Asian Review of Mechanical Engineering
ISSN: 2249 - 6289 Vol. 4 No. 1, 2015, pp. 31-37

Experimental Investigation of Electro-Discharge Face Grinding of Metal Matrix Composite (Al/SiC)

Ram Singar Yadav[1], Gyan Singh[2] and Vinod Yadava[3]
[1,3]Department of Mechanical Engineering, Motilal Nehru National Institute of Technology Allahabad
Allahabad-211004, UP, India
[2]Department of Mechanical Engineering, Institute of Engineering and Rural Technology Allahabad
Allahabad-211002, UP, India
E-mail: rme1309@mnnit.ac.in, vinody@mnnit.ac.in, gyansinghiert@gmail.com

***Abstract* - Surface quality and process productivity are the challenging performance measures in grinding of difficult-to-machine materials these are measured in terms of Surface Roughness (Ra) and Material Removal Rate (MRR). Metal Matrix composites are the materials having aggregate properties of constituents like higher strength to weight ratio, toughness, stiffness and hardness. Because of having these superior properties MMCs are highly desirable in applications ranging from commercial aircraft to sports equipment but still facing challenges in machining of MMCs. Machining of MMCs by conventional machining process results poor surface finish and frequent tool failure due to presence of ceramic particles. Grinding of MMCs by conventional grinding process produces poor surface finish and low material removal rate due to frequent wheel loading. Electro-Discharge Face Grinding (EDFG) process is used on work specimen of the material Al/SiC MMC to investigate the effects of Wheel speed, Gap current, Pulse on-time and Pulse off-time on Surface Roughness (Ra) and Material Removal Rate (MRR). Surface Roughness (Ra) increases with increase in Wheel RPM, Gap current and Pulse on-time. MRR also increases with increase in Gap current and Pulse on-time while it is almost constant on increasing Wheel RPM. SEM micrograph of machined surface is taken for analysis of surface texture.**
***Keywords:*Electro-Discharge Face Grinding (EDFG) process, Al/SiC MMC, Material Removal Rate (MRR) and Surface Roughness (Ra).**

I. INTRODUCTION

Advanced engineering materials are the back bone of modern industries, which are able to meet the stringent operational as well as environmental load requirements. Such advanced engineering materials are super alloys, metal matrix composites and cemented carbides etc. and are duly inherited with the characteristics of high strength at elevated temperature, resistance to chemical degradation, wear resistance and low thermal diffusivity etc. But at the same time, processing of these materials challenges to conventional as well as non-conventional machining processes and these materials are also referred as difficult-to-machine or advanced materials. The problem associated with conventional machining of advanced materials is the frequent failure of the cutting tool, whereas with non-conventional machining is lower production rate and in few cases even not feasible. Machining of metal matrix composites (MMCs) is a great deal for modern industries to achieve better process performances like surface roughness (Ra) and material removal rate (MRR).

In Electro-Discharge Grinding process (EDG), an electrically conductive wheel is used as a tool electrode by replacing stationary tool electrode used in EDM. There is image contact with workpiece and rotating tool electrode. Due to the rotational motion of wheel electrode, the speed of wheel transmitted to the stationary dielectric between wheel electrode and workpiece which results improved flushing efficiency during the process. Therefore, the molten material and debris formed by molten material is effectively taken away from inter electrode gap and the debris accumulation is eliminated. During EDM process debris accumulation is major problem in achieving better surface finish and reduced solidified layers [1]. K. M. Shu and G. C. Tu [2] observed that due to the enhancement in flushing, higher material removal and better surface finish is obtained as compare to the stationary EDM process. At the same machining condition, Electro-Discharge Grinding (EDG) performance better than EDM and it is capable to machine extremely hard materials 2-3 times faster than the conventional grinding [3]. The very high speed of wheel is not always suitable and when it exceeds certain value of speed, the spark becomes unstable and results reduced process efficiency [4]. There is no direct contact between workpiece and wheel electrode therefore the process becomes more beneficial for machining thin, fragile, extremely hard and brittle electrically conductive materials [3, 4]. It is also reported that due to the high flushing efficiency, the molten materials flush away in the form of micro debris from inter electrode gap and formed the crater on work surface [5].

