Effects of Electrical Parameters during Nonconventional Machining of Al/SiC Metal Matrix Composites by Electrical Discharge Machine

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ABSTRACT- *Particulate Reinforced Al/SiC Metal Matrix Composites (PRALSICMMC) is gradually becoming very important materials in manufacturing industries e.g. aerospace, automotive and automobile industries due to their superior properties such as light weight, low density, high strength to weight ratio, high hardness, high temperature and thermal shock resistance, superior wear and corrosive resistance, high specific modulus, high fatigue strength etc. In this study aluminium (Al-6063)/SiC Silicon carbide reinforced particles metal-matrix composites (MMCs) are fabricated by melt-stirring technique. The MMCs bars and circular plates are prepared with varying the reinforced particles of SiC by weight fraction ranging from 5%, 10%, 15% and 20%. The average reinforced particles sizes of SiC are 220 mesh, 300 mesh and 400 mesh respectively. The stirring process is carried out at 150 rev/min rotating speed by graphite impeller for 15 min. The series of machining tests are performed on EDM. Copper electrodes are used as tool (cathode), Prepared specimens of Al/SiC MMCs are used as work piece (anode) and kerosene is used as the dielectric fluid. The Performance parameters measured during experimentation were Tool Wear Rate (g/min), Metal Removal Rate (g/min), Over Cut on diameter (mm) and Average Surface Roughness Ra (μm) for each experiment by varying Pulse Peak Current I_P (2 Amp, 6 Amp, 10 Amp,14 Amp) and gap voltage Vg (25 Volts, 30 Volts, 35 Volts and 40 Volts). The investigations of results are done graphically.*

KEYWORDS: Particulate Reinforced Al/SiC Metal Matrix Composites (PRALSICMMC), Silicon Carbide (SiC), Stirring Technique for Melt, Tool Wear Rate(TWR) and Metal Removal Rate(MRR). Pulse Peak Current (I_P), Gap voltage (Vg).

1. INTRODUCTION

Metal Matrix Composites (MMC's) have very light weight, high strength, and stiffness and exhibit greater resistance to corrosion, oxidation and wear. Fatigue resistance is an especially important property of Al-MMC, which is essential for automotive application. These properties are not achievable with lightweight monolithic titanium, magnesium, and aluminium alloys. Particulate metal matrix composites have nearly isotropic properties when compared to long fibre reinforced composite. Metal Matrix Composite (MMC) is engineered combination of metal (Matrix) and hard particles (Reinforcement) to tailored properties. Stir casting is accepted as a particularly promising route, currently can be practiced commercially. Its advantages lie in its simplicity, flexibility and applicability to large quantity production. It is also attractive because, in principle, it allows a conventional metal processing route to be used, and hence minimizes the final cost of the product. This liquid metallurgy technique is the most economical of all the available routes for metal matrix composite production and allows very large sized components to be fabricated [1]. The cost of preparing composites material using a casting method is about one-third to half that of competitive methods, and for high volume production, it is projected that the cost will fall to one-tenth [2]. Among the non-conventional methods, EDM is most widely and successfully applied process in machining of hard metals or those that would be very difficult to machine with traditional techniques. The material is removed from the work piece by the thermal erosion process, i.e., by a series of recurring electrical discharges between a cutting tool acting as an electrode and a conductive workpiece in the presence of a dielectric fluid. This discharge occurs in a voltage gap between the electrode and work piece. Heat from the discharge vaporizes minute particles of work piece material, which are then washed from the gap by the continuously flushing dielectric fluid [3]. The effectiveness of the EDM process with tungsten carbide is evaluated in terms of material removal rate, the relative wear ratio and the surface quality. the composite electrodes obtained a higher MRR than Cu metal electrodes; the recast layer was thinner and fewer cracks were present on the machined surface [4]. The regression models [5] and Taguchi methods [6] are used for modeling and analyzing the influence of process Variables computer simulation of EDM machining with the side and face of the electrodes is developed [7, 10].

The test results showed the electric discharge machining of WC-Co confirms the capability of the system of predictive controller model based on neural network with 32.8% efficiency increasing in stock removal rate [8].

