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Performance of P/M Cu/SiC$_p$ metal matrix tool electrode in Electrical Discharge Surface Grinding (EDSG) of AISI D2 Die steel

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Abstract In this experimental study metal matrix composite tool electrodes are fabricated by powder metallurgy route for electrical discharge surface grinding process. A rotary spindle attachment was fabricated and mounted on EDM machine to develop EDSG set up. Investigation related to performance measures namely metal removal rate, electrode wear rate and surface roughness was carried out by selecting the input parameters like peak current, gap voltage, on time, off time, speed, abrasive particle size and abrasive particle concentration. The experimental study indicated that material removal rate and electrode wear rate increases with increase in gap current and rotational speed of the tool electrode. The effect of current and speed during the hybrid process is participative and hence contributes to increased material removal rate and electrode wear rate. Surface roughness increases with increase in gap current and decreases with increase in rotational speed of the tool electrode. The role of abrasives in composite tool electrode was observed to be more pronounced at higher rotational speeds during the process.

Keywords Electroless copper plating, metal matrix composite, abrasives, particulates, Electrical Discharge Surface Grinding

Introduction

Hybrid machining is one of the latest developments in the area of enhancement of the process capability of advanced machining processes. In hybrid machining, energy of one process is taken as the source of energy for another process and vice versa. As a result the limitation of one process becomes the advantage of other process. The performance characteristics of hybrid machining processes (HMP) are different from those of constituent processes when performed separately. Abrasive Hybrid Machining (AHM) processes are gaining interest in industries due to

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their higher material removal rates and desirable surface finish. Material removal rate of hybrid machining process can be increased upto 6 times as compared to EDM process and twice that of Electrical Discharge Grinding process (EDG) [1]. Efforts from the researchers are going on to bridge the gap within combined utilization of energies of the constituent processes. The extent of participation of involved energies predicts the performance and surface integrity of the machined component.

Many hybrid machining processes have been developed in the area of EDM in order to enhance the machining efficiency and surface integrity. Electrical Discharge Surface Grinding (EDSG) is one of the hybrid machining processes which finds many applications due to its numerous advantages. It is a combination of electrical discharge machining (EDM) and conventional grinding operation. In this process material is removed from the surface of workpiece with the combined effect of electrical spark assistance and conventional grinding. This process can be achieved through two different configurations depending upon type of tool and its motion with respect to the workpiece. Rotary composite tool electrode or metal bonded grinding wheel can be used to remove the material by combined action of erosive discharges and grinding from the surface of workpiece. The composite tool electrode is made up of metal matrix with higher electrical conductivity and abrasive grains such as diamond, Al_2O_3, B_4C, TiO_2, SiC etc as reinforcements to remove the recast layer developed due to electrical discharges during EDM. During machining abrasive grains help the machining process for achieving more metal removal rate with lesser energy. Therefore material is removed by the combined effect of electro-erosion and micro cutting process.

The area of fabricating copper based composites including Cu-Al_2O_3, Cu-Zr-Al_2O_3, Cu-TiO_2, Cu-Si_3N_4 and Cu-SiC has extensively been explored. Method of fabricating these composites includes casting, co-precipitation, internal oxidation and powder metallurgy [2-7]. The combination of both materials provides special features (strength and thermal conductivity) which are suitable for electrical discharge machining applications. These features can be ensured, if there is a suitable contact between the matrix and the reinforcement. The production of the composite has many difficulties like suitable bonding between SiC and copper, inhomogenity of SiC particles in the matrix and the control of porosity. The possible solution to these problems is the coating of the SiC grains with suitable material to avoid interfacial reactions at interface. The most recommended plating material for SiC is copper. In this study copper is used as coating material for the plating of SiC abrasive grains.

2 Past literature

The development of different modern composite materials in the last decade has led to an expansion of EDM applications. Koshy et al. investigated the material removal mechanism in electrical discharge diamond grinding. The role of current and wheel speed on the MRR, grinding forces and power was investigated. The experimental observations conclude that spark discharges thermally soften the work material in the grinding zone, and consequently decreases the normal force and grinding power. The improvement in grinding performance is due to continuous dressing and declogging of the grinding wheel surface [8].

Shih et al. applied rotary disk electrode with EDM on AISI D2 Steel. In the study, the main aim was to investigate the electrical discharge grinding (EDG) using a rotary disk electrode. The experimental results show that both electrode wear rate and higher material removal rate were obtained when a rotary disk electrode with positive polarity was conducted on EDG, no arcing was found in any machining conditions. Further from the study they concluded that machining parameters such as rotating speed, discharge direction and flushing direction had no significant effect on MRR and SR [9].

Kozak et al. conducted abrasive electro discharge grinding of advanced materials like polycrystalline diamond and polycrystalline cubic boron nitride. This experimental study has been conducted to explore the feasibility and application of deionized water as dielectric medium instead of water [10]. It was reported that neural network prediction is better than multiple regression using limited data of experiments.

The study on abrasive electrical discharge grinding (AEDG) of Ti6Al4V titanium alloy was reported by Swiecik [11]. In this investigation the effect of grinding conditions on the performance of AEDG process was studied. The results of the study were compared with that of convention grinding operation. It was observed that application of AEDG process had a strong impact on the removal of machining allowance and surface machining texture (SGT). The effect of electric parameters, such as working voltage and intensity of current on the tangential force was also investigated.

Jain V.K et al. conducted experiment with a specially fabricated bronze disk as tool electrode to evaluate specific energy in EDM and results were compared with that of electrical discharge diamond grinding (EDDG) [12]. From their experimental observations it has been found that specific energy required in EDDG is less than that required in EDM with a rotating disk electrode.

Kozak J. et al. explored the hybrid machining processes by observing its machining characteristics. Study reveals that complex interactions of electrical, chemical and mechanical characteristics of HMPs are still not completely understood and its potential manufacturing capabilities are not completely recognized. It has been reported that extensive research efforts in advanced machining technologies are required for the improvement in HMPs monitoring and control [13].

Shih. H et al. applied electrical discharge abrasive drilling on hard materials using composite electrodes [14]. It has been observed that higher metal removal rates and lower surface roughness can be achieved when suitable electrode rotating speed, abrasive size and working current are chosen. The surface roughness could be improved in comparison with that achieved after EDM.

An investigation was made into the combined technology of electrical discharge machining and grinding (EDMG) by Shu K.M et al. [15]. A metal matrix (Cu/SiCp) electrode with a rotating device was fabricated and employed on EDM machine to study the EDMG technology. The experimental results confirmed that EDMG machining efficiency is three to seven times that of normal EDM operation. The corresponding surface roughness after EDMG operation was found to be lower than achieved through EDM operation.

