDM, such as very hard materials, super alloys, automotive components, surgical and other biomedical parts etc. Coolant/Di-electric oil is used as a working medium between work piece and tool. The dielectric basically helps in transportation of unwanted or debris from machining zone to increase the energy density in plasma channel, recondition of the dielectric strength and cooling of the electrode. Most common dielectric fluids are mineral oil, kerosene, paraffin, distilled water and de-ionized water. Recent trends involve the use of clear and low viscosity fluids to make cleaning easier. After cycles of usage, dielectric performance will reduce and must be replaced. Compared to other conventional manufacturing methods, EDM process is environmentally hazardous due to the use of the hydrocarbon dielectric fluids. Hence, EDM process has potential research scope to identify and eliminate the sources of environmental pollution to minimize its impacts. The environmental impact of the manufacturing process is evaluated using factors contributing to the environmental pollutions such as emissions, spillage, recycle and disposal etc. Hence this situation draws interest in investigating the consumption of dielectric in EDM process and finds an alternative for Hydrocarbon oil. Bio-dielectric can be an alternative for this.

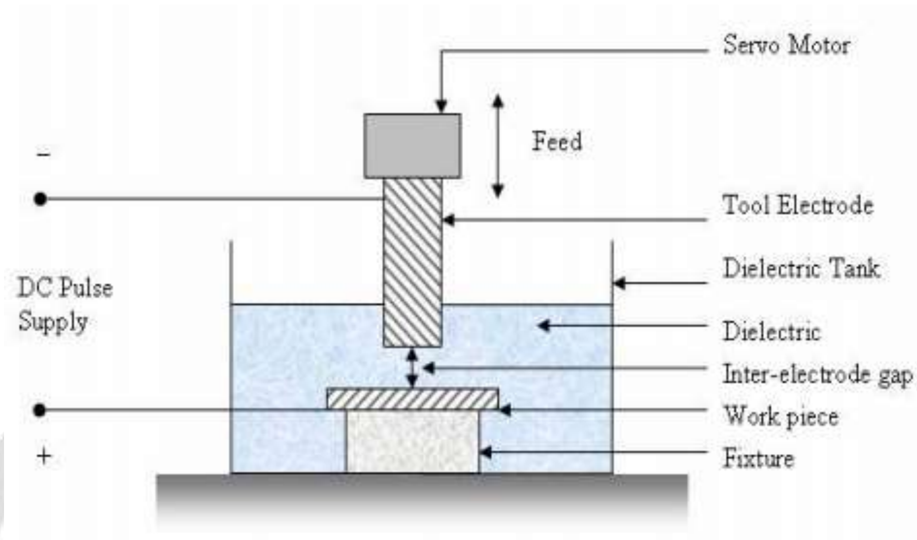

Fig.1 Electric Discharge Machining (EDM) machine tool

1.1 **Di-electric oil Selection:**

Tool and dielectric combination has significant influence on the quality of emissions and dielectric wastes generated. A scientific model is required to be developed to predict and characterize the emission products and toxicity of waste generated. The model provides data for the selection of the best set of parameters to keep the hazardous and toxic emission concentrations within the permissible level in the operator working area.

