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Effect of Cryogenic Treatment of Tool Electrode on the Performance Parameter in Electrical Discharge Machining of JIS443CT - A Review

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***Abstract*—The correct selection of manufacturing conditions is one of the most important aspects to take into consideration in the majority of manufacturing processes and particularly, in processes related to Electrical Discharge Machining (EDM).The principle of Electrical Discharge Machine (EDM) also called electro discharge spark erosion machining is based on the erosion of metals by sparks discharge. Metals are easy to machine by using non-traditional machining such as Electric Discharge Machine (EDM). But, during EDM, with the workpiece, even the tool wears out. This tool wear is not desired as it changes the tool geometry. To overcome this obstruction, cryogenic treatment is carried out for tool material before machining. The machining performances of the process are concluded in terms of Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness values. In this paper, the finding of the literature review on "Effect of cryogenic treatment of tool electrode on the performance parameter in EDM" has been presented.**

***Index Terms*—Electrical Discharge Machining, Cryogenic Treatment, MRR, TWR, SR.**

I. INTRODUCTION

Electrical discharge machining (EDM) is a non-conventional machining process and is found to be more economical during the machining of advanced alloys and composite materials. It works on the principle of erosion of material from the work piece with controlled and repetitive sparks produced by the DC pulse generator.

The origin of electrical discharge machining goes back to 1770, when English scientist Joseph Priestly discovered the erosive effect of electrical discharges. In 1943, Soviet scientists B. Lazarenko and N. Lazarenko had the idea of exploiting the destructive effect of an electrical discharge and developing a controlled process for machining materials that are conductors of electricity. With that idea, the EDM process was born.

The Lazarenkos perfected the electrical discharge process, which consisted of a succession of discharges made to take place between two conductors separated from each other by a film of non- conducting liquid, called a dielectric. The Lazarenkos achieved a form of immortality with this circuit, which today bears their name. Today, many EDMs use an advanced version of the Lazarenko circuit.

1.1 Principle of EDM

Electrical Discharge Machining (EDM) is a controlled metal-removal process that is used to remove metal by means of electric spark erosion. In this process an electric spark is used as the cutting tool to cut (erode) the workpiece to produce the finished part to the desired shape. The metal-removal process is performed by applying a pulsating (ON/OFF) electrical charge of high-frequency current through the electrode to the workpiece. This removes (erodes) very tiny pieces of metal from the work piece at a controlled rate.

Fig.1.1 shows the electric setup of the Electric discharge machining. The tool is made cathode and work piece is anode. When the voltage across the gap becomes sufficiently high it discharges through the gap in the form of the spark in interval of from 10 of micro seconds. And positive ions and electrons are accelerated, producing a discharge channel that becomes conductive. It is just at this point when the spark jumps causing collisions between ions and electrons and creating a channel of plasma. A sudden drop of the electric resistance of the previous channel allows that current density reaches very high values producing an increase of ionization and the creation of a powerful magnetic field. The moment spark occurs sufficiently pressure developed between work and tool as a result of which a very high temperature is reached and at such high pressure and temperature that some metal is melted and eroded. Such localized extreme rise in temperature leads to material removal. Material removal occurs due to instant vaporization of the material as well as due to melting. The molten metal is not removed completely but only partially.

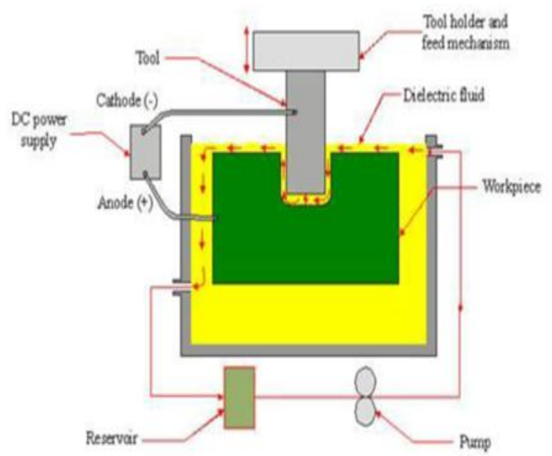

Figure 1.1: Working principle of EDM [1]

As the potential difference is withdrawn, the plasma channel is no longer sustained. As the plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark. Plasma passage occurring exciting increase of temperature make use to remove material. Material removal takes place because of on the spot vaporization of the metallic particle as well as owed to melting process. The melted particle is not withdrawn altogether, however just partly. By means of the potential difference is drawn the plasma passage is no longer continued. As the plasma passage breakdown, it produces pressure force or shock waves, which clears the molten material by flushing method making a depression of removing material all over the place of the spark.