Yadav S.K et.al conducted experimental study on machining parameters of electro-discharge diamond grinding. Yadav suggested that most of the significant factors affecting the EDDG robustness have been identified as wheel speed and peak current. Experimental results confirmed the validity of used Taguchi method for enhancing the machining performance and optimizing the machining parameters in EDDG [16].

The machining of silicon carbide (SiC) ceramics with end electrical discharge milling and mechanical grinding was carried out by Renjie Ji et al. to investigate the effect of tool polarity on the process performance. In this process steel wheel mounted on rotary spindle with uniform-distributed diamond sticks in its circumference is used as tool electrode. The effect of peak current, peak voltage, pulse on-time and pulse off-time on the material removal rate, electrode wear ratio, and surface roughness have been investigated with Taguchi experimental design. The mathematical models for the MRR, EWR, and SR have been established with the stepwise regression method. The contribution of peak voltage, peak current, and pulse off-time have been found to be significant toward MRR. Parameters like peak voltage and pulse off-time are having more pronounced effect on the EWR. Positive polarity of the tool electrode was observed to get better machined surface of the workpiece. This process is able to effectively machine a large surface area on SiC ceramics with a good surface quality [17].

From the review of the literature, it is observed that the hybrid machining process such as combined electrical discharge milling and grinding, AEDG and EDDG etc. has been explored extensively by the authors. However, effect of essential EDSG process parameters like abrasive

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particle size (APS) and abrasive particle concentration (APC) has not been discussed till date by the researchers. The purpose of the present study is to elucidate the process mechanism with reference to participation of abrasives in EDSG process. Effect of peak current and speed on material removal rate (MRR), electrode wear rate (EWR) and surface roughness (SR) is also investigated.

3 Mechanism of material removal in EDSG

Fig. 1 (a) shows the schematic line diagram of EDSG process. The machining set up for EDSG process requires EDM machine with rotary spindle attachment. In this set up rotary spindle attachment was designed and fabricated to provide rotary motion to the tool electrode. Speed controller and sensors are used to adjust the speed as per the experimental trial runs.

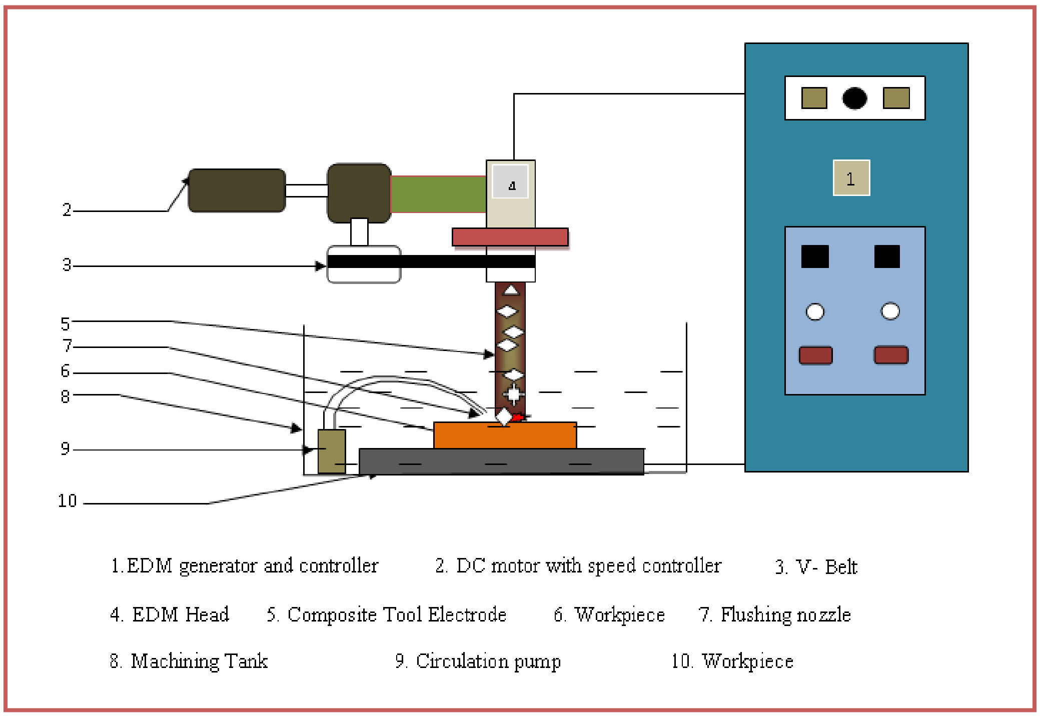

Fig. 1 Schematic line diagram of EDSG set up

The material removal mechanism of EDSG is shown in Fig. 2. It is a combination of electrical discharge machining and grinding in which material is removed with the combined effect of

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electrical spark assistance and conventional grinding process. Rotary metal matrix composite tool electrode is used to remove the material by combined action of erosive discharges and grinding from the workpiece surface. During machining the abrasive grains contributes the process in achieving more metrial removal rate with the assistance of electrical spark energy. During the EDSG operation these protruded abrasives grains remove the recast layer by reaching the base matrix and thus enhance the life of machined components.

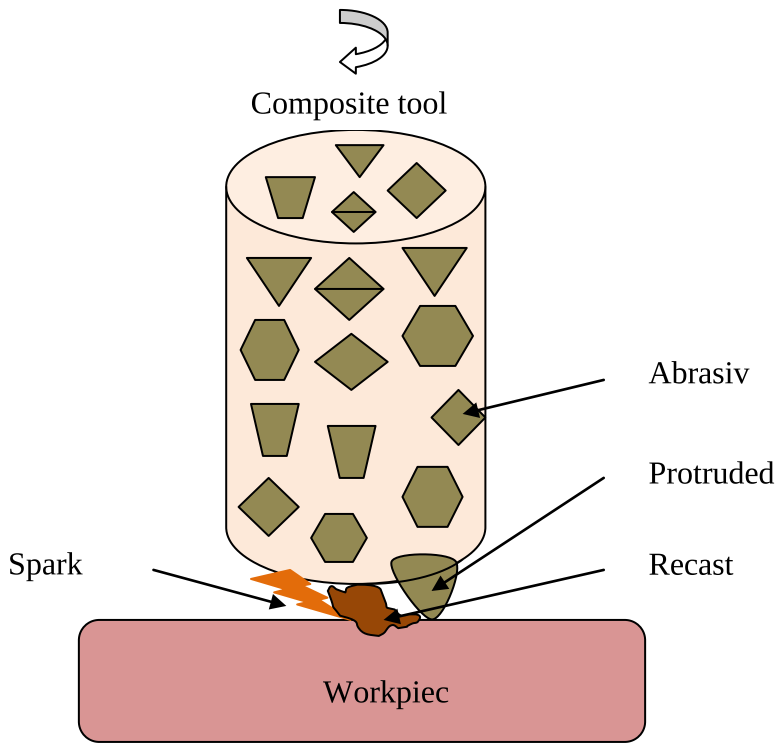

Fig. 2 Material removal mechanism of EDSG process

Fig. 3 represents the relation between protrusion height of the abrasive with size of the abrasive in EDSG process. The protrusion height is the extended length of the abrasive from base metal matrix. As the size of the abrasive particulate increases, protrusion height also increases. During the EDSG operation the material removal rate increases with the increase in protrusion height of the abrasive.