In this study aluminium (Al-6063)/SiC Silicon carbide reinforced particles metal-matrix composites (MMCs) are fabricated by melt-stirring technique. The MMCs bars and circular plates are prepared with varying the reinforced particles of SiC by weight fraction ranging from 5%, 10%, 15% and 20%. The average reinforced particles sizes of SiC are 220 mesh, 300 mesh and 400 mesh respectively. The stirring process is carried out at 150 rev/min rotating speed by graphite impeller for 15 min. The series of machining tests are performed on EDM. Prepared specimens of Al/SiC MMCs are used as work piece (anode), copper electrodes are used as tool (cathode) and kerosene is used as the dielectric fluid. The parameters are The Performance parameters investigated during experimentation were Tool Wear Rate (g/min), Metal Removal Rate (g/min), Over Cut on diameter (mm) and Average Surface Roughness Ra (μm) for each experiment by varying Pulse Peak Current I_P (2 Amp, 6 Amp, 10 Amp,14 Amp) and gap voltage Vg (25 Volts, 30 Volts, 35 Volts and 40 Volts).

2. EXPERIMENTATION

2.1 Fabrication of Al/SiC metal matrix composites as workpiece

Silicon Carbide (SiC) reinforced particles of average particle size 220 mesh, 300 mesh, 400 mesh respectively are used for casting of Al-MMC,s by melt-stir technique. Table (i) represents the chemical composition of commercially available Al-matrix used for manufacturing of MMC. Different dimensions of round bars with 5 vol%, 10 vol%,15 vol% and 20% of reinforced particles of sizes 220 mesh, 300 mesh, 400 mesh respectively .

Table (i) Chemical composition of matrix Al 6063 alloy.

Elements of Al 6063	Si	Mn	Mg	Cu	Fe	Ti	Al
%	0.44	0.07	0.6	0.018	0.2	0.008	98.664

Experiments are carried out on commercially available aluminium (Al6063) as matrix and reinforced with Silicon Carbide (SiC) particulates. The melting was carried out in a clay-graphite crucible placed inside the resistance furnace. An induction resistance furnace with temperature regulator cum indicator is utilized for melting of Al/SiC-MMCs.

Fig. 2.1(a) Designed and developed stirring setup

Fig.2.1 (b) Pouring mixture of molten Al and SiC particles

"Fig. 2.1(a)" shows designed and developed stirring setup of induction resistance furnace along with temperature regulator cum indicator. Aluminium alloy (Al 6063) was first preheated at 450^{0}C for 2 hr before melting and SiC particulates were preheated at 1100^{0}C for 1 hr 30 min to improve the wetting properties by removing the absorbed hydroxide and other gases. The furnace temperature was first raised above the liquidus temperature, cooled down to just below the liquidus temperature to keep the slurry in a semi-solid state. At this stage the preheated SiC particles were added and mixed mechanically. The composite slurry was then reheated to a fully liquid state and mechanical mixing was carried out for 20 min at 150 rpm average stirring speed.

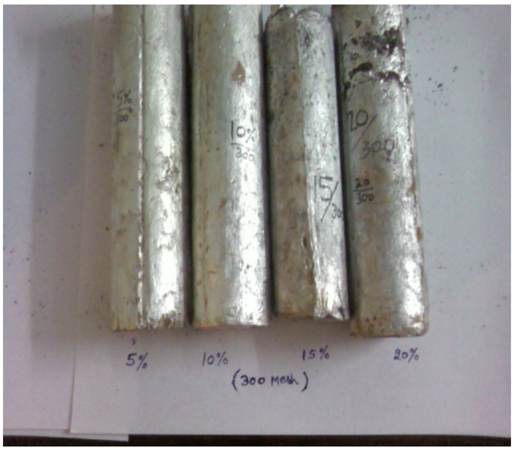


Fig.2.1 (c) Prepared workpiece of Al/SiC-MMCs

In the final stage of mixing, the furnace temperature was controlled within 760 ± 10^0C and the temperature was controlled at 740^0C. Moulds (size 40mm diameter ×170 mm long) made of IS-1079/3.15mm thick steel sheet were preheated to 350^0C for 2 h before pouring the molten Al/SiC -MMC. the permanent mould was prepared of steel sheet utilized for casting of 40mm diameter ×170mm long bar . Fig. 2.1 (b) shows pouring mixture of molten Al and SiC particles and Fig. 2.1 (c) shows prepared workpiece of Al/SiC-MMCs of 300 mesh. Then fabrication of composite was followed by gravity casting. Similar process was adapted for preparing the specimens of varying mesh sizes and weight fractions. The uniform size (dia. 35 mm and thickness is 6 mm) of workpiece was given by lathe machine.

