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Latest Trends in Electro Discharge Machining

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ABSTRACT

EDM is one of the most advanced, non-traditional material removal processes which may help overcome the limitations of conventional mechanical cutting methods. This study represents the recent trends in EDM process. The varying input parameters are identified as peak current Ip, pulse duration Ton, types of dielectric medium and powder-mixed dielectrics. The output responses are measured as Material Removal Rate (MRR), Tool Wear Rate (TWR) and Surface Roughness (Ra). MRR was found to increase with powder-mixed dielectrics. T_{on} and I_p seems to be the most influencing factors for MRR. Addition of powders like SiC and B4C to the dielectric lowers the tool wear. Ra improves with addition of powder to the dielectric medium and also the desired properties like hardness, corrosion resistance etc are imparted to the machined surface of the work piece.

Key words: Powder electro discharge machining (EDM), material removal rate (MRR), surface roughness

INTRODUCTION

Electro-Discharge-Machining is a thermoelectric process where tiny amount of work piece material is melted and vaporized due to generation of very high temperature due to the repetitive spark discharge between the tool and work piece within very small gap. The spark spreads over the entire work piece surface leading to its erosion, or machining to a shape which is mirror image of the tool [1]. As the machining zone is immerged in dielectric fluid, the melted and vaporized materials transform into tiny particles known as debris upon cooling in pulse-off time. This debris is removed from the machining zone by the flushing pressure of the dielectric liquid jet. In micro-EDM process, any type of conducting materials can be used as the work piece material regardless of its hardness [2]. Since there is no direct contact between tool electrode and work piece in EDM, defects like mechanical stresses, clattering and vibration do not create problem during machining.

REVIEW OF LITERATURE

Jaswani et al [3] investigated the performances of kerosene and distilled water over the pulse energy range 72–288 mJ. Machining in distilled water resulted in a higher MRR and a lower tool wear rate than in kerosene when a high pulse energy range was used. They also noticed that with distilled water, the machining accuracy was poor but the surface finish was better. Tariq et al [4] measured the performance of water as dielectric fluid in EDM using distilled water, tap water and a mixture of 25% tap and 75% distilled water. The best machining rates have been achieved with the tap water and machining in water has the possibility of achieving zero TWR when using copper tools with negative polarities parameters that influenced the doping characteristics were pulse current and pulse duration. Mohri et al [5] studied the effects of Si powder addition on machining rate and surface roughness (R_a) in EDM. The fine and corrosion resistant surfaces having roughness of the order of 2 mm were produced. Kruth et al [6] succeeded in depositing Al on steel and TiC on Al using Al and Ti–Al green compact electrodes respectively with a traditional EDM machine. This was obtained by using porous electrodes with negative polarity favoring high tool wear. During investigating on white surface layer, the use of an oil dielectric increases the carbon content in the white layer and appears as iron carbides (Fe_3C) in columnar, dendritic structures while machining in water causes a decarbonization. Miyazaki et al [7] applied a plasma arc produced through a small diameter nozzle on steel. Ceramic powder of silicon carbide was supplied to the processing region with the shielding gas of argon. It was possible to obtain a hardness of 1000 VHN on AISI 1010 steel by self-quenching without any powder and 1200HV with SiC particles. When surfactant was added along with Al powder in the dielectric and observed a more apparent discharge distribution effect which resulted in a surface roughness *R*a value of less than 0.2µm. It has been possible to achieve near mirror-finish using conductive powders (such as graphite and Al) and semi conductive Si powders. Wong et al [8] showed that besides the appropriate settings of electrode polarity and pulse parameters, there is a great influence of work material and powder properties on the response parameters such as MRR, TWR and surface roughness. Whilst graphite and silicon powders gave mirror-finish on SKH-54 work material, Al powder failed to give the same. The use of negative electrode polarity was found to be essential for achieving mirror-finish condition. The non-conductive materials like glass and Si3N4 ceramics can be finely machined by PMEDM [9]. The PMEDM process improved the wear and corrosion resistance of the work surfaces by depositing a hard layer on its outer surface. Chow et al [10] investigated the for titanium alloy effect of using pure water and silicon carbide (SiC) powder in micro-slit EDM and found that by using pure water as dielectric fluid yields a high MRR and relatively low electrode wear and small expanding slit by employing negative polarity (NP). Pure water and silicon causes high conductivity; therefore the gap was larger than using pure water. Pure water and silicon powder could disperse the discharging energy that refines the surface roughness effectively and also attains a higher MRR simultaneously than that of pure water.