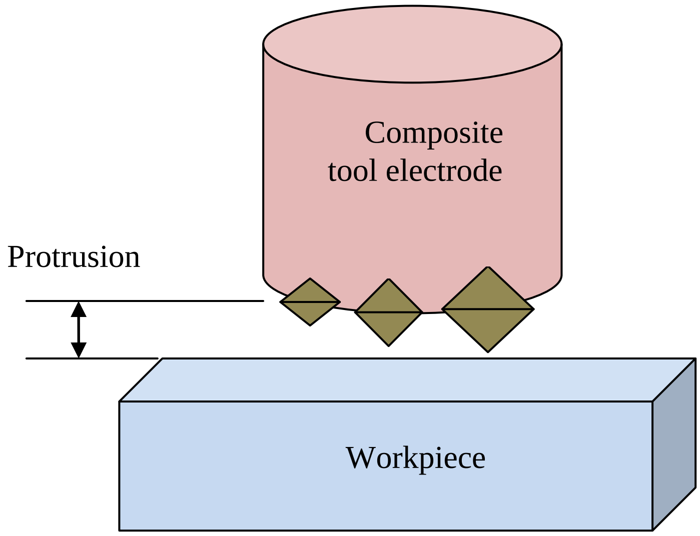

Fig. 3 Relation of protrusion height with size of abrasive

From Fig. 3 it can be observed that larger size abrasives approach the surface of workpiece prior to smaller abrasives. These abrasives can move beneath the upper surface of workpiece and remove recast layer from the base matrix developed due to spark erosion. One of the important benefits of the process is self dressing of tool electrode during the machining operation. The electrical sparks generated through EDM thermally soften the workpiece as well as expose abrasive particulates from the matrix during machining.

In this study detailed procedure for fabrication of composite tool electrode is presented. In later sections observations related to the performance of EDSG process have been discussed.

4 Experimental procedure

The experiments were performed on CNC EDM machine mounted with rotary spindle attachment. Composite tool electrodes were fabricated by powder metallurgy route with different sizes and compositions of abrasives in copper matrix. Electroless copper plating of SiC abrasives was carried out before mixing them with copper powder in required proportions.

4.1 Materials

4.1.1 Fabrication of Composite tool electrode

The silicon carbide is characterized by its tremendous hardness, creep, thermal conductivity and excellent corrosion resistance properties and hence it is selected as reinforcement for the metal matrix composite. Owing to these characteristics, SiC is used at high temperatures under corrosive conditions and in areas where wear must be prevented [18]. Grinding function can be performed with Cu/SiC$_P$ electrode in addition to thermal erosion in electrical discharge surface grinding process. In order to enhance the bonding between reinforcement as SiC and copper matrix, electroless plating procedure was adopted to coat the particulates. The reinforcements used for the fabrication of composites are in 60, 120 & 220 mesh sizes. Fig. 4 shows the morphology of SiC abrasives used as reinforcements in the present study. All the abrasives of different sizes were free from foreign particles and impurities.

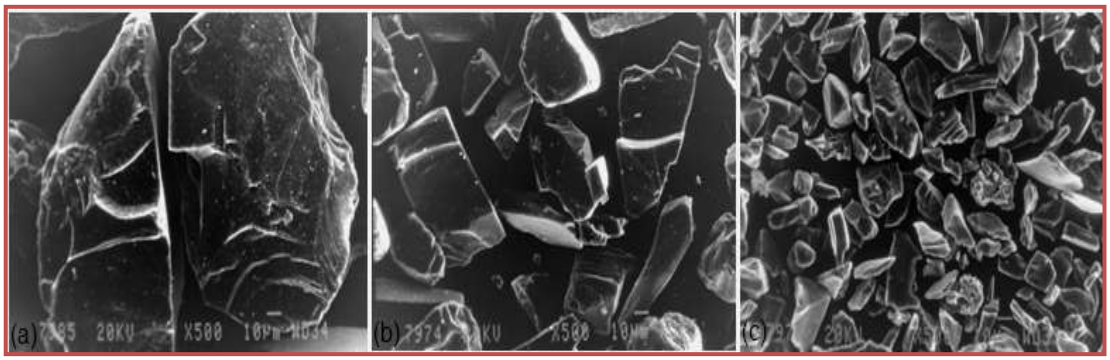

Fig. 4 Morphology of bare SiC abrasives (a) 60 mesh (b) 120 mesh (c) 220 mesh

Electroless plating process was adopted to electroplate the surface of SiC abrasives. In electroless plating process, plating of metal on surfaces is carried out with the help of chemical reaction using oxidizing and reducing agents. Particulate material and chemicals used for the electroless plating is given in Table 1. This process includes three steps; surface cleaning, sensitization and activation and finally copper plating. Surface cleaning was carried out by immersing SiC powder in acetone for half an hour while stirring. This process was repeated 2-3 times to clean the surface completely. Then SiC powder was immersed in distilled water for half an hour with continuous stirring. After removing SiC powder from water it was dried at 250^{o}C in hot air oven. Dried SiC particles were ground to obtain fine particles. Sensitization and activation was achieved by using catalysts. Transition metal salts like $PdCl_2$**,** $SnCl_2$ have been found to be excellent sensitizer and activator [19]. SiC particles were then placed in solution containing acidified $SnCl_2$ for one hour. SiC powder thus obtained was further placed in acidified solution of $PdCl_2$. The composition of these solutions is given in Table 2.

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Table 1 Material used in experimentation

S.No.	Item	Make
1.	120 mesh SiC	TedPella,USA
2.	220 mesh SiC	Central Drug House, INDIA
3.	400 mesh SiC	Central Drug House, INDIA
4.	Potassium sodium tatrtrate	Rankem, INDIA
5.	Copper sulphate	Rankem, INDIA
6.	Formaldehyde	Rankem, INDIA

Table 2 Composition of the solution for SiC sensitization and activation

S.No.	Chemical	Amount per 250ml	Temperature(°C)	Total time (min)
1	$SnCl_2$	2g	20°C	60
2	HCl	8 ml		
3	$PdCl_2$	0.1g		
4	HCl	2ml		

In electroless plating the main source of copper is copper sulphate. A number of reducing agents have been suggested for use in electroless copper baths, like formaldehyde, sugars, hypophosphyte [20]. Formaldehyde was used as reducing agent for this process. SiC powder was first placed in $CuSO_4$ solution with continuous stirring for half an hour. The powder was then recovered from above solution and then placed in potassium sodium tartrate solution with stirring for half an hour. The two prepared solutions were mixed together and stirred continuously. To this solution 40% formaldehyde was added. In order to achieve high pH value (pH=13) NaOH was also added. The amount and concentration of the various solutions is given in Table 3.