Sato et al. [6] have reported that rotation tool electrode served as an effective flushing technique resulting better material removal. The edge quality of various grades of polycrystalline diamond cutting tool blanks after EDG on either the face or periphery of a rotating graphite wheel electrode has been investigated by Thoe et al. [7] and found that the fine grain blank has higher MRR, grinding ratio and lower roughness of surface than that of the coarse grain.

Soni and Chakraverti [8] have developed the orbital motion of the electrode and found that orbital motion of the electrode improves the performance and increases the MRR with rotation of electrode due to improved flushing action and sparking efficiency, but the surface roughness is found quit increased. Guu and Hocheng [9] have proven that rotating workpiece gives twice more MRR than the conventional EDM but this process is most suitable for axial-symmetrical die and mold work. Koshy et al. [10] have also proven experimentally that MRR, TWR, relative electrode wear, corner reproduction accuracy and surface finish aspects of a rotary electrode are better than that of stationary electrode. Chow et al. [11] have modified the EDG process by placing the rotating electrode below workpiece and have claimed that due to gravitational force debris removal rate was significantly improved resulting higher MRR with better finish. Fujun et al. [12] have introduced the new shaping principle of machining these non-sphere materials. They have suggested that the angle speed of workpiece and tool electrode should not be too high otherwise working fluid cannot enter into inter electrode gap under centrifugal effect of rotating wheel.

Machining of metal matrix composites (MMCs) are very difficult due to abrasive in nature which leads to the rapid tool wear [13, 14]. But the MMCs are effectively machined with EDG because the performances of EDG is not affected by mechanical or physical properties of materials. Yan and Wang [15] have studied the machining characteristics of Al_2O_3/6061Al composite using with copper tube electrode and they have found that current and volume fraction of Al_2O_3 have significant effects on the performances but the flushing pressure and electrode rotational speed have minor effect on performance parameters. Wang and Yan [16] have reported that the electrical parameters are having more significant effect on performances than the non-electrical parameters. Mohan et al. [17] have experimented and investigated the effects of electrode material, electrode rotation, volume percentage of SiCp. They compared the performances of brass and copper electrode reported that the brass electrode gives higher MRR than copper electrode with positive polarity electrode. They also claimed that the higher percentage volume of SiCp means lower value of MRR with good surface finish.

Therefore, from above literature review it is concluded that there no work done on parametric study of Electro-Discharge Face Grinding on Al/SiC however few work has been done on MMCs by Electro-Discharge Drilling operation.

In this paper, The authors have made an attempt for parametric study of Electro-Discharge Face Grinding on Al/SiC. Al is reinforced by 10% SiC particulates with size 600 mesh number. The experiments were conducted to investigate the effects of wheel RPM, gap current, pulse on time and pulse off-time on material removal rate (MRR) and average surface roughness (Ra).

II. DEVELOPMENT OF EXPERIMENTAL SETUP AND EXPERIMENTATIONS

A. Development of EDFG Attachment

The EDFG attachment has been designed and fabricated with consideration of all fundamental mechanism of the EDFG process and basic functional requirements. The designed attachment has been fitted on the ram of Sinker EDM machine (ZNC 320 Ecoline) by replacing actual tool holder of die-sinking EDM. The attachment consists of perpendicularly mounted at one side of Al-alloy base plate of thickness 12 mm, electrical permanent magnet direct current (PMDC) motor of 0.25 hp Rotomag (India) make with 1500 rpm, electrically conductive rotating spindle cum wheel electrode holder mechanism, mounted on the horizontal Al-alloy plate.