Cryogenic processing, originally developed for aerospace applications, has been used for 30 years to improve the properties of metals. Many fantastic claims have been made as to the degree of improved performance achieved by cryogenic processing. Practitioners claim that properties such as wear resistance can be improved by factors of two, three, or 100 compared to traditional heat treatment. Other claims improved dimensional stability, increased hardness or shifts in resonant vibrational frequency of cryogenically treated material. Some claims have been validated by research, many have not. However, the use of cryogenic processing is growing.

Cryogenic Treatment (CT) is the process of treating material to cryogenic temperatures in order to seek enhanced stress relief and stabilization, and thereby improved wear resistance. The scientific community generally defines cryogenic temperatures as temperatures below −150◦C. However, this is, admittedly, an artificial upper limit; temperatures used presently in cryogenic treatment are generally −185◦C. CT of tool material appears favorable since cryogenically treated material corresponds to longer part life, improved fatigue life (less failure due to cracking), improved thermal properties (increase in thermal conductivity), better electrical properties including less electrical resistance (increase in electrical conductivity), reduced coefficient of friction, less creep and walk, improved flatness, and easiness of machining.

Generally, the parts can be cryogenically treated either by (i) Shallow Cryogenic Treatment (SCT) or by (ii) Deep Cryogenic Treatment (DCT) (1). During cryogenic treatment the part component is immersed into the liquid nitrogen (LN2) for specified time duration (2).

During DCT, the temperature is gradually reduced to −184◦C at a cooling rate of 1◦C/min and the part component is kept in the cryogenic processor container for about 24 h durations. The temperature is then gradually raised to the room temperature again. The parts are then tempered under similar conditions to incur stress relief. By conducting the cool-down cycle in gaseous nitrogen, temperature can be controlled accurately, and thermal shocks to the material are avoided.

1.2. Cryogenic Treatment (CT)

Fig.1.2: Set up for cryogenic treatment of the tool electrode.

1.2.1 History

Cryogenics in [3] is the science of production and effects of very low temperatures. It is clear from the above definition that, in the studies of cryogenics lowest temperatures below the freezing of water (0o C) to be considered. However, Prof. Kamerlingh Ones of the University of Leiden in the Netherlands first used the word in 1894 to describe the art and science of producing much lower temperatures. He used the word in reference to the liquefaction of permanent gases such as oxygen, nitrogen, hydrogen, and helium. Oxygen had been liquefied at –183oC. Over the years the term cryogenics has generally been used to refer to temperatures below approximately –150oC.

According to the laws of thermodynamics, there exists a limit to the lowest temperature that can be achieved, which is known as absolute zero. Molecules are in their lowest, but finite, energy state at absolute zero. Absolute zero is the zero of the absolute or thermodynamic temperature scale. It is equal to – 273.15 oC or –459.67 oF. In terms of the Kelvin scale the cryogenic region is often considered to be that below approximately 120 K (-153oC). The common permanent gases referred to earlier change from gas to liquid at atmospheric pressure at the temperatures shown in Table 1, called the normal boiling point (NBP). Such liquids are known as cryogenic liquids or cryogens [3].

Table 1. Normal boiling points of common cryogenic fluids

Cryogen	(K)	(º C)	(º R)	(º F)
Methane	111.7	-161.5	201.1	-258.6
Oxygen	90.2	-183.0	162.4	-297.3
Nitrogen	77.4	-195.8	139.3	-320.4
Hydrogen	20.3	-252.9	36.5	-423.2
Helium	4.2	-269.0	7.6	-452.1
Absolute zero	0	-273.15	0	-459.67

Untill the end of 1960s, attempts made to perform CT with the results of cracking components. The cryogenic treatment system developed by Ed Busch in the late 1960s and later improved by Peter Paulin with a temperature feedback control on cooling and heating rates allows to perform effective and crackles. CT until very low temperatures subsequently, the research about CT has been validated during the 1980s by the first request in machine tools [4,5]. Latter with research and development, computerized temperature control systems have been developed to get crackless cryogenic treated components to achieve maximum benefits [6-9].

NASA engineers were the first to notice the effects of cold temperatures on materials. They noticed that many of the metal parts in the aircraft that had returned back from the cold vacuum of space came back stronger than they were before flight.

II. LITERATURE REVIEW

Literature review provides the scope for the present study. It works as guide to run this analysis. Some survey on research papers require to deliberate in this review paper connected towards Electrical Discharge Machining. From the readings out in these papers and thesis is mostly concerned through the EDM settings such as the discharge current, applied voltage, pulse on time, pulse off time, duty cycle, etc. and in what way these parameter will affect the machining outputs like MRR, Ra, TWR etc.

In this review paper search few selected research paper related to EDM with effect of metal MRR, TWR, surface roughness (SR) workpiece material, we are broadly classified all the paper in to five different category, i.e. paper related to material related workpiece or tool, Cryogenic treated electrode, comparative study on cryogenic treated and non-treated workpiece and electrode, some paper related to Effect of multiple discharge and rest of the paper related to Cryogenic treated process.