Table 3 Composition of solution for Electroless plating of SiC

S.No.	Chemical	Amount per 250ml	Temperature (°C)	Time (min)
1	Copper Sulfate(CuSO4.5H_2O)	2g	20°C	30
2	Potassium Sodium Tartrate($KNaC_4H_4O_6$)	5g		30
3	40%Formaldehyde(HCHO)	10ml		30 (after mixing above two solutions)
4	Sodium Hydroxide(NaOH)	4g		

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The copper ions get reduced and deposited on the surface of the SiC particles. Fig. 5 shows the coated SiC particles of sizes 60, 120 and 220 mesh respectively. These figures show that a homogeneous and continuous film of copper was placed on the SiC particulates.

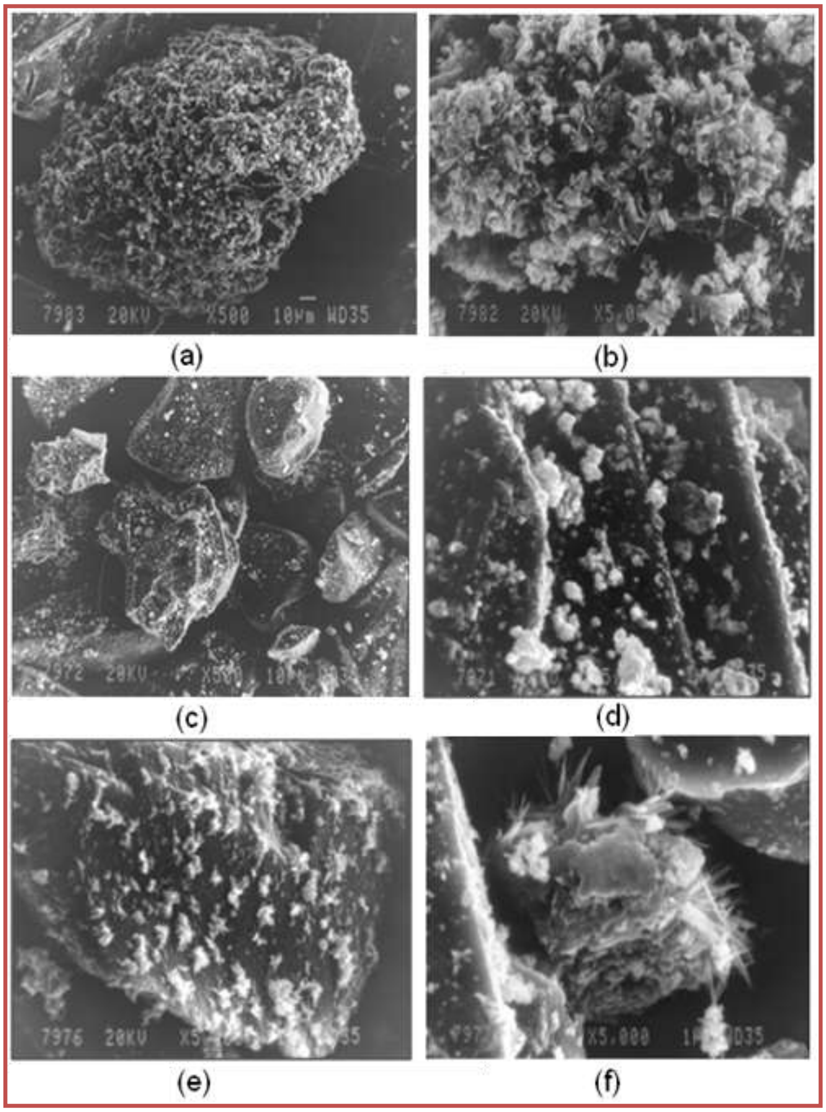

Fig. 5 The morphology of coated SiC abrasives (a-b) 60 mesh, (c-d) 120 mesh, (e-f) 220 mesh at 5000X

A smaller size of silicon carbide abrasive creates difficulties in coating due to cohesion between small particles as compared to larger particles. Sufficient surface exposure is required to accommodate copper layer on SiC during the plating process. After electroless plating, powders of copper coated SiC were mixed in copper powder with different proportions by wt. of 5, 10 and 15%. After milling the powders in ball mill, these powders were compressed under direct load of 55 KN on compression testing machine with help of die steel die designed with suitable dimensions. After removing the green compacts, sintering was carried out at 800^0 C in inert gas (N_2) in the tube furnace to prevent oxidation of green compacts. Microprocessor controlled temperature tube furnace with provision of inert atmosphere was used for sintering of green compacts. Pre-sintering of green compacts was carried out to remove the air and residue from the surface of compacts. The compacts fabricated with different compositions are shown in Fig. 6. These compacts were used as tool electrode on a ZNC EDM machine with attached rotary spindle attachment to investigate the effect of abrasive sizes and their concentration in EDSG process.

Fig. 6 Sintered composite tool electrodes

4.1.2 Workpiece

The candidate material used in the current investigation is AISI D2 Die steel. Due to extreme demand of manufacturing and automobile industries for the same material, it was selected as candidate work material for the current investigation. The chemical composition of the workpiece is shown in Table 4.

Table 4 Chemical Composition of AISI D2 Die steel

Element	C	Mn	Si	Cr	Ni	W	V	Cu	P	S	Fe
Composition (Wt.%)	2.25	0.6	0.6	12	0.3	1	1	0.25	0.03	0.03	Bal.

4.2 Microstructure of fabricated composite tool electrode

Fig.7 (a) shows micrographs of composite tool electrodes fabricated with 60 Mesh 5% SiC abrasives. Fig. 7 (b) shows the micrograph of 60 Mesh with 15 % SiC composite. Appreciable bonding of SiC with copper has been observed from micrographs. No fracture and cracks were observed in the composites. These features show good strength as well as low porosity in the composites. No foreign material and compound formation was observed in the composites.