2.2 Fabrication of electrodes

Copper electrodes with diameter of 4.4 mm and length 70 mm were used in this experiment and their physical properties are given in table (ii).

Table (ii) Physical properties of Copper electrodes

Electrical resistivity(μΩ/cm)	1.96
Electrical conductivity compared with silver (%)	92
Thermal conductivity (W/mK)	268-389
Melting point (°C)	1083
Specific heat (cal/g °C)	0.092
Coefficient of thermal expansion($X10^{-6}$°C^{-1})	6.6
Specific gravity at 20°C(g/cm^3)	8.9

2.3 Experimental techniques

The work piece (Al/SiC –MMC) and the electrode (copper diameter 4.4mm) are mounted on an EDM machine (EMS 5030 + generator of PSR 35).

Fig.2.2 Machined number of holes by EDM

A number of holes were machined shown in “fig 2.2” where the diameter of the holes was the same as the diameter of the electrodes used. Material removal rate of the work piece material and the wear rate of the electrode were obtained based on the calculation of percentage of mass loss per machining time (wt.%/min). The work pieces and electrodes after machining have thoroughly cleaned with acetone to remove the carbon deposition, and the weight measurements were taken on electronic weighing machine, which has a resolution of 0.0001 grams. Each experiment was repeated three times and the averaged for MRR (grams/min), TWR (grams/min) and Time taken.

The MRR and TWR is defined as

$$MRR = \frac{\text{Difference in weight of workpiece before and after machining}}{\text{Time of machining}}$$

$$TWR = \frac{\text{Difference in weight of electrode before and after machining}}{\text{Time of machining}}$$

The design of experiments technique has been implemented to conduct the experiments. It is a powerful work tool which allows us to model and analyse the influence of designed variant parameters and designed constant parameters over the measured parameters. These measured parameters were unknown functions of the former designed parameters. The following designed experimental settings were done-

(1) Variant parameter was Pulse Peak Current I_P (2 Amp, 6 Amp, 10 Amp,14 Amp) and Constant parameters were Mesh size of Sic= 300, Wt. % of Sic= 15%, T_{on} =70 µ sec, T_{off}= 7 µ sec, V_g =35 Volts. Machining was done and parameters were Measured Time Taken (min.), Tool Wear Rate (gm/min) and Metal Removal Rate (gm/min). The investigations of results are done graphically.

(2) Variant parameter was Gap voltage V_g (25 Volts, 30 Volts, 35 Volts and 40 Volts) and Constant parameters were Mesh size of Sic= 300, Wt. % of Sic= 15%, I_p =10amp, T_{on} =70 µ sec, T_{off}= 7 µ sec. Machining was done and parameters were Measured Time Taken (min.), Tool Wear Rate (gm/min) and Metal Removal Rate (gm/min). The investigations of results are done graphically.

3 RESULTS AND DISCUSION

3.1 Results and Graphs

All the experimental results are presented on graphs [from "fig.3.1 to 3.8"] as shown hereunder. In these graphs all measured parameters Tool Wear Rate (gm/min) and Metal Removal Rate (gm/min), Over cut (mm) and Surface roughness (µm)are taken on vertical axes, variant parameters Pulse Peak Current I_P (2 Amp, 6 Amp, 10 Amp,14 Amp) and gap voltage Vg (25 Volts, 30 Volts, 35 Volts and 40 Volts) are on horizontal axes and constant parameters are shown in box.

3.1.1 Effect of Pulse Peak Current on Performance Measures

The pulse peak current (I_P) was varied from 2 Amp to 14 Amp with the increment of 4 Amp. The Al/15 wt. % of SiC 300 mesh MMC as a workpiece material and copper electrodes were chosen for the experimentation. The values of pulse on time (T_{on}), pulse off time (T_{off}) and Gap voltage (V_g) were selected as 70 µ sec, 7 µ sec and 35 Volts respectively on machine control unit. Three holes were machined for each setting of pulse peak current values and performance parameters were measured as Tool Wear Rate, Metal Removal Rate,Over Cut on diameter and Average Surface Roughness. The calculated average values of three experiments for each performance parameters are given in table (iii)

