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Review on research trends in Electric Discharge Machining for biomedical application

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Abstract:
EDM is one of the methods of non-conventional machining process. It works on the principle of thermal electric energy between tool and workpiece. Various advancement has been made on EDM process like use of ultrasonic assisted tools, rotatory tools, using water as dielectric fluid and powder mixed dielectric fluid. From last few years EDM has been used for surface modification of biomaterials as machining by EDM has many benefits over other methods used for machining of biomaterials. This paper reviews recent advancement of EDM in biomedical field.

***Keywords:**EDM, biomedical, surface roughness.*

I. INTRODUCTION

EDM is one of the methods of non-conventional machining process. Non-conventional machining methods does not have physical contact between tool and workpiece so as in EDM which lowers the chances of tool failure and eliminates mechanical stress and vibration because of which workpiece can be machined without being distorted. For conventional methods it is desirable that tool should be harder than workpiece whereas there is no such requirement in EDM. Material with any hardness and toughness e.g. super alloys and composites can be machined by EDM. In conventional machining methods material is removed by chip formation which leaves burs on the surfaces whereas no burs are produced by EDM machining as material removal is based on principle of thermo-electric energy between tool and workpiece. Conventional machines has limitation of producing only rectangular and circular shapes as motion of tool is either rotatory or reciprocating whereas EDM is capable of machining complicated shapes e.g. honeycomb shapes. EDM machining leads to very minor overcut of workpiece that too when machining is carried out at a higher value of machining parameters which results in machining of workpiece with close tolerances. Even very delicate materials can easily be machined which cannot take the stress of conventional machines e.g. washing machine agitators. Even it is possible obtain mirror like surface finish on workpiece with the help of powder additives.

1.1 History of EDM

EDM was introduced by physicist Joseph Priestley in 1770 but it was not as effective as more electrode material was eroded and there were manually operated feed systems which resulted in more arching. Dr B.R. and N.I. Lazarenko in 1943 led most important improvements i.e. RC relaxation circuit was introduced in EDM because of which wear was reduced on electric power contacts. In forties B.N. Solotych and Lazarenko introduced theory of discharge ignition with the help cold electron emissions. In late sixties EDM machining was made more advantageous as it was able to machine workpiece with any hardness, its flexibility in movement was improved and undercut machining could be done. AGIE and CHARMILLES developed static pulse generator which improved precision, machining rate was increased, less wear and gap width was minimised. In 1969 wire electrodes were introduced which were used for cutting workpiece by EDM. In 1980 concept of micro machining was introduced.

1.3 Parameters of EDM

There are various different parameters electrical and non-electrical which are as shown in Fig. 1. These parameters are varied and machining is carried out to obtain desirable machining performance.

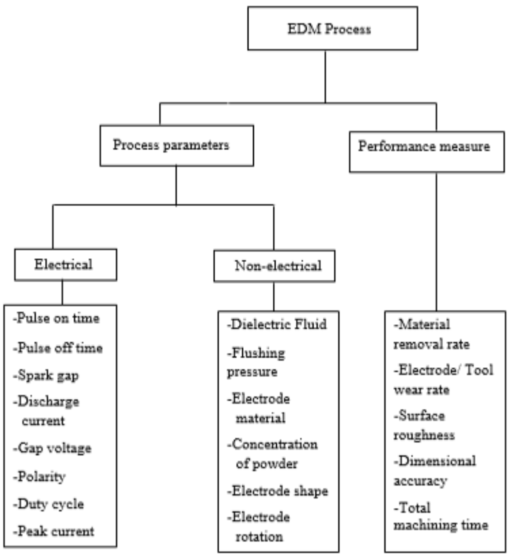

Fig. 1 Important input and output parameters for EDM process (Ubaid *et al.* 2018).

Pulse on time is the time for which energy is allowed to flow between tool and workpiece in a cycle. Material removal and surface roughness is directly proportional to pulse on time. It is observed that as pulse on time increases MRR increases but after a certain point it starts decreases as workpiece does not get sufficient time to cool down.