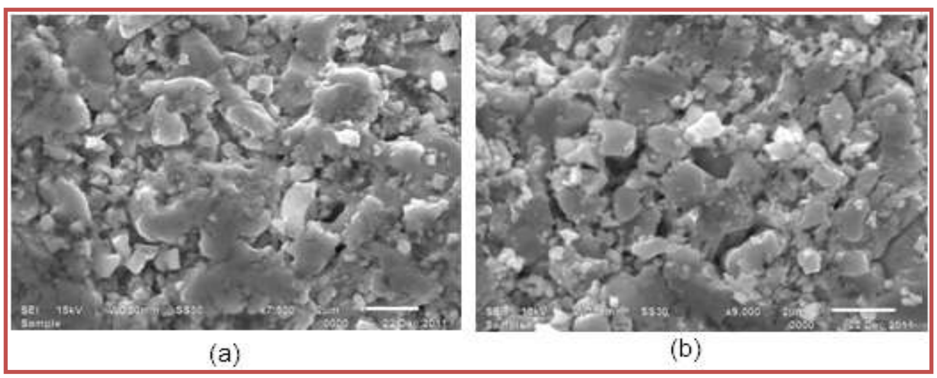

Fig. 7 Micrograph of Cu/SiC_p composite a) 60 Mesh 5% SiC b) 60 Mesh

4.3 Experimental design

Experiments were performed on die sinking machine (EDM Sparkonix S50) mounted with fabricated rotary spindle assembly. Experimental set up for EDSG is shown in Fig. 8 (a). On the basis of past literature and trial experiments a range of electrical and grinding parameters like gap current, rotational speed, abrasive particle size (APS) and abrasive particle concentration (APC) was selected to determine material removal rate (MRR), electrode wear rate (EWR) and surface roughness (SR) as performance measures of the process.

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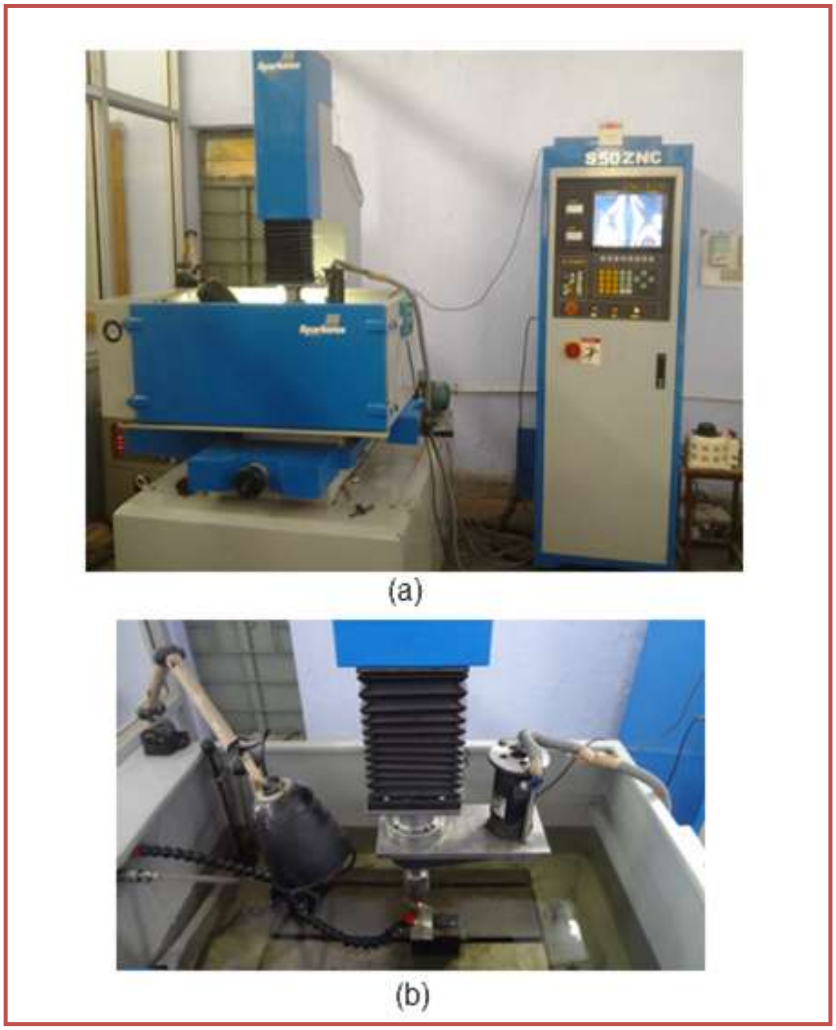

Fig. 8 (a) Electrical discharge surface grinding set up
(b) Machining of workpiece with EDSG

Table 5 lists the experimental conditions adopted for the present study. During the experiments the pulse on time and pulse off time were kept constant at 150 µsec whereas the gap current varied from 1.5 to 9A.

Table 5 Design scheme of experimental parameters for EDSG

Work Conditions	Description
Workpiece	AISI D2 Die steel
Electrode	Cu/SiC_p Composite Tool
Polarity (Electrode)	Negative
Peak current	1.5- 9 A
Pulse on time	150µs
Pulse off time	150µs
Duty factor	0.5
Rotating speed	500 – 1600 rpm
Dielectric fluid	CPC kerosene
Flushing pressure	0.5 kg/cm^2
Copper powder	220 Mesh
Abrasive Particle Size (APS)	60-120-220 Mesh
Abrasive Particle Concentration (APC)	5-10-15 %

The gap voltage remained between 55-60V. Hardened AISI D2 Die steel (60-61 BHN) plate having size 100x100x12 mm was used as a work piece. Electrical discharge surface grinding of workpiece was conducted upto 20 mins for each run of the experiment to measure the performance characteristics.

5 Results and Discussions

The following discussion focuses mainly on the essential parameters which significantly contribute to the process performance. The performance of the combined electrical discharge machining and conventional grinding was verified by evaluating MRR, EWR and SR.

5.1 Analysis of MRR

Comparison 3D graph in Fig. 9 shows variation of material removal rate with gap current at different rotational speeds. Material removal rate observed to be increase with gap current. Increase in rotational speeds also increases material removal rate upto1400 rpm. As the peak current has more impact on discharge energy, hence it removes more material with large size craters from workpiece surface. Increase in speed enhances grinding effect contribution with spark erosion process. Increase in rotational speed of the tool electrode facilitates in removal of debris from the inter-electrode gap and increases machining stability which improves machining efficiency. The material which gets melted due to spark erosion is removed by the abrasive

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grains with rotational effect. Increase in rotational speed of electrode increases material removal rate upto 1500 rpm and then reduces considerably. Considerable values of MRR have been obtained between 800 to 1500 RPM. Above and below this rotational speed significant improvement in MRR was not observed. After 1500 rpm the effect of high speed dominates the process of EDM thermal erosion due to reduction in strength of plasma channel and contamination of gap with more debris within the discharge gap which reduces MRR.