Table. (iii) Effect of Pulse Peak Current on Performance Measures

Pulse Peak Current, I_P (Amp)	Tool Wear Rate (10^{-3}g/min)	Metal Removal Rate (10^{-3}g/min)	Over cut (mm)	Average Surface Roughness, R_a (µm)
2 Amp	2	23.4	0.123	4.445
6 Amp	2.19	35.8	0.153	4.564
10 Amp	2.22	45.8	0.21	4.586
14 Amp	2.45	68.2	0.29	4.626

The Figs 3.1 to 3.4 represent graphical investigation of results. It is observed that with the increase of pulse peak current (2 Amp, 6 Amp, 10 Amp and 14 Amp); Tool Wear Rate, Metal Removal Rate, Over cut and Average Surface Roughness R_a increases. Higher the current meant higher the energy dissipation at the sparking area hence less time was taken to machine the same size hole. Although MRR was increasing by increasing the current beyond 14 Amp but other machining performances were going in adverse direction. The MRR was very less at lower value of I_P. So the range of pulse peak current was selected as 6 Amp, 10 Amp and 14 Amp.

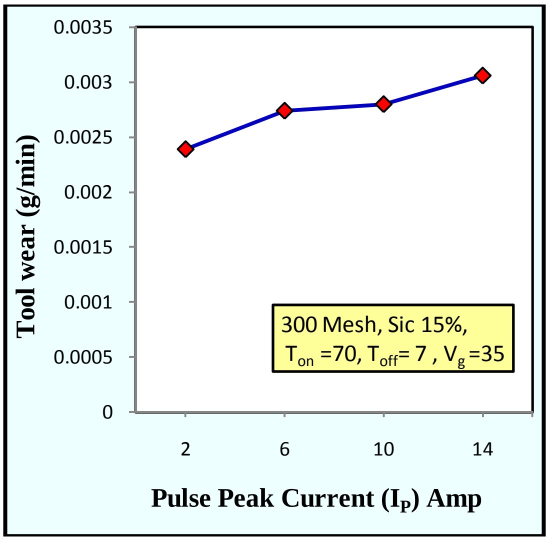


Fig. 3.1 Tool wear Vs Pulse Peak Current

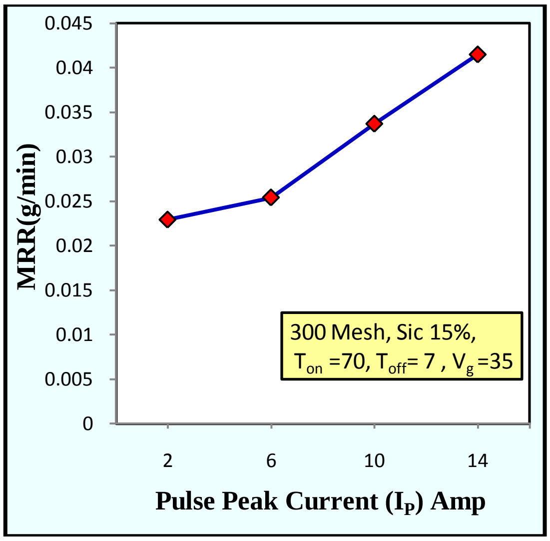


Fig. 3.2 MRR Vs Pulse Peak Current

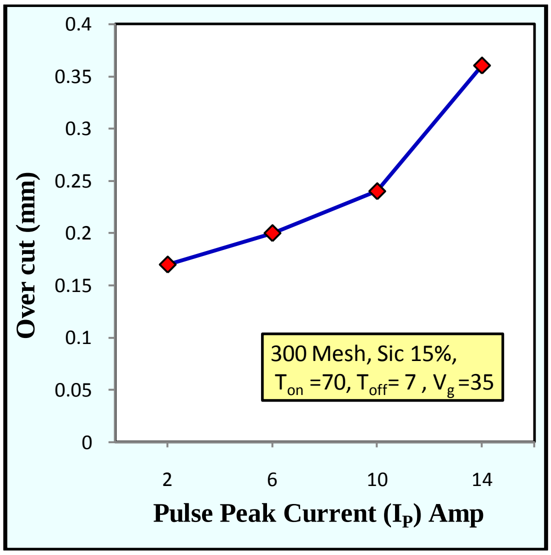


Fig. 3.3 Over cut Vs Pulse Peak Current

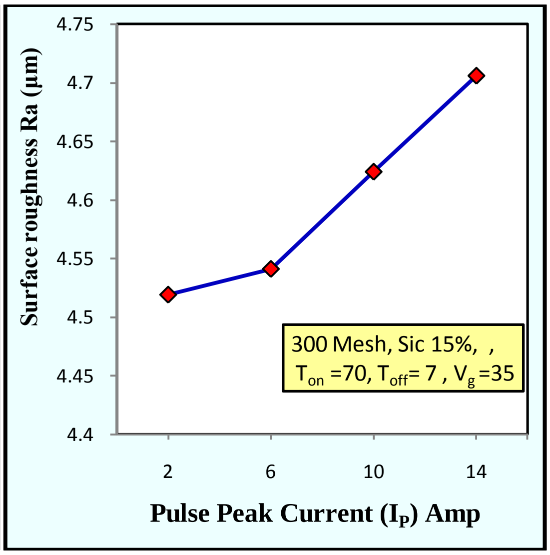


Fig. 3.4 Surface roughness Vs Pulse Peak Current

3.1.2 Effect of Gap Voltage on Performance Measures

