ISSN 2349-9368(Online);EAPJMER/ISSN.2454-2962/2016;

ELK
Asia Pacific Journals

National Conference on Futuristics in Mechanical Engineering
Madan Mohan Malaviya University of Technology

REVIEW OF ADVANCEMENTS IN DIELECTRIC AND TOOL ELECTRODE IN ELECTRICAL DISCHARGE MACHINING

Shweta Srivastava	**Anjani Kumar Singh**	**D. K. Singh**
Mechanical Engineering Department, Madan Mohan Malaviya University of Technology Gorakhpur- 273010,	Mechanical Engineering Department, Madan Mohan Malaviya University of Technology Gorakhpur- 273010,	Mechanical Engineering Department, Madan Mohan Malaviya University of Technology Gorakhpur- 273010,

Abstract

Materials, such as Ti alloys, Ni alloys, etc., that are difficult to machine conventionally are machined using unconventional machining methods like Electrical Discharge Machining (EDM). This paper presents various advancements that took place in the field of essential parts of EDM machining viz. dielectric fluid and tool electrode. Dielectric fluid from its first phase when hydrocarbon oils like kerosene were used to the use of gaseous dielectric in dry-EDM has been discussed. In the same way the progress in the area of using tool electrode from the use of conventional Cu and graphite tool to rotary and porous electrode has been discussed. Mainly comparison between the conventional and contemporary dielectric and tool electrode has been done by observing responses in terms of MRR, TWR, SR is done taking current, pulse-on-time, voltage etc. as input parameters. The detailed review of the above two significant parts has been done and their improved effect on the performance of EDM machining on Ti-6Al-4V, Nitinol, etc. given by researchers has been combined. The gap in the area of dry-EDM working and modern electrodes like porous electrode, etc. has been identified and future scope of work has been discussed.

Keywords: *Electrical Discharge Machining, Dielectric, Tool electrode*

Introduction

Electrical Discharge machining (EDM) is one of the non-conventional machining processes used worldwide. The difficult to machine materials are easily machined by using this thermal process subjecting the workpiece to melting and vaporization [2]. Work material being completely dipped in a dielectric fluid is acted upon by a spark produced between anode and cathode. The material is thus removed by the process of spark erosion by the conductive workpiece [8]. With the advent of wire EDM in the 1970s, new wire tool electrodes, improved flushing and machine intelligence machining speed has gone high and machining costs have gone low. Eco-friendly dielectric fluids have been investigated so as to give boost to the concept of green manufacturing [11]. Tap water [12], powder mixed dielectric.

In PMEDM [8], Dry-EDM [16] some efforts are undertaken to take forward machining without any negative or at least, least negative environmental impact.

In this paper various alternatives to conventional dielectric like kerosene has

ISSN 2349-9368(Online);EAPJMER/ISSN.2454-2962/2016;

been reviewed. Traditional dielectric tends to be an environmental hazard emitting pollution causing agents like CO, CO2, CH4, etc. [1]. Distilled water has been chosen as dielectric but it could not give the desired result of higher MRR than kerosene [1].

Researchers have thus set the trend of incorporating metal powders into the dielectric as a result higher MRR can be obtained with distilled water as well and it can even replace kerosene [7]. Then various metal powders were tested for the improved results like Al powder [7], Al2O3 [8], CNT [10], SiC [5] etc.

The trend setter have now set the trend of using gaseous dielectric called dry-EDM as a response to green manufacturing. Inert gases like Argon [16] have been experimented for observing the responses in terms of MRR, TWR and SR the usual response parameters of any EDM process.

With the advent of these new techniques of improving dielectric there has arisen need to modify the tool electrodes as well.

Tool electrodes have been modified from traditional use of Cu [19] and graphite electrodes to modern day rotary [25] and porous electrodes [26]. Mainly comparative studies have revealed the betterment of new age tool electrode to the conventional one. Bundled electrode [23], multi-material electrodes [24], sintered composite electrodes [20], and perforated electrode [16] have been compared to the traditional electrodes.

The performance of these dielectrics and electrodes has been investigated at experimental level and their incorporation in industries for improved productivity is needed. Still in most industries the traditional EDM with conventional dielectric and electrodes are being used. So the researches should make effort to take the improved performance of these EDM parts to the industries.