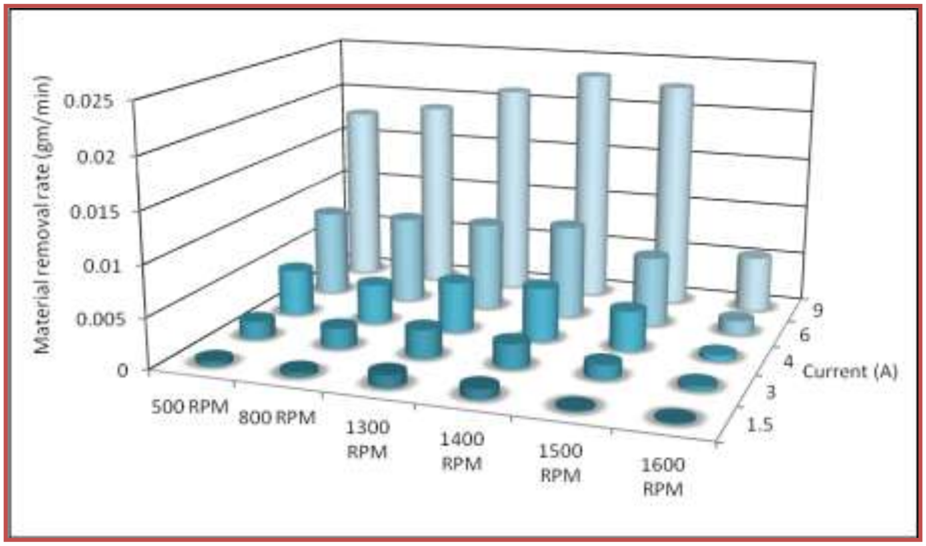

Fig. 9 Effect of Gap current on metal removal rate at variable speed

5.2 Analysis of EWR

Fig. 10 shows the comparison 3D graph for electrode wear rate at different settings of rotational speeds. Electrode removal rate (EWR) increases with increase in gap current. Large peak current generates more discharge energy and hence causes large EWR. Sharp rise in EWR has been observed after current of 6A. EWR also increases with increase in rotational speed of the tool electrode. Maximum values of EWR are observed at 1600 rpm. At higher rotational speeds grinding effect becomes more pronounced and hence contributes to increase in wear rate of tool electrode as observed by Yan et al. in their investigations [21].

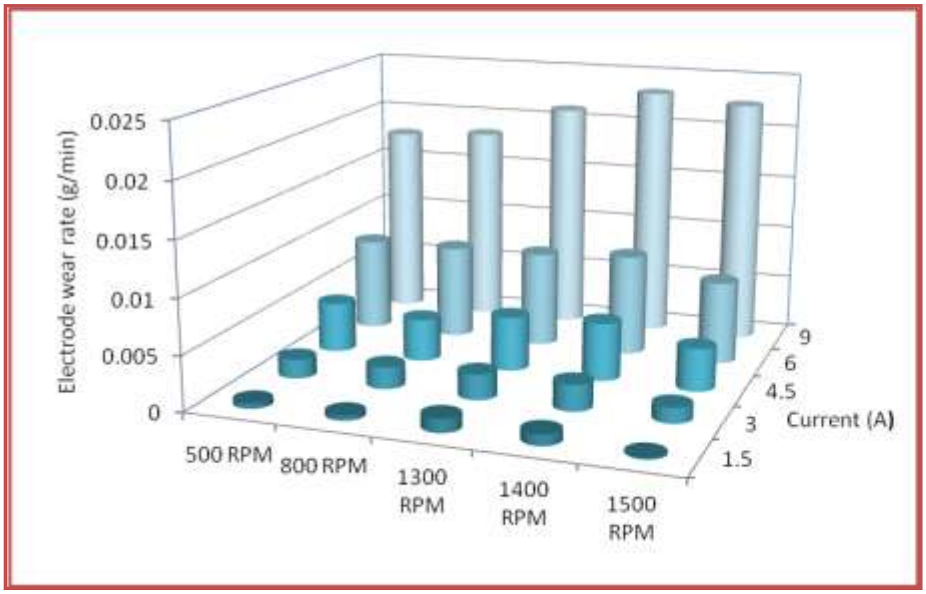

Fig. 10 Effect of Gap current on electrode removal rate at variable speed

At higher values of rotational speeds EWR is high because the grinding effect increases with increase in rotational speed of the electrode. This effect is attributed to the fact that at higher rotational speeds, more material is removed by abrasion which causes excessive wear and pull out of abrasives from the face of the tool electrode.

5.3 Analysis of SR

Fig. 11 indicates the increase in surface roughness with increase in gap current at selected range of grinding speed. At higher amperage more discharge energy is released due to which more material is removed per spark and hence increases SR of the workpiece. Surface roughness decreases with increase in rotational speed (Fig.12). This is due to the fact that higher grinding energy is available at higher speeds due to which more material is removed uniformly from the surface of workpiece. Moreover resolidified layer is also thin due to fast removal of the material from workpiece surface before solidification.

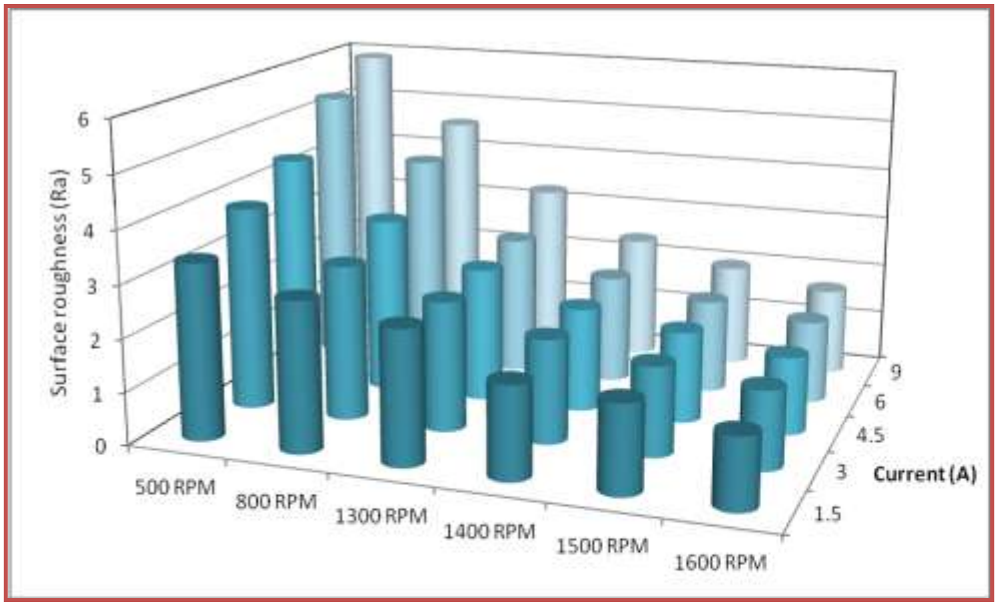

Fig. 11 Effect of gap current on surface roughness at variable speed [22]