The housing assembly of rotating spindle has one side pulley and another side for holding of wheel electrode. The spindle housing is mounted on lower side of horizontal plate. The driven pulley is mounted on the top of the spindle. The rotary motion transmitted from electrical motor to spindle through driver pulley mounted on shaft of the motor and driven pulley by V-belt and pulley arrangement with trapezoidal cross-section.

TABLE I SPECIFICATIONS OF DIFFERENT PARTS

S. No.	Name of parts	Specification
1	PMDC Motor	0.25hp, 1500 RPM
2	Variac	0.5 hp DC drive
3	V-belt	M 6x500
4	Diameter of driving & driven pulleys	60 mm
5	Bearing housing	Outer diameter 50 mm and inner diameter 45 mm, mild steel
6	Bearing	Antifriction ball bearing
7	Shaft	13 mm diameter, mild steel
8	Thickness of Al-alloy base plate	12 mm

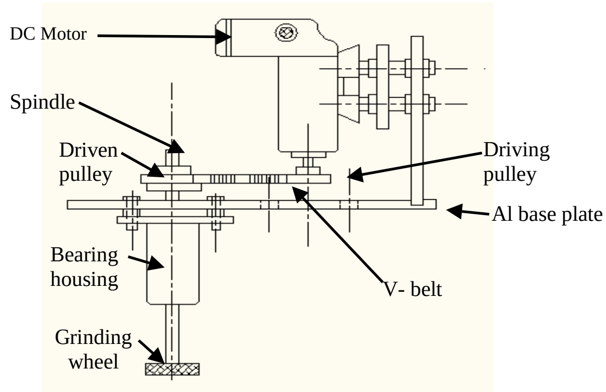

Fig. 1 Schematic diagram of EDFG attachment

The rotating spindle is supported on four antifriction ball bearings in housing, so that axial thrust load is taken care of and to avoid the axial movement of rotating spindle. The selection of these four antifriction ball bearings is done based on the expected load, motor power, motor RPM and endurance run. The tension is provided in V-belt to avoid slippage. The motor is mounted on vertical Al-alloy plate fitted on horizontal Al-alloy base plate.

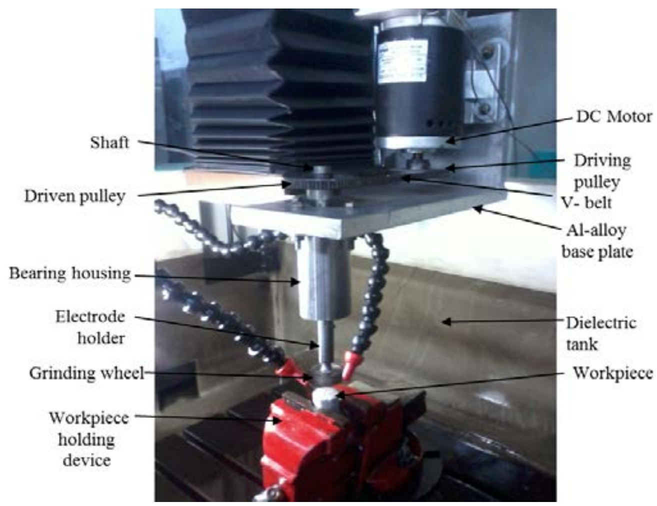

Fig. 2 EDFG attachment fitted on EDM

B.Experimentations

The EDFG process is performed on the work specimens in reverse polarity on Smart ZNC EDM machine. During EDFG process, rotating wheel electrode of material copper moves downwards under servo control mechanism and maintains inter electrode gap (IEG). IEG depends upon breakdown strength of dielectric fluid. Both wheel electrode and workpiece are submerged in dielectric fluid. The variac was connected in-line with PMDC motor used to control wheel electrode RPM. Workpeice specimens were held in vice and leveled horizontal with help of spirit level. After an exhaustive screening experimentation input process parameter ranges are determined. The input process parameters are gap current, pulse on-time, pulse off-time and wheel RPM. On the basis of pilot experimentation it was decided to conduct the experiments in reverse polarity with constant pulse off time of 30 µs. The variation in Ra and MRR were investigated by varying one input process parameter at a time and keeping other parameters constant. The Ra value was measured using a Surface Roughness Tester with accuracy of 0.01µm (SURTRONIC-25 model, Taylor Hobson Ltd.) and for evaluation of MRR, the loss in weight of the machined specimen was measured on a weighing digital microbalance (accuracy 10 µg, CAS India Private Limited).