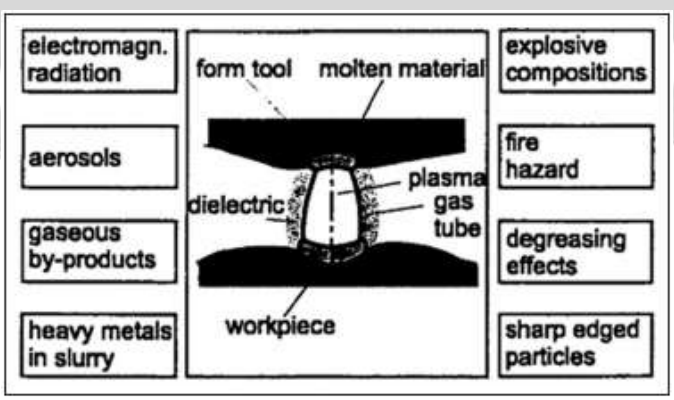

Fig.2 Electric discharge machining and its hazard potentials

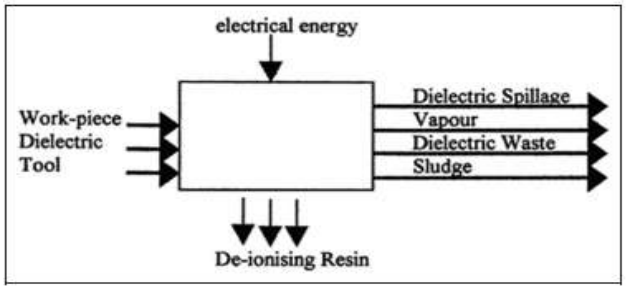

Fig.3 EDM ecological block scheme

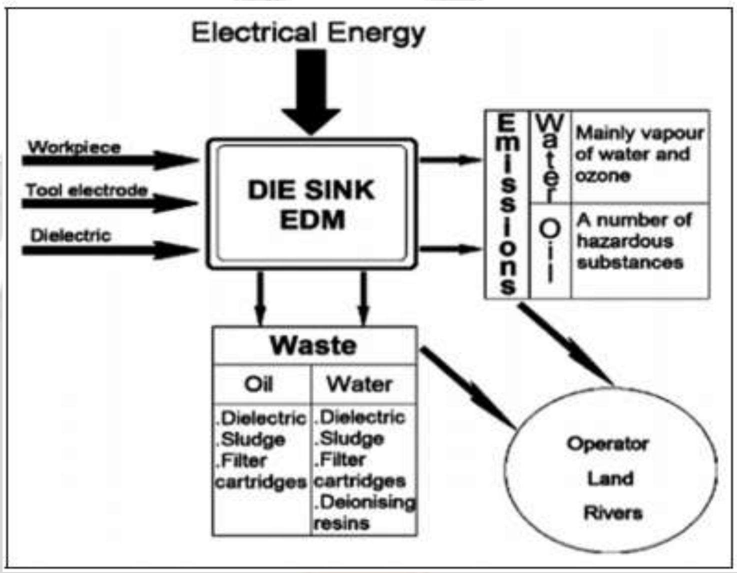

Fig.4 Environmental impact of die-sink EDM

Qualitative assessment for justification of bio-oils as EDM dielectric *(Table 1)*

S. No.	Desired Property	Mineral oil	Bio oils	Justification
1	High breakdown voltage	Lower	Higher	For minimum arcing (random and uncontrolled low energy arc, higher energy utilization ratio)
2	Low relative permittivity/dielectric constant	Lower	Higher	For min. Energy loss, For lower electrostatic energy to minimize magnetic field effect, prevent localized spark reoccurring
3	Low dissipation factor	Lower	Higher	For minimum power loss, prevent aging and deterioration
4	Higher density	Lower	Higher	For better flushing effect
5	Lower viscosity	Lower	Higher	For better cooling capacity
6	Higher flash and fire points	Lower	Higher	For fire prevention
7	Lower pour point	Lower	Higher	For better flow characteristic at low temp
8	Higher oxidative stability	Higher	Lower	For longer working life of fluid
9	Lower sulphur, iodine and acid numbers	Higher	Lower	For better personnel health

10	Higher oxygen content	Lower	Higher	For minimum combustion hazard release
11	Higher biodegradability	Lower	Higher	For environment protection
12	Higher thermal conductivity and specific heat	Lower	Higher	For better cooling of electrode and work material and material integrity

1.2 **Tool Specifications:**

In electric discharge machining (EDM) process, the tool shape and size along with wear are of great importance because they adversely affect the accuracy of machined work-piece. Material removal rate (MRR) and Tool wear rate (TWR) will be the decisive parameter for specific tool shape/size. White layer thickness formed on workpiece during EDM process and thermal conductivity of white layer affects the material removal rate and electrode wear rate in the process.