Discharge current is the amount of energy supplied between tool workpiece. More is the value of discharge current higher is MRR and SR. As energy supplied increases crater produced are of bigger size and SR increases. As discharge current value increases MRR also increases as more material is melted and eroded.

Pulse off time is the time between consecutive spark. Pulse off time also plays important role as it is allows proper flushing away of debris between workpiece and tool, and responsible for proper cooling of workpiece. There should be proper selection of pulse off time as shorter pulse off time makes spark unstable. When pulse off time is small debris will not be properly flushed away and will remain in dielectric fluid and fluid will not be deionised and leads to instability of spark.

Spark gap is distance between electrode and workpiece. It is desirable to have minimum inter electrode gap so as to have minimum resistance. Lesser is resistance between tool and electrode will results proper discharging of capacitor between tool and workpiece.

Duty cycle is the ratio of time for which energy is supplied between tool and workpiece to total cycle time. In other words it can be explained as ratio of pulse on time to total cycle time. Total cycle time means sum of pulse on time and pulse off time

2. Role of EDM in biomedical

Abbas et al. (2007) reviewed the research trends in EDM on ultrasonic vibration, dry EDM machining, EDM with powder additives, EDM using water as dielectric and modeling technique in predicting EDM performances. In each topic, the development of the methods for the last 25 years was discussed. The ultrasonic vibration method is suitable for micro machining, dry machining is cost effective, and EDM with water as dielectric is introduced for safe and conducive working environment. EDM modeling is introduced to predict the output parameters which leads towards the development of precise and accurate EDM performance. For each and every method introduced and employed in EDM process, the objectives was same to enhance the capability of machining performance, to get better output product, to develop technique to machine new materials and to have better working conditions.

Pandey and Singh (2010) studied that advanced material like super alloys, ceramics and composites were facing big challenge from manufacturing industries as they are hard and difficult to machine. They required high precision and surface quality which increases machining cost. Non-conventional

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machining method could meet this challenges with high material removal rate, better surface finish and greater dimensional accuracy with less tool wear. Electric Discharge Machine is non-conventional machining process which has wide application in automotive, defense and aerospace industries. Its capacity to machine hard and difficult material made it most important machining process. Die sinking EDM, wire EDM, micro EDM, Rotating pin electrode, Dry EDM and Rotatory disk electrode EDM are some of the various methods of EDM. These various methods has brought tremendous improvement in surface finish in advanced material.

Stráský et al. (2011) studied machining of Ti–6Al–4V alloy by EDM for surface treatment. Surface roughness, chemical alterations of surface and osteointegration was studied. Graphite as electrode and hydrocarbon oil as dielectric fluid was used. EDM with high peak current i.e. 29A induced high surface roughness and carbon enriched layer was formed on surface after machining which improved osteointegration. Micro structure changes of surface and sub surface layer were seen by means of scanning electron microscopy. They also stated that higher surface roughness after EDM process positively affects cell growth and carbon enriched surface acted as good substrate for the adhesion and growth of bone derived cells.

Harcuba et al. (2011) investigated the properties of Ti–6Al–4V alloy after surface treatment by the electric discharge machining (EDM) process. Investigation of the biocompatibility of the surface-treated Ti–6Al–4V samples in cultures of human osteoblast-like MG 63 cells revealed that the samples modified by EDM provided better substrates for the adhesion, growth and viability of MG 63 cells than the TiO2 coated surface. Thus, EDM treatment can be considered as a promising surface modification to orthopaedic implants, in which good integration with the surrounding bone tissue is required. Samples modified by EDM provide a better substrate for the adhesion and growth of human bone-derived cells than the alloy plasma-sprayed with TiO2.