III. RESULT AND DISCUSSION

Influences of wheel RPM, gap current and pulse on-time and pulse off-time on the material removal rate (MRR) and average surface roughness (Ra) are investigated.

A. *Effect of wheel RPM*

The effect of wheel RPM on MRR is shown in fig. 3, for different values of gap current keeping constant pulse on-time at 40 µs and pulse off-time at 30 µs. MRR is almost constant on varying wheel RPM at different values of gap current within specified range because of increase in wheel RPM sparking become unstable which nullify the advantage of effective flushing therefore increase in MRR is insignificant.

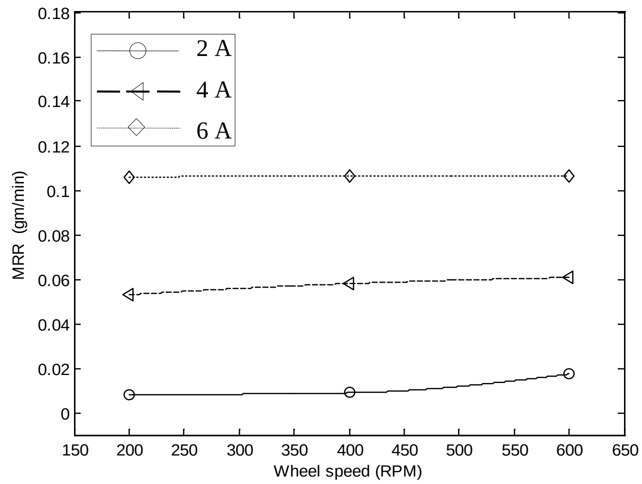

Fig. 3 Effect of wheel RPM on MRR at different gap current, pulse on-time 70 µs and pulse off-time 30 µs

The effect of wheel RPM on surface roughness as shown in fig. 4, surface roughness increases on increasing wheel RPM at different values of gap current within specified range while keeping constant pulse on-time at 20 µs and off-time at 30 µs. Surface roughness increases as a result of effective flushing in inter electrode gap (IEG) and uneven sparking due to unstable sparks at higher wheel RPM.

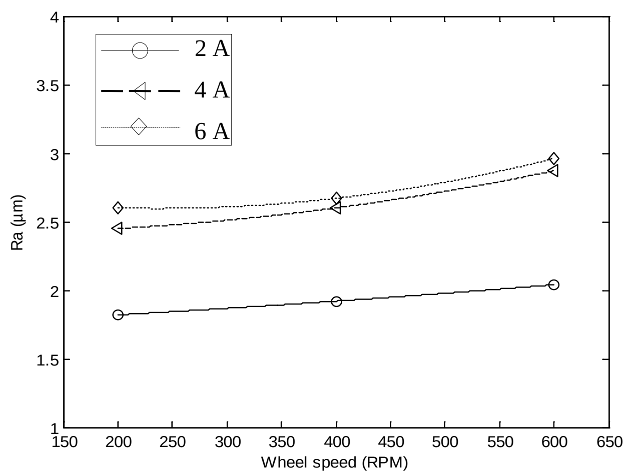

Fig. 4 Effect of wheel RPM on Ra at different gap current, pulse on-time 20 µs and off-time 30 µs

B. *Effect of Gap Current*

The effect of gap current on MRR as shown in fig. 5, MRR increases on increasing gap current at different values pulse on-time within specified range while keeping constant wheel RPM at 600 and pulse off-time 30 µs. MRR increases due to increase in gap current subsequently increase in spark energy causes more and more melting and evaporation of work material. While at low value of gap current MMR slightly more than that of at higher pulse on-time as result of low spark intensity.