Chemical Compostion of Electrode Material *(Table 2)*

Element	Cu	Ni	Tin	Zn	Mn	Al	C	Si	Lead
Composition (%)	99.71	0.019	0.005	0.13	0.001	0.007	0.03	0.002	0.01

Chemical Compostion of Work Piece Material *(Table 3)*

Element	C	Si	Mn	P	S	Cr	Mo	Ni	Al
Composition (%)	0.36	0.28	1.52	0.008	0.001	1.88	0.22	0.95	0.021

1.3 **Sustainable EDM:**

The sustainable machining practices has to be implemented in EDM process which in turn helps to implement the ISO14000 series environmental standards to control the life cycle impact assessment of the manufactured parts in EDM industries. KPI's framed for the EDM process suggests that the dielectric fluid used in the process is one of the major sources affecting the sustainability of the EDM process. Vegetable oil has the potential to replace the commercial hydrocarbon oil-based dielectric fluids. Characteristics of vegetable oils and its effects on sustainability indicators are listed.

Prime performance indicators for sustainable EDM *(Table 4)*

S. No.	Sustainability criteria	Prime performance indicators for sustainable EDM
1	Environmental impact	Biodegradability of dielectric fluid Non-toxicity of dielectric fluid Green manufacturing practices index
2	Manufacturing Cost	Minimum deterioration of metallurgical structures of tool-work materials Minimum amount of post material removal operations, rework and defective parts produced Lean manufacturing measures
3	Personnel health	Emissions of organic and inorganic compounds in the form of gases, molten vapour and solid particulate concentration in the operator breathing zone Exhaust ventilation in the operator breathing zone to keep
4	Material and energy consumption	Use of minimum amount of dielectric for the same amount of material removed Recondition, recycle and reuse of use dielectric
5	Waste management	Recyclability and reusability of waste dielectric, sludge and used electrode

		Ensure minimum spillage Minimum hazardless index of waste
6	Operational safety	Minimum fire risk for dielectrics Prevention of vapour accumulation zones for fire risk mitigation

1.4 **Minimum Quantity Lubrication:**

MQL is the process of using little amounts of high-quality lubricant directly to the cutting tool and work piece interface instead of using commonly used lubricants. Minimum Quantity Lubrication setup for EDM process will be designed and developed. This will be helpful for optimal use of lubricant such that wastage and harmful effect to human life can be reduced.

2. Literature Survey in EDM process for better efficiency:

Researchers have made continuous effort since last decade to hybridize the electrical discharge machining process and still numbers of researchers are performing significant efforts to make this process more useful. This work attempts to cover the efforts of various researchers those tried to improve the EDM process to get high MRR with acceptable range of surface roughness, lower surface crack density, minimum white layer thickness, higher fatigue and other metallurgical properties.

S. No.	Conclusion	Scope	Author
1	Study represents the condition with the best match of all the key factors which give a more balanced result, leading to savings in resources, which helps in protecting the environment.	A Method for Green Process Planning in Electric Discharge Machining.	Yeo and New
2	As cutting fluid is one of the main root of environmental pollution. A multi-objective decision making model of cutting fluid selection for green manufacturing is put forward in which objects of quality, cost and environmental impact are considered together.	A decision making framework model of cutting fluid selection for green manufacturing and a case study.	Tan et al
3	This paper presents a literature survey on the use of dielectric fluids that provide an alternative to hydrocarbon oil. It has been reported that water-based dielectrics may replace oil-based fluids in die sink applications. Gaseous dielectrics such as oxygen may also be the alternative.	A review on the use of environmentallyfriendly dielectric fluids in electrical discharge machining.	Leao and Pashby
4	The paper shows the specific effects of some selected groups of additives, which were added to the dielectric working fluid. The aim of this investigation was to find additives which led to modified discharge channels.	Influence of selected groups of additives on breakdown in EDM sinking	Rehbein et al.
5	In this work, researcher's uses micro EDM with de-ionized water as dielectric fluid and shows that the use of deionized water instead of kerosene can reduce the tool wear and increase the machining speed and reduce the environmental impact. Machining characteristics such as the tool wear, machining gap and machining rate were investigated according to resistivity of deionized water.	Micro electrical discharge milling using deionized water as a dielectric fluid	Chung et al.