Research works

Effect of different types of dielectrics on the performance of EDM

One of the EDM research area incorporates performance improvement of the EDM by improving the response parameters viz. material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR) [1].

Use of dielectric is one of the most significant factors that affect the response parameters. Researchers have worked on various types of dielectric and investigated the effect of different dielectrics caused on the material removal rate (MRR), tool wear rate (TWR) and surface roughness (SR).

The advancement in EDM dielectric led to the improved form of EDM and hence EDM took its name from the dielectric type that was incorporated like if the dielectric is mixed with metal powder then the name that EDM got is powder mixed EDM (PMEDM), if gas is used as dielectric then the name becomes Dry-EDM, etc.

Initially, the conventional die sinking EDM used hydrocarbon oil like kerosene, EDM oil, etc. as the dielectric. Hydrocarbon oil kerosene is widely used as it has very low viscosity because of which the flushing of the debris takes place very smoothly. Though the benefits offered by kerosene are required but the drawbacks like low flash

ISSN 2349-9368(Online);EAPJMER/ISSN.2454-2962/2016;

point, odour, skin reactions, environmental pollution, etc. cannot be ignored. Thus, finding alternatives to hydrocarbon oils was the need of the hour.

Niamat et al., [2] made a comparative study of the effects of kerosene and distilled water on the performance of EDM. The material chosen for the study is an Aluminium alloy 6061 T6 and the input parameters are pulse on time and current. The response are measured in terms of MRR, TWR and SR. From the study it was found that kerosene provided higher MRR and lower EWR as compared to distilled water. Distilled water caused the problem of arcing that spoils the workpiece and tool electrode by causing short circuit [3]. Thus, in this study kerosene was preferred over distilled water for Al alloy.

Jean Paulo et al. [4], took three dielectric fluids viz. 'A', 'B' and 'C' for comparing their respective effects on the surface quality and heat affected zone (HAZ). Out of the three dielectrics, the one with the lowest value of viscosity i.e. dielectric 'B' reflected lowest micro crack density and least recast layer size.

With the search of proper dielectric fluid for improving machining performance of EDM, powder mixed EDM came into picture. Metal powders Al, graphite, SiC, chrome, etc. [9] of appropriate size (micro/ nano) and concentration are mixed into the dielectric fluid. Kuriachen& Mathew [5] investigated the effect of SiC particles mixed into the dielectric for machining of Ti-6Al-4V with dielectric suspended with SiC particles of micro level dimension. At low level of powder concentration MRR is found to be maximum and TWR minimum. Along with this medium voltage and capacitance is the required criteria. But as voltage and capacitance increases TWR also increases. Ultrasonic vibration incorporated with PMEDM, is the new advancement in the field of EDM for machining at a miniaturized level [6].

Distilled water in [2] was proved to be inferior to kerosene as it provided lower value of MRR. Khalid et al. [7] mixed distilled water with Al powder and used it as dielectric. Input variables are taken to be peak current, powder concentration, pulse-on-time and polarity. Response is observed by measuring MRR, TWR and thickness of the white layer on the W300 die steel workpiece. Copper is used as the tool. The result has shown that distilled water mixed with Al powder provides higher MRR than pure distilled water and can replace hydrocarbon oil. Moreover, maximum MRR, low TWR and SR and minimum thickness of white layer is obtained at low powder concentration (1g/l). The result also reflects that polarity, one of the input variables, also plays a significant role in EDM performance. Positive polarity results in higher MRR, thus can be used for rough machining whereas negative polarity results in lower SR value hence, can be used for obtaining better surface finish.

As the size of particles influence the performance of dielectric thus investigations started by mixing nano particles in the dielectric. Kuman Mandal et al. [8] used Al2O3 particle of nano size. Intensity of the electric field is influenced by the particles of the powder resulting in performance

ISSN 2349-9368(Online);EAPJMER/ISSN.2454-2962/2016;

improvement. Also the properties of powder being mixed are the influencing factor for improving the efficiency of machining. Experiment is conducted taking Inconel 825 alloy as the workpiece material. Nano powder of Al2O3 is mixed in deionised water and used as dielectric. Peak current, gap voltage and pulse-on-time are the input variables. Voltage, current waveform, MRR and surface morphology are analysed. With NPMEDM drastic reduction in micro-cracks is observed. Maximum MRR and minimum SR are found to be 44% and 51% higher respectively when compared to regular EDM. When the waveforms were analysed it was found that NPMEDM causes less tendency of arcing [3] because it results in increased gap between the electrodes which means achievement of higher stability of machining.