The preliminary experiments were performed on EDM by varying the Gap voltage V_g from25 Volts to 40 Volts with the increment of 5 volts. The workpiece of size 35 mm diameter and 6 mm thick made of Al/15 wt. % of SiC 300 mesh MMC and copper electrodes were used for machining operation on EDM. The values of Pulse Peak Current, Pulse on time and Pulse off time were selected as 10 amp, 70 µ sec and 7 µ sec respectively. For each setting Machining was done three times with different gap voltage. Performance parameters measured were as Tool Wear Rate (g/min), Metal Removal Rate (g/min),Over cut on diameter (mm) and Average Surface Roughness R_a (µm). Calculated average values of machining performance parameters are shown in table. (iv)

Table . (iv) Effect of Gap voltage V_g on Performance Measures

Gap voltage, V_g (Volts)	Tool Wear Rate (10^{-3}g/min)	Metal Removal Rate (10^{-3}g/min)	Over cut (mm)	Average Surface Roughness, R_a (µm)
25 Volts	2.02	22.4	0.13	4.345
30 Volts	2.18	34.8	0.16	4.461
35 Volts	2.25	45.9	0.21	4.506
40 Volts	2.44	58.2	0.30	4.546

To explore the effects of gap voltage on performance parameters, the results were presented graphically as shown in Figs 3.5 to 3.8 respectively. With the increase of Gap voltage, Tool Wear Rate (g/min) increases with slow rate, Metal Removal Rate (g/min) increases with fast rate.