Prakash et al. (2015) stated that different techniques are used for surface modification of biomaterials such as plasma spraying deposition (PVD), chemical vapor deposition (CVD), anodization, nitriding and laser cladding etc. These techniques have become ineffective due to poor adhesion and low physical bond strength and unable to serve under cyclic loading conditions in corrosive environment. Surface preparation is required before these techniques such as shot peening and grit blasting which increases the processing cost. Surface modification by EDM is acknowledged for biomaterials. EDM machined surface shows improved biocompatibility, proliferation and adhesion of human osteoblast MG-63 cells response. It does not require any surface preparation before machining. When machining is done by EDM, formation of carbides on surface takes place which increases hardness, wear resistance and corrosive resistance of material surface. It was experimentally found that EDM machined surface shows higher growth factor for the attachment of human osteoblast cell (MG-63).

Aliyu et al. (2017) showed that surface treatment is a main issue for several problems of hard tissues. Basic methods used for surface modification consists of many physical and chemical decomposition techniques but also has various disadvantages such as surface crack and requires very high temperature for sintering and are also very costly. They suggested the use of powder additive EDM that acts for both machining and surface modification which is also a research focus for implant shaping and surface treatment in recent years, as the additives in EDM dielectric fluids are melted and moves towards machined surface where they forms nano porous layer that helps in strengthen of cell adhesion and bone in growth.

Kumar et al. (2018) Stated that EDM has potential in treatment and modification of titanium alloy and other metallic materials used in bio-medical applications. In comparison to the several existing techniques such as PVD, CVD and iodizing, EDM shows better potential for surface

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treatment of metallic implants. EDM machined samples are preferable substances for MG- 63 cells of human osteoblast as per adhesion and growth is concerned. The only disadvantage of EDM machining is fatigue performance of highly rough EDM sample is low, which can be further improved by surface treatment method or by the reduction of recast layer by shot blasting, CM and SP etc.

Prakash et al. (2016) studied the application of powder mixed electrical discharge machining (PMEDM) for the machining of β-phase titanium (β-Ti), which has application in dental, orthopaedics, shape memory, and stents. It aimed at fabrication of submicron- and nanoscale topography by PMEDM process to enhance the biocompatibility without affecting machining efficiency. The effect of Si powder concentration along with pulse current and duration on the machining characteristics was investigated. A significant decrease in surface crack density on the machined surface with 4 gm/l Si powder concentration was observed. When β-Ti alloy was modified at 15 A pulse current, longer pulse interval with 8 g/l concentration of Si powder particles, the interconnected surface porosities with pore size 200–500 nm was observed. Elemental mapping analysis confirmed that PMEDM generated carbides and oxides enriched surface, a favourable surface chemistry to enhance the biocompatibility of β-Ti alloy. PMEDM also enhances the machining performance by improving material removal rate and reducing tool wear rate.

Prakash et al. (2016) studied that powder mixed electric discharge machining (PMEDM) a novel nonconventional machining technique has been proposed for surface modification of β -Ti implant for orthopaedics application. The surface topography and morphology like roughness, surface cracks, and recast layer thickness of each of the machined specimens were investigated using Mitutoyo surface roughness tester and field-emission scanning electron microscopy (FE-SEM). Fatigue performance and cell attachment and proliferation on β -phase Ti alloy surface treatment by polishing, EDM, and PMEDM was studied. The following conclusions were drawn from that investigation. PMEDM significantly improved the surface quality by reducing surface defects like micro cracks, craters/pit size, recast layer thickness. PMEDM significantly reduced the thickness of recast layer. Fatigue performance of PMEDM-treated specimen is significantly improved. PMEDM surface has promoted cell adhesion and proliferation. Overall, PMEDM has the potential to enhance the mechanical properties and enhances the osteoblast response. The modified surface provides a promising range of application in orthopaedics.

Karastrojkovic and Janjusevic (2003) studied hardness and structural changes at surface after electrical discharge machining of steel C 3840. It was stated that the electrical spark can produce high local temperature. High temperature lead to structural changes. As a result of breaking the impulse current, melted metal undergoes rapid solidification just on the periphery of crater. Melted, solidified metal and partially condensed vapor made thin layer and such layer may have greater roughness. After rapid cooling on melted surface produces white layer. This white layer consists of cementite carbide, austenite and ferrite. Just below this white layer was quenched layer, third layer from center spark was is tempered layer. Tempered material has lower hardness then quenched material. Temperature changes are responsible for hardness changes in material.