Yan et al [11] modified the surface of titanium with EDM using dielectric of urea solution in water. The nitrogen element decomposed from the dielectric that contained urea, migrated to the work piece forming a titanium nitrate (TiN) hard layer resulting in good wear resistance of the machined surface. Hansal et al [12] studied to optimize the process parameters of powder mixed electrical discharge machining (PMEDM). Response surface methodology has been used to plan and analyze the experiments. Pulse on time, duty cycle, peak current and concentration of the silicon powder added into the dielectric fluid of EDM were chosen as variables to study the process performance in terms of material removal rate and surface roughness. The results identify the most important parameters to maximize material removal rate and minimize surface roughness. The recommended optimal process conditions have been verified by conducting confirmation experiments. Si powder was suspended into the dielectric fluid of EDM and an enhanced rate of material removal and surface finish has been achieved. Empirical modeling with the help of response surface methodology has led to the following conclusions about the variation of response parameters in terms of independent parameters within the specified range. The silicon powder suspended in the dielectric fluid of EDM affects both MRR and Ra. The slope of the curve indicates that the MRR increases with the increase in the concentration of the silicon powder. Therefore, more improvement in MRR is expected at still higher concentration level of silicon powder. There is discernible improvement in surface roughness of the work surfaces after suspending the silicon powder into the dielectric fluid of EDM. However, more improvement in Ra is still expected at higher concentration level of silicon powder. The analysis of variance revealed that the peak current factor and concentration factor are the most influential parameters on MRR and Ra. The combination of high peak current and high concentration yields more MRR and smaller Ra. The confirmation tests showed that the error between experimental and predicted values of MRR and Ra are within} 8% and −7.85% to 3.15%, respectively. In [13] Hansal et al studied powder mixed EDM of different materials mixed in dielectric fluid. The floating particles impede the ignition process by creating a high discharge probability and lowering the breakdown strength of the insulating dielectric fluid. As a result MRR and Ra increases, TWR is lowered and sparking efficiency is improved also as the conductive powders enlarge the gap distance and dispersing the discharges more randomly throughout the surface. Thickness of recast layer is smaller and micro-cracks are reduced. Consequently, the corrosion resistance of the machined surface is substantially improved. Pradhan et al [14] performed experiments using Ti-6Al-4V alloy in micro-EDM by changing the polarity of the electrodes for improving the machining accuracy of straight through micro-hole. The study was based on use of different dielectrics in machining performance characteristics for the successful implementation of micro-EDM process with effective dielectric, which may improve titanium alloy machining efficiency in micromachining domain. Ho et al [15] carried out experiments with alloying titanium Ti–6Al–4V, using both solid and powder compacted copper electrodes with a commercial water-based dielectric fluid. At the discharge energies employed, recast layer thickness varied from 4 to 11 µm with thicker and rougher layers evident when using positive tool electrode polarity. All layers were in general discontinuous; however those produced with negative polarity were more uniform, especially when using solid electrodes. The hardness of the recast varied between 200 and 1100HK0.025 compared to the bulk material365HK0.025. They found that electrodes used with positive polarity produced thicker recast layers. Other than when using a solid copper electrode under negative polarity, recast/alloyed workpiece hardness was in general of lower or of comparable hardness to the bulk material.