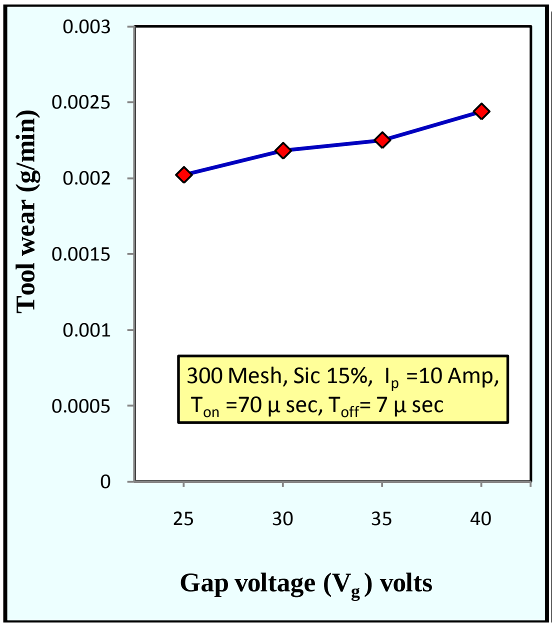


Fig. 3.5 Tool wear Vs Gap voltage

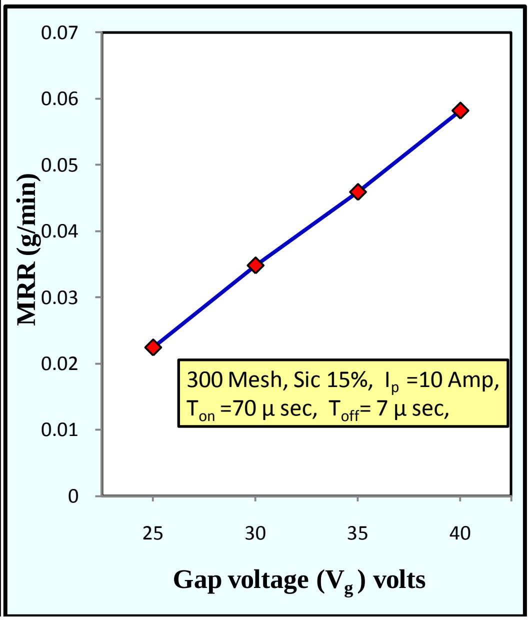
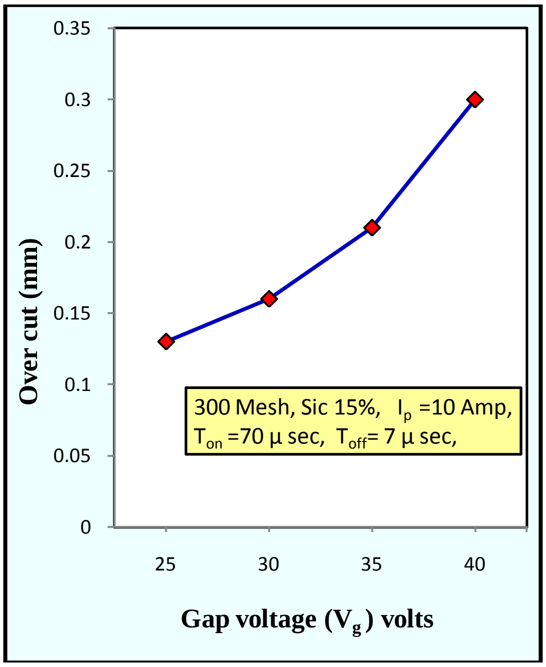


Fig. 3.6 MRR Vs Gap voltage



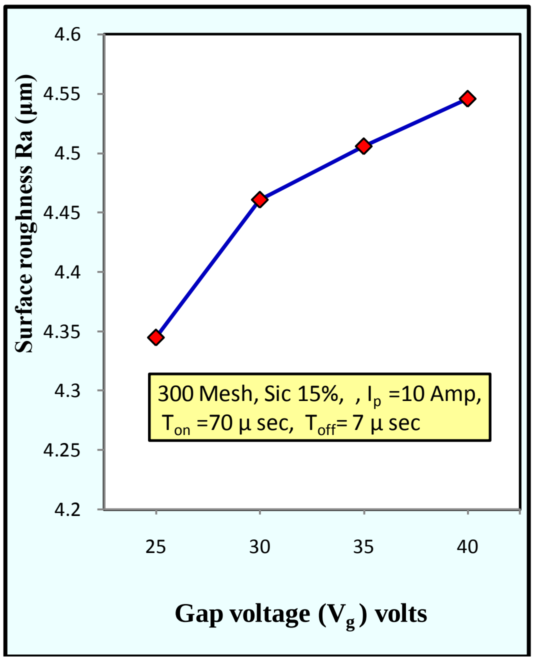


Fig. 3.7 Over cut Vs Gap voltage

Fig. 3.8 Surface roughness Vs Gap voltage

Over cut (mm) and Average Surface Roughness R_a (µm) increases with moderate rate. Higher the gap voltage, higher the energy dissipated due to development of a strong electrostatic field between the electrodes. The dielectric medium break down at higher gap voltage and millions of electrons were developed in each spark. Because of higher energy sparks larger over cuts and larger chips were produced. Higher gap voltage was best suited for larger metal removal rate but played adverse role for tool wear rate, over cut and surface roughness. Although MRR was increasing by increasing the gap voltage beyond 40 volts but other machining performances were going in adverse direction. The MRR was very less at lower value of gap voltage. So the range of gap voltage was selected as 30 Volts, 35 Volts and 40 Volts.

4. CONCLUSION

- Performance parameters were increasing with the rising of pulse peak current. Maximum over cut was achieved at 14 Amp pulse peak current value during machining by EDM.
- The gap voltage is affecting all performance parameters (TWR, MRR, Over cut and Surface Roughness). Performance parameters were increasing with the increase in gap voltage.

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