Another nano particle mixing is observed by Mai Hong et al. [9] and Shabgard et al. [10] i.e. carbon nanotube (CNT). CNT possesses brilliant characteristics like high conductivity both thermal and electrical, its tensile strength is also high, and also its specific gravity is small and it has shape of a straight pin. Its shape makes it possible for CNT to disperse uniformly into the dielectric and float continuously. Al, SiC, etc. particles possess high specific gravity thus control of flushing becomes difficult for them. Thus low specific gravity of CNT solves this problem [9]. In [10] machining of Ti-6Al-4V was investigated by CNT mixed dielectric in PMEDM to study its effect on MRR, quality of surface and TWR. The results revealed that MRR increases when pulse durations are long, machining stability is achieved, SR is lower than hydrocarbon dielectric, also size and length of micro-cracks reduced with CNT mixed dielectric. The improvement of 70% is obtained in surface finish and 66% in machining time. [9]

The present trend of EDM focuses on green EDM i.e. there should be no adverse impact on the environment while performing machining on EDM. If hydrocarbon oil is used for machining like kerosene, its decomposition takes place in the form of CO, CO2 and CH4 which are pollution causing agents [1] to see which one of the following EDM i.e. dry-EDM, near-dry EDM and EDM in water causes least harm to the environment. K. Singh et al. [11] made a review study. Dry-EDM is the new emerging technology for machining which incorporates a huge gap to be investigated.

Moving forward with the concept of green EDM Tan Du et al. [12] used tap water as dielectric for machining of Ti-6Al-4V as no harmful gas is released in the working environment. SR, MRR and TWR are the responses that reflect the effects of machining under the input parameters viz. pulse width to pulse interval ratio, current, gap voltage and lifting height. Tap water as dielectric results in the achievement of higher MRR, lower TWR and low cost of machining.

Gaseous dielectrics are being focussed upon and the EDM named upon it is dry-EDM. It offers numerous advantages [13] like simple machining at a cheaper cost, combination of various processes can be easily achieved and work accomplishment in a 3-D environment. It requires high pressure gas to be flushed

ISSN 2349-9368(Online);EAPJMER/ISSN.2454-2962/2016;

through the electrodes. Rotary symmetrical electrode is to be employed for stable operation. Multi-channel electrode can also accomplish the task. There are additional parameters related to dry-EDM in addition to usual parameters viz. flushing pressure, electrode wall thickness, rotational speed, etc. dry-EDM uses gases like air, O2, CO2, etc.

Weissner et al. [14] and Shabgard et al. [15] made a comparative study of machining with wet and dry-EDM. In [15] surface topography of wet, dry and near-dry EDM are compared by performing drilling process of SPK steel. The results produced show that when discharge energy is low then maximum MRR and least SR is obtained by near-dry EDM and when discharge energy is high wet EDM has the highest MRR, SR and TWR. Hence near-dry EDM is better compared to the rest.

Normally air, O2, CO2, etc. [13] has been used by researchers in dry-EDM. Singh et al. [16] used an inert gas i.e. Argon for dry-EDM process. Investigations are done with process variables i.e. discharge current, pulse-on-time, tool rotation, gas pressure and duty cycle and their effect is seen on MRR, TWR and SR on high-chromium-high-carbon die steel. A comparative study is conducted with rotary tools that are solid (REDM), air-assisted (AAEDM) and argon-assisted (AGAEDM). The results reveal that with AGAEDM, SR and EWR were less compared to other tools but higher MRR is obtained with AAEDM. Also recast layer formation with AGAEDM is less compared to AAEDM. AGAEDM is a better option available with high capacity of carrying heat resulting in intact surface integrity of the workpiece.

Micro-EDM is considered to be the best non-conventional machining process for producing micro-holes. Pradhan et al. [17] investigated what influence can different dielectrics cause on the micro-machining of Ti-6Al-4V alloy. Pure deionised water, EDM oil and deionised water mixed with Copper (Cu) powder are taken to be dielectrics. MRR, overcut (OC), TWR and taper are the observed responses. Cu powder mixed deionised water has shown improving micro-EDM performance. Also better surface topography and its profile obtained with this dielectric compared to others.