The effect of gap current on surface roughness as shown in fig. 6, surface roughness increases with increase in gap current at different pulse on-time within specified range while keeping constant wheel RPM 200 and pulse off-time at 30 µs. Surface roughness increases due to increase in gap current subsequently increased spark energy results more melting of work material causes larger crater size therefore surface roughness increased.

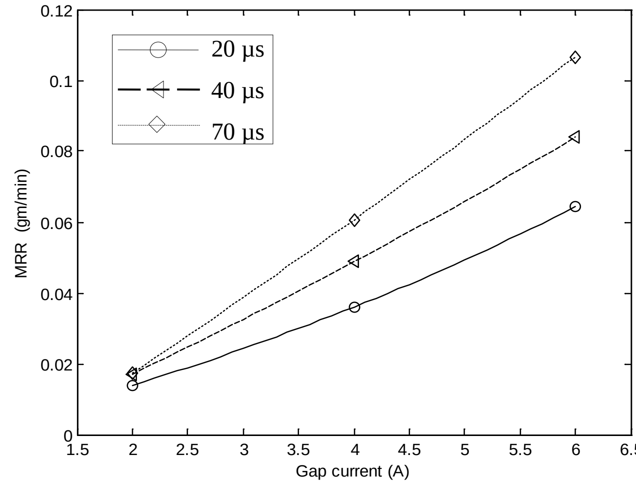

Fig. 5 Effect of gap current on MRR at different pulse on-time, wheel RPM 600 and off-time 30 µs

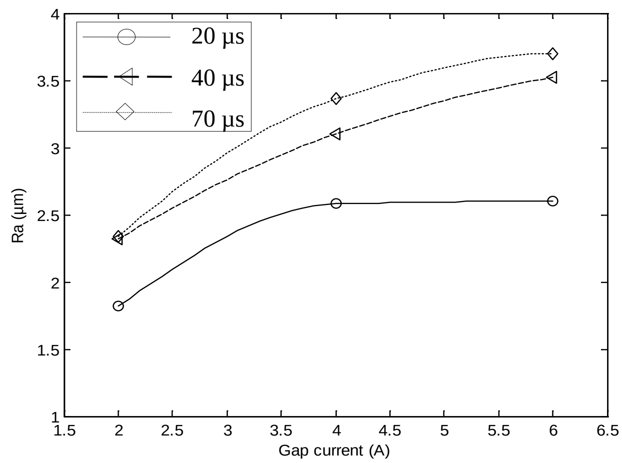

Fig. 6 Effect of gap current on Ra at different pulse on-time, wheel RPM 200 and off-time 30 µs

C. Effect of Pulse on-time

The effect of pulse on-time on MRR as shown in fig. 7, MRR increases on increasing pulse on-time at different wheel RPM within specified range while other parameters keeping constant, gap current at 6 A and pulse off-time 30 µs. MRR increases due to increase in pulse on-time subsequently increase in time of heat addition in each spark causes more and more heat addition for material removal.

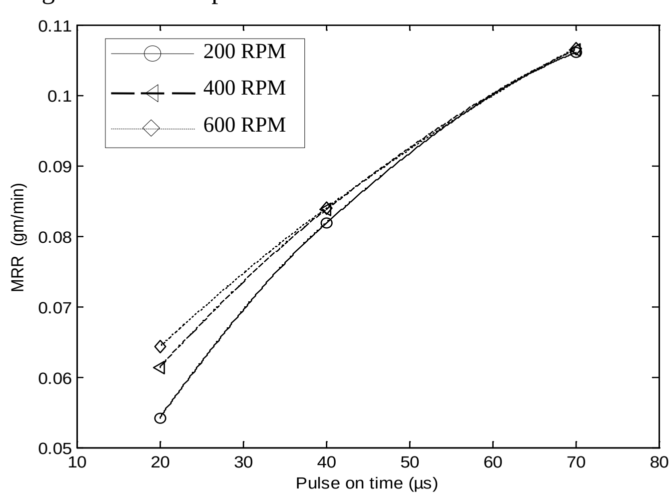

Fig. 7 Effect of pulse on-time on MRR at different wheel RPM, gap current 6 A and off-time 30 µs