Wu et al [16] added a surfactant along with Al powder in the dielectric and observed a more apparent discharge distribution effect which resulted in a surface roughness *R*a value of less than 0.2µm. Pecas and Henriques [17] compared the EDM machining of AISI H13-0.39% C, 1.00% Si, 0.40% Mn, 5.2% Cr, 1.4% Mo, 0.90%V (quenched and tempered-54 HRc) using copper tool electrode with simple dielectric and silicon powdered (PMEDM) mixed dielectric (2g/lit). They found the the use of PMD-EDM conditions promotes the reduction of surface roughness, crater diameter, crater depth and the white-layer thickness. Senthilkumar et al [18] investigated the effect of current (Ip), Pulse On-Time (ton) and flushing pressure (P) on Metal Removal Rate (MRR), Tool Wear Rate (TWR) during electrical discharge machining of as-sintered Al-MMC with 5% and 2.5% tit6nium carbide (TiC) reinforcement. The use of kerosene as a dielectric fluid was employed in the present investigation. A copper tool of diameter 7 mm was used to drill the specimens. Al–TiC composites can be machined using electrodischarge machining and by selecting optimum levels for the EDM parameters, namely, discharge current, pulse on time and flushing pressure the effectiveness of process like metal removal rate and electrode wear rate can be improved. A careful investigation into the structure of the material after the machining suggests that ceramic particles (TiC) were not melted during the process and removal of material occurs as a result of matrix melting and ceramic particle pull out thereafter. The above phenomenon results in the reduced metal removal rate with the increased titanium carbide content in the composite material. Material removal rate and tool wear rates are influenced by discharge current. Flushing pressure plays an important role in continuing the process and improving the material removal rate at higher discharge current and pulse duration levels. Wu et al [19] explored the influence of surfactant on the characteristics of electrical discharge machining (EDM) process on mold steel (SKD61). In this study, particle agglomeration is reduced after surfactant molecules cover the surface of debris and carbon dregs in kerosene solution. Debris is evenly dispersed in dielectric to improve the effects of carbon accumulation and dreg discharge, and reduce the unstable concentrated discharge. The EDM parameters, such as peak current, pulse duration, open voltage and gap voltages are studied. The experimental results show that after the addition of Span 20 (30 g/L) to dielectric, the conductivity of dielectric is increased. The machining efficiency is thus increased due to a shorter relay time of electrical discharge. When proper working parameters are chosen, the material removal rate is improved by as high as 40–80%. Although the improvement of surface roughness is not obvious, the surface roughness is not deteriorated since the material removal rate is great. Ojha et al [20] studied material removal rate (MRR) and tool wear rate (TWR) study on the powder mixed electrical discharge machining (PMEDM) of EN-8 steel. Response surface methodology (RSM) has been used to plan and analyze the experiments. Peak current, pulse on time, diameter of electrode and concentration of chromium powder added into dielectric fluid of EDM were chosen as process parameters to study the PMEDM performance in terms of MRR and TWR. The powders used were Cr, C, S, P, Si, Al & Fe. It was found out that MRR shows increasing trend for increase in powder concentration. The trend shows that MRR will increase further with further increase in concentration. TWR increased with lower range of powder concentration but then decreased.