Effect of different types of tools on the performance of EDM

If the proper dielectric is combined with the proper tool that suits the material for performing machining operation then performance of EDM can be highly increased.

As seen above, EDM performance is highly affected by dielectric similarly, it is also affected by the electrode used. The commonly used electrode in EDM are Cu, graphite, brass, etc. [19]. Apart from these conventional used electrode effect of electrodes, made by different materials and processes, can be seen considerably on the performance of EDM. Kumar Sahu et al. [20] has compared Cu and graphite tool electrode with AlSiMg electrode which is prepared by the process of Selective Laser Sintering (SLS) which is a process of additive manufacturing on Nitinol workpiece. The response of voltage, current,

ISSN 2349-9368(Online);EAPJMER/ISSN.2454-2962/2016;

pulse-on-time, duty cycle and tool material is observed on SR. Result obtained shows that specimens with better surface morphology were produced with AlSiMg electrodes. The next electrode in series is Cu followed by graphite. For best result in the form of surface finish all the input parameters need to be minimised and AlSiMg electrode should be used as tool electrode.

Khamra et al. [21] has made an attempt to compare ZrBr2-Cu composite tool with Cu tool. For preparation of ZrBr2-Cu composite, firstly, technique of self-propagating high-temperature synthesis (SHS) has to be used for preparing ZrBr2 powder and then the powder obtained is fused with varying proportion of Cu powder. Then this mixture is sintered at 1250 C to produce the ZrBr2-Cu composite. MRR is found to be highest for ZrBr2-40wt%Cu composites among all other formed composites. It is then compared with the Cu toll and the result shows that the composite electrode gives higher MRR and TWR is lower compared to Cu tool but SR and diametral overcut (DOC) is more than its counterpart.

Wire EDM is in great demand for its features of increased productivity as it possesses high cutting speed with highly precise machining features. Ideal wire is difficult to be found for WEDM. The technology for wire electrodes has been evolved from Cu to brass wire and finally to coated wire electrodes. The wire chosen is according to the need of the user for increasing productivity. [22]

Moving on to the next comparison of tool electrode Dove et al. [23] took solid electrode and bundled electrodes with Cu being the base material for the tool to investigate their respective performance on AISI 304 workpiece in the manifestation of TWR and MRR. The effect of input variables i.e. peak current and pulse-on-time are to be manifested on the responses. The results obtained show that the MRR for solid electrode is 45% more than that of bundled electrode and both of them show the same TWR.

Liu Wang et al. [24] has compared multi-material electrode with Cu electrode. The three multi-material electrodes chosen are Iron, Brass and Cu-Tungsten. The study reveals the effect on discharge breakdown that are caused by electrodes with varying material under single and continuous discharge conditions. The results show that under single discharge conditions probability of breakdown of varying material electrode is same as that of Cu tool. The tool material with high capacity of specific heat and thermal conductivity being poor has high probability of breakdown in case of conditions of continuous discharge.

More advancement of electrode led to the formulation of rotary electrode used in dry-EDM [14]. Robinson et al. [25] investigated machining of Al6061 alloy with rotating tool in EDM. The comparative study has been made of the effect of current, pulse-on-time, pulse-off-time on MRR, TWR and SR with stationary electrode. The results have shown that there is an increase in MRR and decrease in SR and TWR with rotary electrode as compared to the stationary one.

ISSN 2349-9368(Online);EAPJMER/ISSN.2454-2962/2016;

Also as the speed of rotation of tool increases MRR and TWR decreases but at the cost of decreased surface finish. Thus there has to be limitation for rotary speed which is 220 rpm to obtain optimum MRR and surface finish.

Improper flushing and deterioration of the gap are the common problems faced during Electric Discharge Machining of complex cavities with large depth. For solving these problems researchers have brought porous electrodes to its rescue. Janayi et al. [26] investigated machining with porous electrodes. Cu particles undergo high temperature sintering process to produce porous material and porous electrode is fabricated in the mould of graphite. The porous electrode has multi-hole which is easier for flushing of inner surface and porosity also leads to the formation of channels for flow of liquid. The roughing machine can be carried out efficiently with porous electrodes making them strong contender for machining complex cavities.