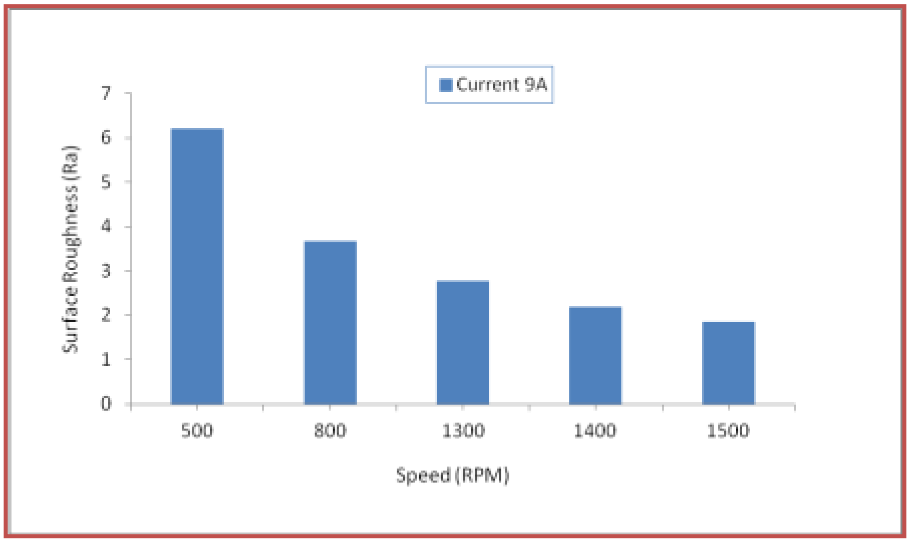

Fig. 12 Effect of rotational speed on surface roughness

5.4 Effect of Abrasive Particle Size (APS) on EDSG process

Effect of sizes of abrasives on material removal rate at constant 3A gap current & 800 rpm is shown in Fig. 13. Three sizes of abrasive (60, 120 & 220 mesh) have been selected to investigate the effect of these sizes on the performance of EDSG process. This figure indicates that MRR increases with increase in size of abrasive during EDSG operation, which is due to increased protrusion height of abrasives in composite electrode. As larger sized abrasives are more exposed from the copper matrix and comparatively provide more protrusion height which causes more material removal from the workpiece surface at higher grinding speeds.

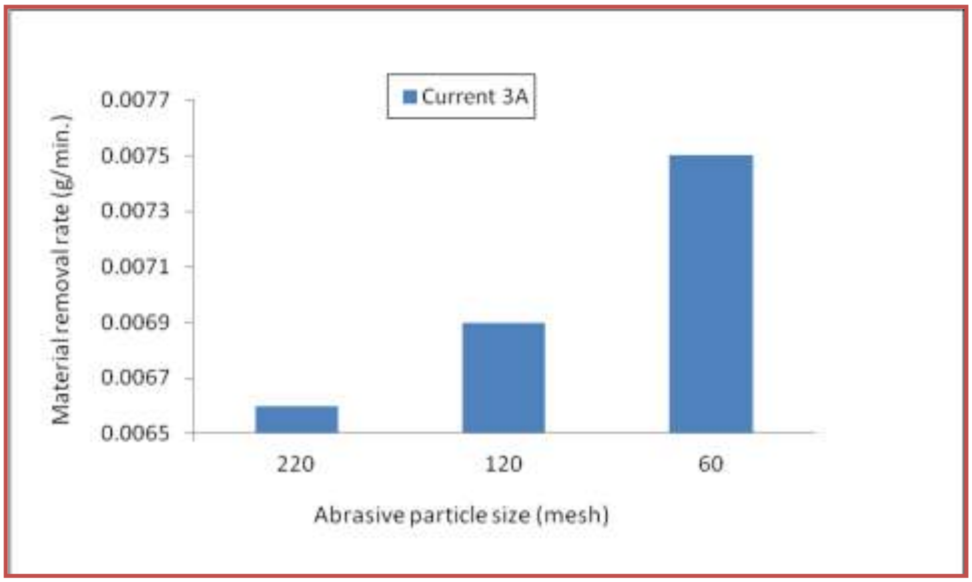

Fig. 13 Effect of size of abrasive on material removal rate

5.5 Effect of Abrasive Particle Concentration (APC) on EDSG process

In composite fabrication abrasive particle concentration plays major role in developing the thermal and physical properties of the composite. Electrode fabricated through powder metallurgy route should possess good thermal and electrical conductivity and strength to remove material in hybrid EDM and grinding process. Fig.14 shows the effect of APC on MRR during EDSG process. It is indicated that MRR first increases from 5 to 10% APC after that it decreases upto 15% APC. APC of 10% is optimal concentration for maximum MRR at constant gap current and rotational speed due to the fact that the optimal value of electrical conductivity of the composite tool electrode is required to perform in electrical discharge surface grinding process which varies with the concentration of SiC in the copper matrix.

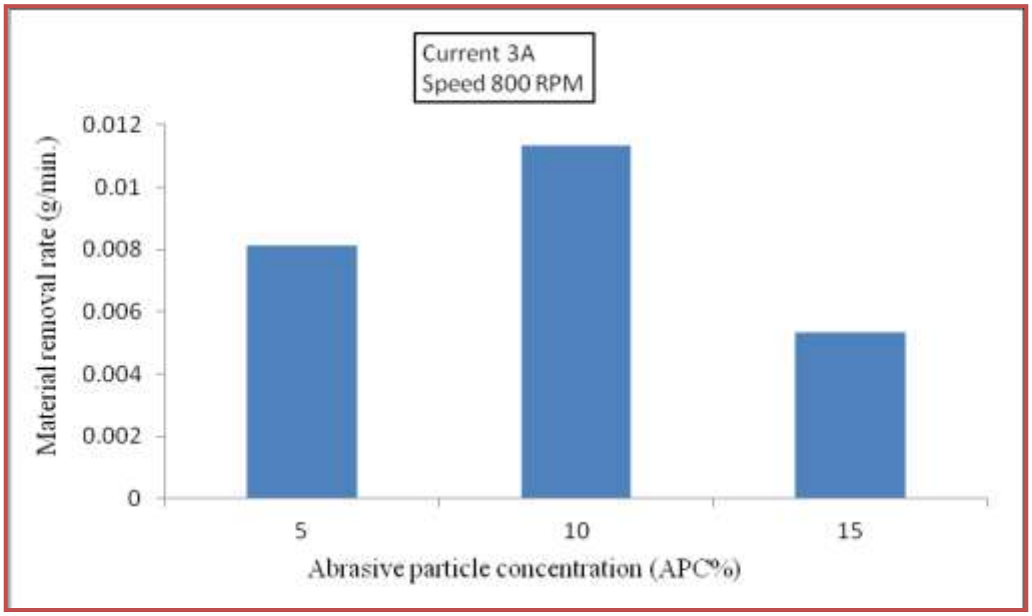

Fig. 14 Effect of abrasive particle concentration on material removal rate

5.6 Comparison of material removal rate in EDM and EDSG

The electrical discharge machining of AISI D2 Die steel was also carried out by restricting rotary motion of tool holder assembly to measure MRR. Fig. 15 shows the comparison of MRR during EDM and EDSG processes. It has been clearly observed that MRR during EDSG is considerably increased from 2 to 3 times as compared to EDM process. Hybridization of specific energies of EDM and grinding causes increased and controlled removal of material from the workpiece surface. These energies assist to each other in such way so that the limitation of one is overcome by another.