The effect of pulse on-time on surface roughness as shown in fig. 8, surface roughness increases with increase in pulse on-time at different wheel RPM within specified range and keeping other parameters constant as gap current 2A and pulse off-time 30 µs. At the low gap current (2A), Ra increases due to increase in pulse on-time which result more and more heat addition in each spark and subsequently increased surface roughness as a result of larger crater size due to increased melting and evaporation of work material. But further increase in pulse on-time surface roughness become almost constant due to presence of recast layers on machined surface as a result large heat addition in each spark.

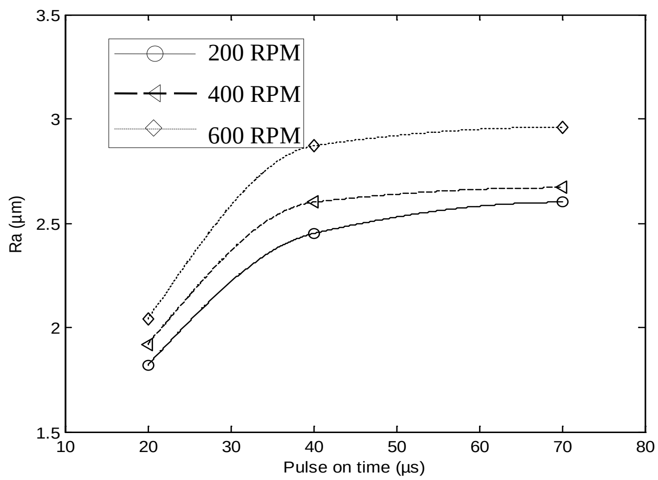

Fig. 8 Effect of pulse on-time on Ra at different wheel RPM, gap current 2 A and off-time 30 µs

IV. Analysis of SEM Micrograph

Irregular surface texture is seen in micrograph taken as shown in fig. 9 (a) before machining. Irregular surface texture which is rectified upto some extent after machining as shown in fig. 9 (b) but presence of recast layers on machined surface as a result of higher pulse on-time and presence the small scratches on machined surface due to rubbing action of dislodged SiC particles from work surface during machining in IEG.

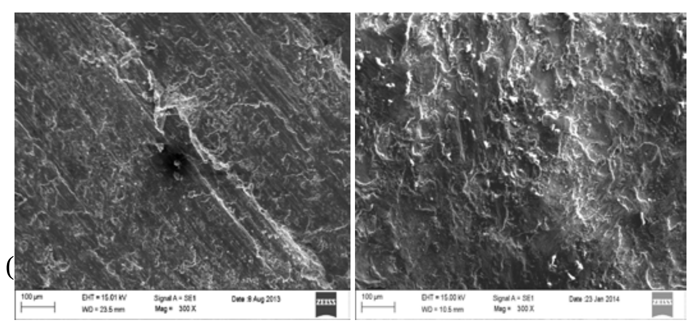

Fig. 9 Micrographs (a) before machining (b) after machining

V. Conclusions

1. The developed setup with rotating wheel electrode has proved to be an improved technique to achieve better process performance parameters like MRR and average surface roughness (Ra).
2. MRR increases with increase in gap current and pulse on-time within specified range while almost constant on variation of wheel RPM within specified range.
3. Average surface roughness increases with increase in wheel RPM and gap current within specified range while on increasing pulse on-time at lower gap current at first it increases then become almost constant.
4. In EDFG, rotation of wheel electrode provides effective flushing than the stationary tool electrode but sparks become unstable and dies out the weak sparks at very high wheel RPM causes poor surface finish.
5. Effect of wheel RPM on MRR is less significant than gap current and pulse on-time while it has significant effect on surface roughness.
6. Irregular surface texture is rectified upto some extent during EDFG process but presence of recast layers on machined surface as a result of higher pulse on-time.
7. Presence the small scratches on machined surface due to rubbing action of dislodged SiC particles from work surface in between electrodes during EDFG process.