It was observed by Wang [28] that by using hollow tube electrode MRR could be increased. Selvarajan [27] investigated machining of conductive Si3N4-TiN ceramic composite in EDM using a hollow tube electrode and found out optimal conditions for responses viz. cylindricity, circularity, perpendicularity, taper angle, bottom radial overcut and top radial overcut by input variables of current, dielectric pressure, servo speed, pulse-on-time and pulse-off-time.

Some more features of tool are found out by researchers which can affect EDM performance. Wang et al. [29] found out what effect can tool size cause on the performance of micro-EDM while machining Ti-6Al-4V alloy. It was found that as the tool size increases TWR, DOC and MRR also show an increasing trend. With diameter of tool more than 500 micro metre MRR increases more than the increase in TWR. Stray capacitance is important in case of micro-EDM and cannot be ignored as in macro-EDM which shows increment in its value with the increasing tool size. Debris removal becomes difficult with the tool size lower than 500 micro-metre whereas it has negligible effect on DOC.

Hadad et al. [30] investigated how the tool which initially had SR affects the performance of EDM while machining SS410. The result shows that MRR decreases and TWR increases as SR of the tool increases. Workpiece SR after machining by EDM also depends slightly on initial SR of the tool while machining parameters of EDM highly influence SR of the tool after machining.

Scope of future works

1. Ultrasonic vibration with PMEDM need to be investigated more.
2. Future materials like metal foams and smart materials should also be investigated for their EDM machinability.
3. Machining at the scale of miniaturized level need to be investigated more.
4. Heat affected zone and dimensional accuracy of different materials should be taken into consideration while selecting the dielectric and tool electrode.
5. Accurate method of choosing correct combination of dielectric and tool for

particular material need to be discovered for improving the performance of EDM.

6. Very few gases have been used in the dry-EDM for machining. More number of gases like inert gas Helium, etc. need to be experimented for their capabilities.
7. Measures are to be taken to diminish the arcing phenomena taking place in EDM depleting the tool and work surface.
8. Rotary and porous electrodes are the new generation electrodes thus they incorporate a huge gap to be investigated.

CONCLUSIONS

1. It has been found that dielectric with low viscosity [4], lower powder concentration [5-10] in PMEDM produces higher MRR and lower TWR.
2. The effect of CNT powder in dielectric produces better result than other powder mixed dielectric [9-10].
3. As tool initial SR decreases MRR so it should be clearly taken into account that the tool does not have very high value of SR initially [30].
4. Rotary tool has been found to be more effective compared to stationary tool [25].
5. Though numerous factors are covered but still the new input factors produced by dry EDM like flushing pressure, thickness of the wall of electrode, rotational speed of tool [13] need to be further investigated for full phase industrial application.

References

[1] Chakrabortya S., Dey V., Ghosh S.K. A review on the use of dielectric fluids and their effects in electrical discharge machining characteristics. Precis Eng (2014), http://dx.doi.org/10.1016/j.precisioneng.2014.11.003

[2] Niamat Misbah, Sarfraz Shoaib, Aziz Haris, Jahanzaib Mirza, ShehabbEssam, Ahmad Wasim, Hussain Salman. Effect of Different Dielectrics on Material Removal Rate, Electrode Wear Rate and Microstructures in EDM. 27th CIRP Design Conference Procedia CIRP 60 (2017) 2 – 7.

[3] Pandey A B, Brahmankar P K. A method to predict possibility of arcing in EDM of TiB2p reinforced ferrous matrix composite. International Journal of Advanced Manufacturing Technology 86(9) (2016) DOI: 10.1007/s00170-016-8414-x.

[4]Robert Jean, Ricardo Paulo, Pereira Adilto, Soeiro Rubens, Noronha Lurdes and CéliaCarmem. Influence of different dielectrics fluids on the surface integrity of high speed steel. Acta Scientiarum. Technology (2018) Doi: 10.4025/actascitechnol.v40i1.35386.

[5] Kuriachen B, Mathew J. Effect of Powder Mixed Dielectric on Material Removal and Surface Modification in Micro Electric Discharge Machining of Ti-6Al-4V. Northeastern University (2015).