Zeilmann et al. (2013) studied metallurgical alterations in the surface of steel cavities machined by EDM. Several variables i.e. cavity depth, electrode geometry and technological parameters of process. It was aimed at finding out different metallurgical changes occurred after electric discharge machining. Evaluation of this surface was done by metallographic analysis. Study revealed several metallurgical changes like formation of white layer, hardness variation and change of microstructure. Occurrence of micro cracks was also observed in severe conditions. Technological parameters caused maximum variation in results. Variation in depth cavity and change in electrode geometry also showed some influence on results. Tool copper was used as electrode and ABNT 1045 steel was used as workpiece. Metallurgical changes can have major influence on mechanical properties of the surface.

Shunmugam and Philip (1993) studied improvement of wear resistance by EDM machining with tungsten carbide powder mixed. It was stated that using powder compact electrode and reverse polarity modifies the surface properties of a machined surface. Using hard and wear resistant material in the compact, wear resistant of material after EDM machining can be improved. After EDM machining wear resistant is calculated by cutting tests. Results evaluates that there is considerable increment in wear resistant of machined material.

Gungor and Ekmekci (2015) studied effect on wear resistance after electrical discharged machining of austenite stainless steel, dual phase steel and plastic mold steel surfaces using two different pulse duration for two different electrodes i.e. copper and graphite. Wear rate was measured using reciprocating mode tribometer. Wear resistance increased by EDM machining. Wear rate gradually decreased with tool graphite. Increasing pulse on duration during EDM machining increased surface roughness and wear rates continued to decrease. Wear rate decreased due to complex carbide formation in the re-solidified layer.

Mahamat et al. (2011) studied machining of cemented tungsten carbide by EDM. Tungsten carbide is ceramic and mixed with small amount of metallic binder, this material has property of neither ceramic nor metal. Very low thermal expansion and low thermal conductivity in combination with high melting point and brittleness makes this material difficult to machine. This material has application in tool and die material due to its property of high resistant to abrasive wear and high melting point. While machining difficulty due to thermal stress is encountered. Micro cracks enlarge and becomes macro and leads top fragmentation. This is because of low thermal expansion, thermal conductivity and brittleness, which create high thermal stress. L9 Taguchi Orthogonal array was used. This array was used for optimization of variables i.e. peak current, pulse on time, pulse off time and gap voltage. Results shows that surface roughness is mainly affected by pulse on time and peak current. Study revealed that it is possible to machine cemented tungsten carbide using copper electrode but at cost of material removal rate. High dielectric pressure is required to remove debris and broken up particles in the discharge gap Due to low thermal conductivity, low thermal expansion and high heating rate, proper cooling is not possible which leads to thermal stress higher than ultimate tensile strength which is main source of cracks of this material.

Mahmud et al. (2012) studied that Electrical Discharge Machining is a non-contact machining process for shaping and forming deep and complex shaped holes for all kinds of electro-conductive materials regardless of their hardness. Recently, a demand in micro machining has extended into biomedical application for lubrication of artificial human joint. A micro pits formation is therefore proposed for lubrication purpose, which eventually prolong the lifespan of the hip implant. In this case, particular size of crater in micro will be developed in various positions and depth on the artificial joint surface to ease friction between metal joint. Therefore, this paper proposed a new design of Pulse Power Generator by considering the optimum material removal rate, the relative wear ratio, the surface crack density and the surface finish quality of the workpiece produced. From the study it is concluded that RC type generator gives better surface quality, but its machining efficiency can be affected due to the time needed to charge the capacitor. Thus, for machining hip implant, it is strongly recommended to use transistor type generator since it can provide improvement in the removal rate due to its higher machining speed.

Sidhom et al. (2012) investigated the effect of electrical discharge machining on microstructural changes of AISI 316L SS. EDM machining induces high substantial changes by the high thermal gradients by electrical sparks. Experimental

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technique like roughness measurement, scanning electron microscopy, energy dispersive microanalysis and X-ray diffraction technique revealed chemical, mechanical, micro-geometrical and microstructural changes. EDM surface shows rough and porous texture which occurs as melting drops with craters due to collapse of plasma channel during machining. Formation of white layers contains carbon on it. Residual stresses are encountered on EDM machined surface.