ACKNOWLEDGMENT

Authors would like to thank the Aeronautics R & D Board, Government of India, New Delhi for using the facility and financial support for this work of the project entitled "Electro-Discharge Diamond Grinding: Development and Optimization" [Project No.: DARO/08/2031574/M/I].

REFERENCES

[1] K. P. Rajurkar and S. M. Pandit, "Formation and ejection of EDM debris," Transaction of ASME-Journal of Engineering for Industry, vol. 108, pp. 22-26, 1986.

[2] K. M. Shu and G. C. Tu, "Study of electrical discharge grinding using metal matrix composite electrodes," International Journal of Machine Tools and Manufacture, vol. 43, pp. 845-854, 2003.

[3] V. K. Jain, "Advanced Machining Processes," Allied Publisher, New Delhi, 2005.

[4] H. E. Hofy, "Advanced Machining Processes: Nontraditional and Hybrid Machining Processes," McGraw-Hill Companies, New Delhi, 2005.

[5] K. H. Ho, S. T. Newman, "State of the art electrical discharge machining (EDM)," International Journal of Machine Tools and Manufactures, vol. 43, pp. 1287-1300, 2003.

[6] T. Sato, T. Mizutani, K. Yonemouchi and K. Kawata, "The development of an electro discharge machine for micro hole boring," Precision Engineering, vol. 8, pp. 163-168, 1986.

[7] T. B. Thoe, D.K. Aspinwall, M.L.H. Wise and I.A. Oxley, "Polycrystalline diamond edge quality and surface integrity of electrical discharge grinding," Journal of Materials Processing Technology, vol. 56, pp. 773-785, 1996.

[8] J. S. Soni and G. Chakraverti, "Machining characteristics of titanium with rotary electro-discharge machining," Wear, vol. 171, pp. 51-58, 1994.

[9] Y. H Guu and H. Hocheng, "Effects of workpiece rotation on machinability during electrical discharge machining," Materials and Manufacturing Processes, vol. 16, pp. 91-101, 2001.

[10] P. Koshy, V.K. Jain and G.K. Lal, "Experimental investigations into electrical discharge machining with a rotating disk electrode," Precision Engineering, vol. 15, pp. 6-15, 1993.

[11] H. M. Chow, B. H. Yan and F. Y. Huang, "Micro slit machining using electro-discharge machining with a modified rotary disk electrode (RDE)," Journal of Materials Processing Technology, vol. 91, pp. 161-166, 1999.

[12] R. Fujun, H. Dechen and W. Dianjun, "Analysis of motion laws of machining non-sphere by EDM with rotary electrode," Journal of Materials Processing Technology, vol. 149, pp. 323-327, 2004.

[13] N. P. Hung, I. J. Yang and K.W. Leong, "Electrical discharge machining of cast metal matrix composites," Journal of Material Processing Technology, vol. 44, pp. 229-236, 1994.

[14] M. Ramulu, P.N. Rao and H. Kao, "Drilling of (Al2O3)p/6061 metal matrix composites," Journal of Material Processing Technology, vol. 124, pp. 244-154, 2002.

[15] B.H. Yan and C.C. Wang, The machining characteristics of Al/6061 metal matrix composites, Journal of Material Processing Technology, 124:244-154, 2002.

[16] C.C. Wang and B.H. Yan, Blind-hole drilling of Al_2O_3/6061Al composite using rotary electro-discharge machining, Journal of Materials Processing Technology, 102:90-102, 2000.

[17] B. Mohan, A. Rajadurai and K.G. Satynarayana, Effect of SiC and rotation of electrode on electric discharge machining of Al-SiC composite, Journal of Material Processing Technology, 124:297-304, 2002.