[6] Jain Naman, Singh Prashant, Kasera Mayank, Bhatt Prashant, Kumar Vikas. OPTIMIZATION CHARACTERISTICS OF POWDER MIXED ELECTRICAL DISCHARGE MACHINING (PMEDM). International Journal of Applied Engineering

Research ISSN 0973-4562 Volume 13, Number 6 (2018) pp. 93-98.

[7] Hussain Khalid, PalaniyandiKuppan.Performance of electrical discharge machining using aluminium powder suspended distilled water. Turkish J. Eng. Env. Sci. 36 (2012) 195 – 207doi: 10.3906/muh-1202-2.

[8] Kumar Amit, Mandal Amitava, Rai Dixit, Kumar Alok. Performance Evaluation of Al2O3 Nano Powder Mixed Dielectric for Electric Discharge Machining of Inconel 825. Materials and Manufacturing Processes ISSN: 1042-6914 1532-2475 DOI: 10.1080/10426914.2017.1376081

[9] Mai C., Hocheng Hong, Huang S. Advantages of carbon nanotubes in electrical discharge machining. Int J Adv ManufTechnol (2012) 59:111–117 DOI 10.1007/s00170-011-3476-2.

[10] Shabgard Mohammadreza, Khosrozadeh Behnam. Investigation of carbon nanotube added dielectric on the surface characteristics and machining performance of Ti–6Al–4V alloy in EDM process. Journal of Manufacturing Processes 25 (2017) 212–219.

[11] Singh Nishant, Pandey Pulak, Singh K.K., Sharma Manish. Steps towards green manufacturing through EDM process: A review. Cogent Engineering (2016), 3: 1272662 http://dx.doi.org/10.1080/23311916.2016.1272662.

[12] Tang L., Du Y.T.Experimental study on green electrical discharge machining in tap water of Ti–6Al–4V and parameters optimization. Int J Adv ManufTechnol (2014) 70:469–475 DOI 10.1007/s00170-013-5274-5.

[13] Roth Raul. Dry electrical discharge machining. (2011)IWF InstitutfürWerkzeugmaschinen und Fertigung ETH Zürich.

[14] M. Weissner, F.T.B. Macedo, C.P. Martendal, F. Kuster and K. Wegener. Fundamental Investigation of EDM Plasmas, Part I: A Comparison between Electric Discharges in Gaseous and Liquid Dielectric Media. 19th CIRP Conference on Electro Physical and Chemical Machining, 23-27 April 2018, Bilbao, Spain Procedia CIRP 68 (2018) 330 – 335.

[15] GholipoorAhad, Baseri Hamid and Reza Mohammad. Investigation of near dry EDM compared with wet and dry EDM processes. Journal of Mechanical Science and Technology 29 (5) (2015) 2213~2218 DOI 10.1007/s12206-015-0441-2.

[16] Singh Nishant, Pandey Pulak, and Singh K.K. Experimental Investigations into the Performance of EDM Using Argon Gas Assisted Perforated Electrodes. Materials and Manufacturing Processes ISSN: 1042-6914 (Print) 1532-2475 (2016).

[17] Tiwary A.P., Pradhan B.B., Chattacharyya B. Investigation on the effect of dielectrics during micro-electro-discharge

ISSN 2349-9368(Online);EAPJMER/ISSN.2454-2962/2016;

machining of Ti-6Al-4V. Int J Adv ManufTechnol (2018) 95:861–874 https://doi.org/10.1007/s00170-017-1231-z.

[18] Experimental Study of Process Parameters through Dissimilar Form of Electrodes in EDM Machining - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Figure13-Schematic-setup-diagram-of-Electric-Discharge-Machining-14_fig3_306082278]

[19] Mahajan Rahul, Krishna Hare, Kumar Ankit and Kr Ranjan. A Review on Copper and its alloys used as electrode in EDM. International Conference on Mechanical, Materials and Renewable Energy IOP Publishing IOP Conf. Series: Materials Science and Engineering **377** (2018) 012183 doi:10.1088/1757-899X/377/1/012183.