6	Authors developed a decision making model for selection of process parameters for EDM taking into account both environmental and manufacturing attributes. Authors successfully optimized the environmental favored factors in this study.	Multi-attribute decision making for green electrical discharge machining	Sivapirakasam et al.
7	The purpose of this study to notice the effect of process parameters on breathing zone concentrations of gaseous hydrocarbons generated from an EDM process. Pulse-on time, current, dielectric level above the spark location, and flushing pressure were considered as process parameters. Gas chromatography coupled with mass spectrometry (GC/MS) was used to investigate the hydrocarbon components of gaseous emission. Current and pulse-on time found most significant.	Effect of process parameters on the breathing zone concentration of gaseous hydrocarbons – A study of an Electrical Discharge Machining Process.	Sivapirakasam et al.
8	Authors performed a study which investigated EDM practices in Malaysian industries and revolutionize towards green manufacturing. They concluded that the use of dielectric not only turns into waste but also has economic impact. The use and decomposition of such a high quantity of dielectric oil is an alarming factor for the world	Electrical Discharge Machining (EDM): Practices in Malaysian Industries and Possible Change towards Green Manufacturing.	Abbas et al.
9	In this article, authors reviewed the research work done in three of the sustainability indicators for the EDM process i. e. environmental impact, personnel health and operational safety.	Environmental impact, personnel health and operational safety aspects of electric discharge machining: A review	Valaki et al.

3. Experimental procedures:

An experimental was conducted with dielectric getting supplied using a submerged type single jet, which included a dielectric supply system with a submersible pump. This configuration helps in maintaining an equal and efficient gap during machining and also prevented fire explosion by covering the full sparks. Effect of four control parameters Gap Current, Gap Voltage, Pulse on Time and Pulse off Time (Five levels of each), on four response parameters vis. Material removal rate (MRR), Surface Roughness (SR) and surface Hardness (SH) is measured through sets of experimental runs and each run having specific material erosion time. A total of 5 sets of experiments were performed for the study with 100μs material erosion time for each set. TWR was calculated taking the ratio of EWR/MRR.

3.1 Experimental parameters and its levels

S. No.	Parameters	Levels				
1	Pulse current (Amp.)	3	6	9	12	15
2	Gap voltage (kV)	30	40	50	60	70
3	Pulse ON time (μs)	21	50	100	200	400
4	Pulse OFF/interval time (μs)	6	11	20	30	40

Table 5

3.2 Experimental plan and results

S. No.	Current (Amp)	Ton (μs)	Toff (μs)	Voltage (V)	Hydrocarbon oil			Bio-Lubricant		
					SH	SR (μm)	MRR (mm^3/min)	SH	SR (μm)	MRR (mm^3/min)
1	3	100	10	50	270	3.83	1.67	291	4.78	4.78
2	6	100	10	50	255	5.70	7.87	276	8.45	6.54
3	9	100	10	50	265	9.86	19.42	261	11.50	10.52
4	12	100	10	50	276	10.46	27.5	281	11.93	23.44
5	15	100	10	50	240	11.77	29.8	251	13.84	24.78

Table 6

4. Results and discussion:

Based on experimental results, effects on Material removal rate (MRR), Surface roughness (SR) and Surface hardness (SH) have been investigated and discussed as below, under the influence of various parameters like current, gap voltage, Ton and Toff.

4.1 Effect on MRR:

MRR is related to the rate of material removal per unit time implying that it is related to productivity. Higher MRR is need of EDM process. Table 6 shows the influence of various control parameters on MRR. Responses obtained for MRR with Bio-Lubricant are found to be similar to Hydrocarbon oil. It indicates that material removal mechanics involved in both the fluids are similar but due to variation in property values, resulted in performance variation. It can be seen that Bio-Lubricant resulted in higher MRR under the influence of all the four control parameters.

Results also conclude the behavior of MRR under the influence of current for Bio-Lubricant and hydrocarbon oil as dielectric fluids. As current is directly related to energy available for material removal, MRR increased for both fluids. However, Bio-Lubricant performed with higher MRR than hydrocarbon oil.

4.2 Effect on SR:

SR is associated with an average roughness of the surfaces produced in EDM. Lower SR is desirable from the accuracy and tribological point of view to maintain a lubricating layer for a longer period and hence longer service life.