Furutania et al [21] studied surface modification method by electrical discharge machining (EDM) with a green compact electrode has been studied to make thick TiC or WC layer. Titanium alloy powder or tungsten powder is supplied from the green compact electrode and adheres on a workpiece by the heat caused by discharge. To avoid the production process of the green compact electrode, a surface modification method by EDM with powder suspended in working fluid is proposed in this paper. After considering flow of working fluid in EDM process, the use of a thin electrode and a rotating disk electrode are expected to keep powder concentration high in the gap between a workpiece and an electrode and to accrete powder material on the workpiece. The accretion machining is tried under various electrical conditions. Titanium powder is suspended in working oil like kerosene. TiC layer grows a thickness of 150 mm with a hardness of 1600 Hv on carbon steel with an electrode of 1 mm in diameter. A wider area of the accretion can be obtained by using the rotational electrode with a gear shape. It was found that TiC layer can be accreted by using a thin electrode to keep the powder concentration high. A column can be also formed. A wider area with uniform thickness can be deposited with gear shaped electrode. Yan et al [22] investigates the influence of the machining characteristics on pure titanium metals using an electrical discharge machining (EDM) with the addition of urea into distilled water. In the experiments, machining parameters such as the dielectric type, peak current and pulse duration were changed to explore their effects on machining performance, including the material removal rate, electrode wear rate and surface roughness. Moreover, the elemental distribution of nitrogen on the machined surface was qualitatively determined by EPMA to assess the effects on surface modification. Micro hardness and wear resistance tests were performed to evaluate the effects of the reinforced surface. Experimental results indicate that the nitrogen element decomposed from the dielectric that contained urea, migrated to the work piece, forming a TiN hard layer, resulting in good wear resistance of the machined surface after EDM. The results show that the MRR and TWR value of the two dielectrics did not show significant difference. It was found that adding urea into the dielectric, MRR and TWR increased with an increase in peak current. Moreover MRR and EWR declined as the pulse duration increased. This was due to the peak current increase, increasing the discharge energy. Roughness deteriorated with an increase in peak current. Since an increase in the peak current increased the discharge energy and the impulsive force, removing more molten material and generating deeper and larger discharge craters. Hence, the surface roughness became coarser. Gu et al [23] investigated an efficient Ti_6Al_4V electrical discharge machining (EDM) process with a bundled die-sinking electrode. The feasibility of machining Ti_6Al_4V with a bundled electrode was studied and its effect on EDM performance was compared experimentally using a solid die-sinking electrode. The simulation results explain the high performance of the EDM process with a bundled electrode by through the use of multi-hole inner flushing to efficiently remove molten material from the inter electrode gap and through the improved ability to apply a higher peak current. Compared with a solid die-sinking electrode, bundled electrodes can endure a much higher peak current, which results in a substantially higher MRR and a comparably lower TWR. When using a bundled electrode with multi-hole inner flushing, the fluid field simulation results show that the flow velocity increases continuously from the centre to the periphery along the radial direction of the tool electrode, and it is therefore more effective than other flushing methods. This benefit of the bundled electrode makes it much more feasible for application in large-area rough machining. In order to extend the advantages to the semi-finishing process, further research about the improvement of work piece surface quality need to be carried out. EDS results indicate that even with strong inner flushing, the electrode surface is partially covered by the ejected melting work piece material, leading to an electrode protection effect and uniform tool wear. Peak current, fluid flow rate and the interactions between peak current and pulse duration have been found to have a significant influence on the MRR. The TWR is significantly influenced by the peak current and the fluid flow rate during EDM with a bundled electrode. Jabbaripour et al [24] studied the two series of machining tests are designed. Firstly the PMEDM of titanium aluminide inter metallics by means of different powders such as Al, chrome, SiC, graphite and Fe is performed to investigate the output characteristics of surface roughness and topography, MRR, electrochemical corrosion resistance of machined samples and also the machined surfaces are investigated by means of EDS and XRD analyses. In the first setting of input machining parameters, Al powder improves the R_a of TiAl sample about 32% comparing with EDM case and also Al particles with the size of 2 μm, in the second setting of input parameters lead to 54% enhancement of MRR comparing with EDM case. The electrochemical corrosion results show that, corrosion resistance of the samples which are machined by graphite and chrome powders respectively are about three and two times more than the sample which is machined without powder.

It was found that Al powder produces the least surfaces roughness and also the best surface topography, followed by SiC, Gr, Cr and Fe in sequence. Considering the EDS results, in addition to the main elements of titanium and Al, elements such as carbon, oxygen and copper are existed on all machined surfaces. Depending on the used powder in PMEDM process, about 5–10% of that element is added into the surface layer of machined sample and different chemical phases are produced on the machined samples which are determined by means of XRD analysis. Based on the electrochemical impedance spectroscopy results, the highest corrosion resistance (R_{tota}l) is for the sample which is machined by graphite powder whereas the least value is for the sample which is machined by Al powder. The former sample has the least contents of aluminium and oxygen elements, while the latter one has the most contents of aluminium and oxygen elements. The order of total electrochemical corrosion resistance (R_{total}) for the samples which are machined by different kinds of powders comparing with the machining case without powder (EDM) is as the following: $R_{Gr} > R_{Cr} > R_{SiC} > R_{EDM} > R_{Fe} > R_{Al}$.

RESULTS AND DISCUSSIONS

Analysis of Material Removal Rate (MRR)

It is found that MRR increased with increase in powder concentration in dielectrics. Higher MRR was achieved with distilled water as dielectric then with kerosene, though the best machining rates have been achieved with tap water. Also with deionized water, a higher MRR could be achieved than with kerosene when machining Ti-6Al-4V. With suspended particles like B_4C, MRR was found to increase. Addition of powders like Cr, C, S, P, Si, Al and Fe has shown increased rate in MRR and is expected to increase with further increase in concentration. It was also found that a highly concentrated aqueous glycerin solution has an advantage as compared to hydrocarbon dielectrics when working with long pulse duration and high pulse duty factors and discharge currents.

It was also observed that for machining titanium alloy using pure water with suspended SiC powder in micro-slit EDM, yields a higher MRR, but when urea was added to distilled water as dielectric medium, MRR declined with an increase in pulse duration. Also, with addition of surfactant to dielectric, particle agglomeration reduced. The debris evenly dispersed in dielectric improved the effects of carbon accumulation and dreg discharge and reduce the unstable concentrated discharge. When proper working parameters were chosen, MRR improved by as high as 40 to 80 %.