2.1 Material Removal Rate (MRR)

Year	**Author**	**Workpiece Material**	**Electrode Material**	**MRR**
2008	Kuppan et al	Inconel 718	copper	This paper reports on an experimental investigation of small deep hole drilling of Inconel 718 using the EDM process The MRR increases with the increase in peak current, duty factor and electrode speed [10].
2010	Gill and Singh	Ti 6246	copper	MRR of DCT workpiece is less than the MRR for non-treated workpiece for 30 min and 60 min drilling time, but for longer durations of drilling (90 min, 120 min, 150 min, and 180 min) the trend is reversed [11].
2010	Yildiz et al	beryllium-copper	C-122 copper	20-30 % increase in material removal rate of cold and cryogenic treated workpiece. Current is the most effective parameter affecting the MRR. In the case of using treated work pieces, MRR increased averagely by about 19% with cold treatment and by about 20% with cryogenic treatment according to data means. It should be noted that MRR differences between EDM of non-treated, cold-treated and cryogenically treated Be-Cu work pieces are increased remarkably by increasing working current [12].
2012	Srivastava and Pandey	M2 grade high speed steel	copper	MRR increases with the increase in discharge current This could be due to an increase in discharge energy with increase in discharge current, which improves the rate of melting and evaporation. Also it can be seen that MRR decreases with the increase in pulse-on time initially but after a certain value of pulse-on time, it increases [13].
2013	Ahmad and Lajis	Inconel 718.	copper	They have concluded that the peak current is the most influence parameter for achieving high MRR while for pulse duration it shows insignificant for improving MRR [14].
2013	Mathai V.J. ,Vaghela R.V. , Dav	Stainless steel (SS 304)	copper	Material removal rate increases with increase in current and pulse ON time irrespective of the cryogenic treatment condition applied on the tool [15].

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2013	Singh and Abbas	High Carbon High Chromium WC 6 WC 9	Graphite	Some increment is reported in Material Removal Rate (MRR) in all the three types of alloy steels after cryogenic treatment but in case of WC 6, it is comparatively less affected [21].
2014	Raghu et al	EN 31 steel	Graphite	They had conclude that the optimized parameters for the EDM process for the graphite electrode and both the work pieces in common for MRR are current 20A, voltage 30V, duty factor 40, and for surface roughness are current 10A, voltage 50V and duty factor 30.Significant increase in MRR had been observed on cryogenically treated work piece at most of the levels
2015	Kulwinder and Dinesh	H11 tool steel	copper tungsten	MRR increases with the increase in peak current for both electrode, but MRR is more with the cryogenic copper tungsten (CuW) electrode as compared with the copper tungsten electrode [16].
2015	R.Thanigaivelan et al		Copper Brass	Cryogenic treated electrode is Best In this study, for copper electrode, the machining rate slowly increases. At higher voltage, large discharge takes place in gaseous zone resulting in impaired material removal [17].

Material Removal rate are critical parameter in EDM. Since cryogenic treated tool has a significant positive effect on this parameter, it can be recommended that cryogenically treated electrode gives best result in material removal rate .Current is the most effective parameter affecting the MRR

2.2 Tool Wear Rate (TWR)

Year	**Author**	**Work piece Material**	**Electrode Material**	**TWR**
2009	Abdulkareem et al	titanium alloy (Ti-6Al-4V)	copper	They observed that it was possible to reduce electrode wear ratio up to 27% by electrode cooling. The cooling effect of liquid nitrogen improves thermal conductivity of the electrode materials thereby minimizing heat trapped in electrode. As a result, melting and vaporization of electrode material

				minimizes and, thus, wear rate of electrode is reduced [18].
2010	Abdulkareem et al	titanium alloy (Ti-6Al-4V)	copper	They observed that it was possible to reduce electrode wear ratio up to 27% by electrode cooling. The TWR increases with the current and pulse on time. It means that high current and long pulse duration results in high TWR. Also, TWR decreases as pulse off-time increases from 4µs to 5µs. But as pulse off-time increases to 6µs, a sharp increase is observed in the TWR during machining without electrode cooling as against sharp reduction in the TWR during the EDM with electrode cooling by liquid nitrogen. The gap voltage resulted in a gradual reduction in TWR for the two conditions during EDM process [19].
2010	Gill and Singh	Ti 6246	copper	Tool wear rate of copper electrode is less when drilling DCT Ti 6246 alloy workpiece as compare to tool wear rate of non-treated tool [11].
2010	Yildiz et al	beryllium-copper	C-122 copper	TWR was increased by about 50% between 10 A and 25 A working currents. However, there was a decrease about 14% in EWR between 20 µsec and 80 µsec pulse durations
2012	Srivastava and Pandey	M2 grade high speed steel	copper	Tool wear rate were found to be lower in ultrasonic assisted cryogenically cooled copper electrode as compared to conventional EDM for the same set of process parameters The shape of the electrode has also been measured and it was found that the shape retention was better when cryogenically cooled electrode as compared to conventional EDM process [13].
2012	Kumar et al	Inconel 718	copper	They found that both TWR and WR are minimum with the use of cryogenically treated copper electrode. This may be due to increase in wear resistance, hardness, toughness, and improvement in thermal and electric properties of the electrode after cryogenic treatment [20]. . When thermal conductivity increases, the local temperature

				rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear [15].
2013	Ahmad and Lajis	Inconel 718.	copper	They have concluded that the longer pulse duration used may improve the EWR but affect adversely when higher peak current is used [14].
2013	Mathai V.. ,VaghelaR.V. ,Dave H.K ,Raval H.K .,And Desai K.P.	Stainless steel (SS304)	copper	When thermal conductivity increases, the local temperature rise would be less due to faster heat conducted to the bulk of the tool and thus less tool wear [15].
2013	Singh and Abbas	High Carbon High Chromium WC 6,WC 9	Graphite	The best improvement in Tool Wear (72.22%) is reported by WC 9 followed by HCHCr (47.12%) and then WC 6 (30.07%) [21].
2015	R. Thanigaivelan et al		Copper Brass	The cryogenic treated copper electrode shows significant improvement in TWR. TWR for copper electrode is found to increase up to half way in the beginning but then starts decreasing with further increase in voltage. The cryogenic treated copper and brass electrode produces lower TWR compared with other electrodes The cryogenic treated copper electrode improves the TWR by 24 times compared to copper electrode at pulse on time of 150µs, current of 3A and voltage of 70V [17]

2.3 Surface Roughness (RA)

Year	Author	Work piece Material	Electrode Material	SR
2009	Abdulkareem et al	titanium alloy (Ti-6Al-4V)	copper	8% improvement in surface roughness with cooling by liquid nitrogen. They have also concluded that the current and pulse and pulse on time are most significant parameters which affect to surface roughness The high temperature during the EDM reduces the thermal conductivity of the

				electrode material and the heat generated during the process cannot pass easily through the electrode. This results in melting and vaporization of electrode material. But during cryogenic cooling, the low temperature of liquid nitrogen cools the electrode and reduces its melting and vaporization resulting in smoother surface of the electrode with a uniformly distributed sparks. This reproduces a better surface of the workpiece [18]
2010	Gill and Singh	Ti 6246	copper	The roughness values for DCT Ti 6246 alloy workpiece are less as compared with the non-treated workpiece on both the base of the blind hole as well as side walls, irrespective of the drilling time. So the surface finish produced on the DCT Ti 6246 alloy workpiece is better than the non-treated workpiece. Overall, Surface roughness increases as we go for longer durations of drilling for both the work pieces [11].
2010	Yildiz et al	beryllium-copper	C-122 copper	Surface roughness is affected by current and pulse duration, roughness increases with the current and pulse on time in all the cases. The differences between results of cold and cryogenically treated work pieces are negligible [12].
2012	Srivastava and Pandey	M2 grade high speed steel	copper	Surface roughness increases with discharge current up to 6 A and then slightly decreases for all the processes [13].
2013	**L. Liqing, S. Yingjie**	Inconel 718.	copper	Surface Roughness improvements were 0.7% and 4% for runs with peak currents of 29A and 20A
2013	Mathai V.J., Vaghela R.V., Dave H.K.,	Stainless steel (SS304)	copper	no significant effect of cryogenic treatment has been observed on improvement of surface quality of the workpiece [15]

	Raval H.K., And Desai K.P.			
2013	Singh and Abbas	High Carbon High Chromium WC 6 WC 9	Graphite	The best improvement in surface finish (57.36%) is reported by WC 6 followed by WC 9 (42.40%) and then HCHCr (41.53%) [21].

Tool wear as well as surface finish of the workpiece after machining are critical parameters in EDM. Since cryogenic treatment has a significant positive effect on both these parameters, it can be recommended that cryogenically treated alloy steels can be efficiently machined through EDM

III. CONCLUSION

From literature review it is understood that cryogenic treatment has a significant positive effect on the performance of EDM. Observation made from literature review is as describe below

- Application of Cryogenic treatment to EDM is also one of efficient process for improving the output parameters of EDM process like MRR, TWR and surface roughness
- It is observed that major work has been concentrated on cryogenic treatment of tool.
- Maximum improvement is achieved when cryogenic treatment is applied for 24 hours.
- Mostly copper and graphite are used as electrode.

The review of literature indicates that there is limited published work on the effect of variation in current, pulse on time when cryogenic treatment is applied to only tool or tool and workpiece both. This study shall be carried out in cryogenic treated tool & workpiece during EDM.

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