Results in Table 6 show the response trends for SR under the influence of current for Bio-Lubricant and hydrocarbon oil as dielectric fluids. Sparks strike on the work piece with more intensity at high current causing more material to be eroded due to impact force developed. Furthermore, an increase in energy due to current increases energy penetration in the material surface which eventually results into deeper and wider craters which in turn results in to coarser surface. However, resulted lower SR in the case of Bio-Lubricant may be due to higher thermal conductivity and lower specific heat, which could have minimized the energy density due to better heat transfer to the surrounding dielectric media to produce shallower craters.

4.3 Effect on SH:

Higher SH is desirable for improved wear resistance of the surfaces to have enhanced the life of dies, punches and tooling's. Bio-Lubricant resulted in higher SH than hydrocarbon oil. Higher SH of surfaces in case of Bio-Lubricant is an indication of better surface integrity, internal stresses etc compared to hydrocarbon oil.

Results in Table 6 show that increased melting and evaporation deteriorated the work surface with an increase in current. At higher energy, the amount of resolidified work material increased which decreased the SH. However, resulted higher SH in the case of Bio-Lubricant is attributed to intense oxidation due to the higher oxygen content which could have augmented the melting and evaporation of work material, higher thermal conductivity produced quenched surface and effective flushing due to higher viscosity ensured minimum solidification.

5. Conclusion:

Bio dielectric oil resulted in increased production rate, better surface finish and increased surface hardness. Main outcomes of this research study are listed as below:

(1) Bio-Lubricant resulted in higher MRR than hydrocarbon oil under the influence of process variables gap current, gap voltage, Ton and Toff, respectively. It indicates that higher production rate can be achieved using Bio-Lubricant oil.

(2) Bio-Lubricant resulted in lower SR than hydrocarbon oil for gap current, gap voltage, Ton and Toff, respectively. Improved surface finish is an indication of better tribological performance of the surfaces generated for increased life of dies, punches and other tooling's.

(3) Bio-Lubricant resulted in higher SH than hydrocarbon oil for gap current, gap voltage, Ton and Toff, respectively. Higher surface hardness obtained for Bio-Lubricant indicates life of dies, punches and other tooling's can be enhanced using Bio-Lubricant due to improved wears resistance through high surface hardness

6. References:

[1] Janak B. Valaki, Pravin P. Rathod, C.D. Sankhavara, 'Investigations on technical feasibility of Jatropha curcas oil based bio dielectric fluid for sustainable electric discharge machining (EDM)', Journal of Manufacturing Processes, 1526-6125/© 2016 The Society of Manufacturing Engineers. Published by Elsevier Ltd.

[2] Norliana Mohd Abbas, Noriah Yusoff, Rohidatun Mahmod, 'Electrical Discharge Machining (EDM): Practices in Malaysian Industries and Possible Change towards Green Manufacturing', International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012), 1877-7058 © 2012 Published by Elsevier Ltd.

[3] Janak B. Valaki, Pravin P. Rathod, 'Assessment of operational feasibility of waste vegetable oil based bio-dielectric fluid for sustainable electric discharge machining (EDM)', Int J Adv Manuf Technol DOI 10.1007/s00170-015-7169-0, Springer-Verlag London 2015.

[4] Jagdeep Singh, Rajiv Kumar Sharma, 'Green EDM Strategies to Minimize Environmental Impact and Improve Process Efficiency', Journal for Manufacturing Science & Production · January 2017 DOI: 10.1515/jmsp-2016-0034.

[5] Janak B Valaki, Pravin P Rathod, Bharat C Khatri, 'Environmental impact, personnel health and operational safety aspects of electric discharge machining: A review', Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture published online 22 DOI: 10.1177/0954405414543314.

[6] Janak B. Valaki, Pravin P. Rathod, 'Investigating Feasibility through Performance Analysis of Green Dielectrics for Sustainable Electric Discharge Machining', Materials and Manufacturing Processes, DOI: 10.1080/10426914.2015.1070430.

[7] Anil Raj, K Leo Dev Wins, A S Varadarajan, 'Evaluation of the performance during hard turning of OHNS steel with minimal cutting fluid application and its comparison with minimum quantity lubrication', Materials Science and Engineering 149 (2016) 012021 doi:10.1088/1757-899X/149/1/012021.