Analysis of Tool Wear Rate (TWR)

It was found that TWR decreased with distilled water as dielectric than with kerosene. It was observed that the addition of powders in dielectric medium lowered the tool wear. Addition of powders like SiC and B_4C has been found to lower the electrode wear. The parameters that influenced the doping characteristics were peak current and pulse duration. It was also found that TWR declined with increase in pulse duration. At negative polarity, tool wear was found to be high. When using bundled electrode with multi-hole inner flushing, a uniform tool wear was achieved. There could also be the possibility of achieving zero TWR using copper electrodes with negative polarity.

Analysis of Surface Roughness (Ra)

It was found that the addition of doping elements to the dielectric medium could be used to impart desired properties to the top layer of the workpiece. It was investigated that, on white surface layer, with the use of oil dielectric increased the carbon content appearing as Fe_3C in columnar, dendritic structures as machining in water causes a decarbonisation. It was also possible to obtain a hardness of 1000 VHN on AISI 1010 steel by self quenching without any powder and 1200 VHN with SiC particles. With conductive powders, the gap distance enlarged dispersing the discharges more randomly throughout the surface hence recast layer and micro-cracks got reduced. The recast layer thickness varied from 4 to 11 μm. It was observed that adding urea to distilled water for machining titanium, friction and wear resistant TiN layer was formed on the work surface.

It was also observed that when surfactant was added in dielectric with Al powder, a more apparent discharge distribution effect was observed which resulted in Ra value less than 0.2 μm. It was also reported that, with use of powder-mixed EDM, surface roughness, crater diameter, crater depth and white layer thickness reduced. The electrochemical impedance spectroscopy result shows that the highest corrosion resistance was for the sample machined by graphite powder than with Cr, Si, Fe and Al powders.

CONCLUSIONS

From the above study following conclusions can be drawn -

- MRR increases with powder-mixed dielectrics and further increases with increase in powder concentration. Higher MRR can be achieved with tap water and distilled water as dielectric than with kerosene.
- A higher MRR can be achieved by using pure water with SiC powder. When machining with Al powder mixed dielectric, MRR increased with respect to the other standard dielectrics.
- The TWR decreases with distilled water than with kerosene. Addition of powders like SiC and B4C to the dielectric lowers the tool wear.
- TWR declined with increase in pulse duration. It seems to increase with low powder concentration and then decrease. At negative polarity tool wear was found to be high. With addition of urea, electrodes wear increases with increase in peak current.
- Surface roughness improves with addition of doping elements to the dielectric medium and also the desired properties like corrosion resistant, hardness, strength etc to the machined surface of the workpiece is imparted.
- Addition of surfactant with Al powder for machining titanium, a more apparent discharge distribution effect was observed which resulted in surface roughness values of less than 0.2 μm.
- The work surface machined by graphite powder mixed dielectric has highest corrosion resistance than with Cr, Si, Fe, and Al.

REFERENCES

[1] S Singh and A Bhardwaj, Review to EDM by Using Water and Powder- Mixed Dielectric Fluid, *Journal of Minerals &Materials Characterization & Engineering* jmmce.org, **2011**, 10(2), 199-230.

[2] OA Abu Zeid, On the Effect of Electro Discharge Machining Parameters on the Fatigue Life of AISI D6 Tool Steel, *Journal of Materials Processing Technology*, **1997**, 68(1), 27–32.

[3] ML Jeswani, Electrical Discharge Machining in Distilled Water, *International Journal of Wear*, Elsevier, **1981**, 72, 81–88.

[4] S Tariq Jilani and PC Pandey, Experimental Investigations into the Performance of Water as Dielectric in EDM, *International Journal of Machine Tool Design and Research*, **1984**, 24, 31–43.

[5] N Mohri, N Saito, T Takawashi, K Kobayashi, Mirror-like Finishing by EDM, *Proceedings of the 25th International Symposium on Machine Tool Design and Research*, UK, **1985**, 329–336.

[6] JP Kruth, L Stevens, L Froyen and B Lauwers, Study of the White Layer of a Surface Machined by Diesinking Electro Discharge Machining, *CIRP Annals Manufacturing Technology*, **1995**, 169–172.