[20] Kumar Anshuman, Chatterjee Suman, Kumar Praveen and Sankar Siba.Study on effect of tool electrodes on surface finish during electrical discharge machining of Nitinol. NCPCM 2017 IOP Publishing IOP Conf. Series: Materials Science and Engineering **338** (2018) 012033 doi:10.1088/1757-899X/338/1/012033.

[21] Khanra A. K., Pathak L. C. and Godkhindi M. M. Application of new tool material for electrical discharge machining (EDM). Bull. Mater. Sci., Vol. 32, No. 4, August 2009, pp. 401–405. © Indian Academy of Sciences.

[22] Maher Ibrahem, A. D. Ahmed and Hamdi M. Review of improvements in wire electrode properties for longer working time and utilization in wire EDM machining. Int J Adv ManufTechnol (2015) 76:329–351 DOI 10.1007/s00170-014-6243-3.

[23] K. Harshit, Kumar Sudhanshu, C. Nipul and K. Harit. ELECTRO DISCHARGE MACHINING OF AISI 304 USING SOLID AND BUNDLED ELECTRODES. 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014, IIT Guwahati, Assam, India.

[24] Liu Y., Wang W., Zhang W., Ma F., Wang Y., Rolfe B. and Zhang S. Study on Breakdown Probability of Multimaterial Electrodes in EDM. Hindawi Advances in Materials Science and Engineering Volume 2018, Article ID 2961879, 8 pages https://doi.org/10.1155/2018/2961879.

[25] Robinson D S, JenishJoses, Periasamy C, Samuel P S. Investigations of Effect of Rotary EDM Electrode on Machining Performance of Al6061 Alloy. IOP Conf. Series: Materials Science and Engineering **346** (2018) 012064 doi:10.1088/1757-899X/346/1/012064.

[26] Yia Jiang, Qia LI, Lingleia Kong, Xuelianga Ping and Wanshengc Zhao. Electrical Discharge Machining for Complex Cavity with a Porous Electrode. 18th CIRP Conference on Electro Physical and Chemical Machining (ISEM XVIII) Procedia CIRP 42 (2016) 618 – 622.

ISSN 2349-9368(Online);EAPJMER/ISSN.2454-2962/2016;

[27] Selvarajan L, Mouri P, Ramesh Raja R. Experimental Investigation of EDM Parameters on Machining Si3N4-TiN Conductive Ceramic Composite Using Hallow Tube Electrode for Improving Geometrical Accuracy. Materials Today: Proceedings 5 (2018) 8080–8088.

[28] C wang, B H Yan. Journal of materials processing technology the machining characteristics of Al2O36061 composite using rotary electrode- discharge machining with a tube electrode.

[29] Wanga Kan, ZhangaQinhe, ZhuaGuang, HuangaYuhua and Zhanga Jianhua. Influence of tool size on machining characteristics of micro-EDM. 19th CIRP Conference on Electro Physical and Chemical Machining, 23-27 April 2018, Bilbao, Spain Procedia CIRP 68 (2018) 604 – 609.

[30] HadadMohammadjafar, Quang Lan and Nguyen Cong Thanh. Experimental investigation of the effects of tool initial surface roughness on the electrical discharge machining (EDM) performance. The International Journal of Advanced Manufacturing Technology (2017) https://doi.org/10.1007/s00170-017

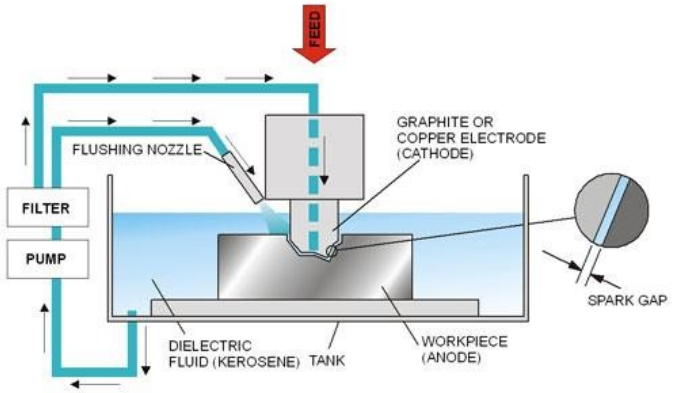

Fig 1: Working Princple of EDM

ISSN 2349-9368(Online);EAPJMER/ISSN.2454-2962/2016;