From above literature we can see that Electric Discharge machining has been used effectively for bio- medical implants for surface modification as it enhances adhesion and proliferation of human cell. Earlier various different techniques were used for surface modification of bio material but these techniques have become ineffective due to poor adhesion and weak physical bond strength. Even these techniques require surface treatment before coating. Recently EDM has been acknowledged as better potential for surface preparation of biomaterials. EDM machined surfaces produces nano porous surfaces which enhances the growth of mineralized tissue into the pore space which allows body fluid to be transported through the interconnected pores. High surface roughness leads to formation of carbides and oxides on surface which increases hardness, wear and corrosion resistance of the material.

2.2 SURFACE ROUGHNESS

It has been acknowledged that biomaterials surface texture play an important role in cell adhesion and cell proliferation. Various literature survey was made to identify the effect of increases in SR of EDM machined material on cellular activity for biomedical use. Some of them are reviewed here.

Buser et al. (1991) study was carried out to evaluate the influence of different surface characteristics on bone integration of titanium implants and stated that the extent of bone-implant interface is positively correlated with an increasing roughness of the implant surface and rough implant surfaces generally demonstrated an increase in bone apposition compared to polished or fine structured surfaces.

Shalabi et al. (2006) reviewed on studies investigating the effects of implant surface roughness on bone response and implant fixation. It was stated that the statistical analysis on the available data provided supportive evidence for a positive relationship between bone-to-implant contact and surface roughness.

Alla et al. (2011) reviewed that response of the tissues to the implant is largely controlled by the nature and texture of the surface of the implant. Compared to smooth surfaces, textured implants surfaces exhibit more surface area for integrating with bone via osteointegration process. Textured surface also allows ingrowth of the tissues.Most implant systems of this category are based on the fact that bone tissue can adapt to surface irregularities in the 1 – 100 micron range, and that altering the surface topography of an implant can greatly improve its stability. Goal of various surface textures and techniques is to enhancing bone growth towards the implant surface. A number of invivostudies have demonstrated that increased surface area on the implant improves bone-to-implant contact after the implant placement. Primary aim of the surface texturing or treating the implant surface is to enhance cellular activity and improve bone apposition. Studies using endosseous dental implants in human clinical trials indicated that rough surfaces integrate better with the bone than those materials with relatively smooth surfaces.

Saini et al. (2015) stated that Alterations in the surface roughness of implants influence the response of cells and tissue by increasing the surface area of the implant adjacent to bone and thereby improving cell attachment to the bone.

From Literature review it is observed that increasing surface roughness of biomedical implants leads to increase in surface area and results in better integration with bone and allows cell growth and bone formation and bone fixation. It is desirable to increase surface roughness of implant for positive results between bone and implant.

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3 CONCLUSION

There are different techniques which are used for machining of biomaterials like nitriding, anodising, CVD and PVD. These techniques have become ineffective due weak adhesion bond and inability to serve under repeated loading conditions in corrosive environment. Even it requires surface preparation like shot peening and grit blasting before these techniques whereas there is no such requirement for EDM.

Surfaces machined by EDM are better than other techniques due to following reasons:

- There are various different techniques for surface modification of biomaterials such as PVD, CVD, nitriding and anodizing etc. but they require surface treatment before coating where as there is no such requirement for EDM machined surfaces.
- When machining is carried out by EDM dielectric fluid used for machining degenerates into oxides and carbides and it gets deposited on workpiece which increases biocompatibility.
- Nano porous surfaces are produced when machined by EDM as a result, available pore spaces encourages the mineralized tissue growth into pores which allows the transportation of body fluid by interconnected pores. As a result cell proliferation and adhesion is improved.
- Attainment of high temperature during sparking when machined by EDM improves hardness of surface.
- EDM machined surfaces improves corrosion and wear resistance

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