[7] T Miyazaki, S Yoshioka, T Kimura and N Kinoshita, Surface Modification of Steel by a Small Diameter Plasma Arc, *Annals of CIRP*, **1995**, 44(1), 161-165.

[8] YS Wong, LC Lim, I Rahuman and WM Tee, Near Mirror-Finish Phenomenon in EDM using Powder Mixed Dielectric, *Journal of Materials Processing Technology*,**1998**, 79 (1-3), 30–40.

[9] Y Uno, A Okada, Y Hayashi and Y Tabuchi, Surface Integrity in EDM of Aluminum Bronze with Nickel Powder Mixed Fluid, *Journal of Jpn. Soc. Electr. Mach. Eng*, Japan, **1998**, 32 (70), 24–31.

[10] HM Chow, BH Yan and FY Huang, Micro Slit Machining using Electric Discharge Machining with a Modified Rotary Disk Electrode (RDE), *Journal of Materials Processing Technology*,**1999**,91(1-3), 161–166.

[11] BH Yan, HC Tsa and FY Huang, The Effect in EDM of a Dielectric of a Urea Solution in Water on Modifying the Surface of Titanium, *International Journal of Machine Tools and manufacture,* **2005**, 4, 194- 200.

[12] HK Kansal, S Singh and P Kumar, Parametric Optimization of powder Mixed Electrical Discharge Machining by Response Surface Methodology, *Journal of Materials Processing Technology*, **2005**, 169(3), 427-436.

[13] HK Kansal, S Singh and P Kumar, Technology and Research Developments in Powder Mixed Electric Discharge Machining, *Journal of Materials Processing Technology,* **2007**, 184 (1), 32-41.

[14] BB Pradhan and B Bhattacharyya, Improvement in Microhole Machining Accuracy by Polarity Changing Technique for Microelectrode Discharge Machining on Ti-6Al-4V, *Proc of Institute Mechanical Engg., B J Eng Manuf*,**2008**,222(2), 163–173.

[15] SK Hoa, DK Aspinwall and W Voice, Use of Powder Metallurgy (PM) Compacted Electrodes for Electrical Discharge Surface Alloying/Modification of Ti–6Al–4V Alloy, *Journal of Materials Processing Technology*, **2007**, 191, 123–126.

[16] KL Wu, BH Yan, FY Huang and SC Chen, Improvement of Surface Finish on SKD Steel using Electro-Discharge Machining with Aluminum and Surfactant added Dielectric, *International Journal of Machine Tools & Manufacture*, **2005**, 45, 1195–1201.

[17] P Pec and E Henriques, Electrical Discharge Machining using Simple and Powder-Mixed Dielectric, *Journal of Materials Processing Technology*,**2007**, 200 (1), 250-258.

[18] V Senthilkumar and Bidwai U Omprakash, Effect of Titanium Carbide Particles Addition in the Aluminum Composite on EDM Process Parameters, *Journal of Manufacturing Processes*, **2011**, 13, 60–66.

[19] KL Wu, BH Yan, JW Lee and CG Ding, Study on the Characteristics of Electrical Discharge Machining using Dielectric with Surfactant, *Journal of Materials Processing Technology*,**2009**, 209, 3783–3789.

[20] K Ojha, RK Garg and KK Singh, Experimental Investigation and Modelling of PMEDM Process with Chromium Powder Suspended Dielectric, *International Journal of Applied Science and Engineering*, **2011**, 9 (2), 65-81.

[21] K Furutani and Y Shimizu, Experimental Analysis of Deposition Process of Lubricant Surface by EDM with Molybdenum Disulphide Powder Suspended in Working Oil, *Proceedings of the American Society for Precision Engineering*, **2003**, 30, 547–550.

[22] BH Yan, HC Tsai and FY Huang, EDM Performance of Cr/Cu based campsite Electrodes, *International Journal of Machine Tools &Manufacture*, **2005**, 45 (3),194–200.

[23] L Gu, L Li, W Zhao and KP Rajurkar, Electro Discharge Machining of Ti_6Al_4V, *International Journal of Machine Tools &Manufacture*, **2012**, 53(1), 100–106.

[24] B Jabbaripour, MH Sadeghi, MR Shabgard and H Faraji, Investigating Surface Roughness, Material Removal Rate and Corrosion Resistance in PMEDM of Titanium Aluminide Intermetalics, *Journal of Manufacturing Processes*, **2012**, 15(1), 56-68.