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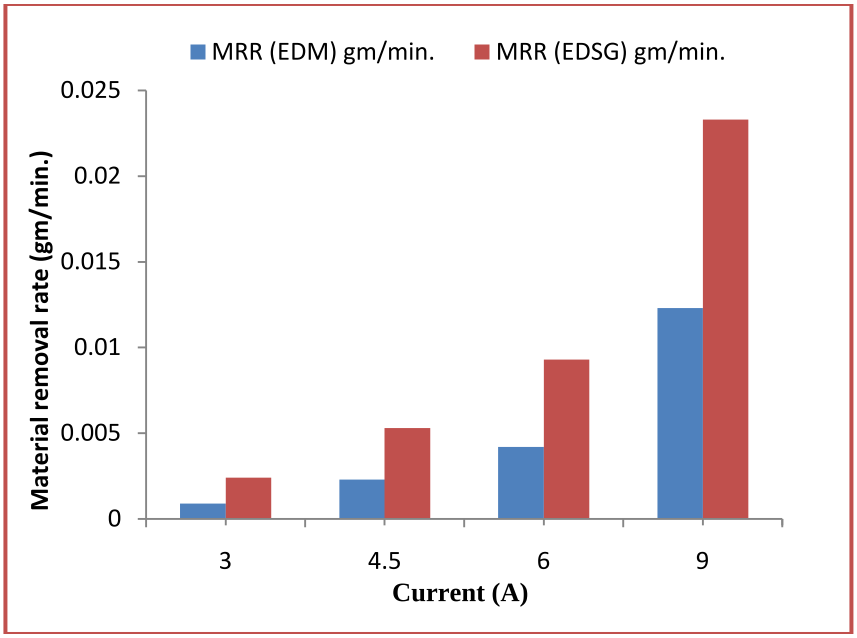

Fig. 15 Comparison of MRR of workpiece during EDM and EDSG [23]

6 Surface topography of machined surface

The workpiece machined by EDSG process was observed under scanning electron microscope to analyse the effect of input parameters on surface integrity. The observed surfaces are found to be free from foreign debris and major cracks. From the Figs. 16 (a-d), it has been observed that most of the molten metal removed during electrical sparks was forcibly removed from the surface of workpiece to eliminate recast layer. The obtained surface is free from debris of tool and workpiece and seems to be uniform. Fig. 16 (a-b) reveals that material eroded by electrical discharges is removed by grinding action effectively. No dense occurrence of recast layer has been observed on the surface of machined workpiece. Removal of recast layer in EDSG process reduces the chances of early failure of components due to creep and fatigue in service. As the intensity of residual thermal stresses are more in recast layer due to thermal mismatch of conduction of heat between tool and workpiece during the machining process. Fig. 16 (a) and (b) shows the workpiece surface machined by 220 mesh and 60 mesh tool electrode respectively. It has been observed that the surface machined by 60 mesh electrode is ground upto base material due to its larger size. Both the micrographs show the removal of recast layer from the machined surface. Fig. 16 (a-b) shows the grinding dominant state of EDSG process at 1100 rpm. The surface machined by 120 mesh electrode is having thin layer of molten metal above base material (Fig. 16 c-d).

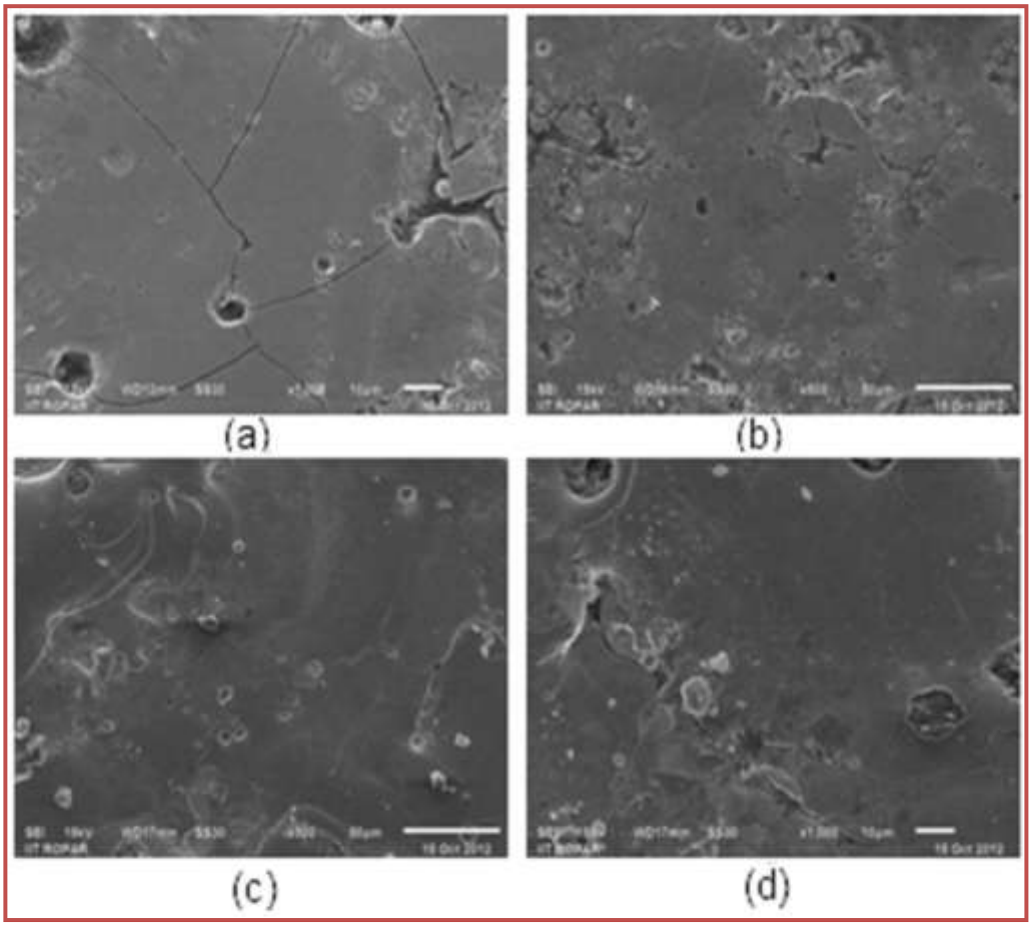

Fig. 16 Surface integrity of AISI D2 Die steel machined by EDSG (a) 3A, 120 Mesh, 1100 rpm (b) 3A, 60 Mesh, 1100 rpm (c) 4.5 A, 120 mesh, 800 rpm (d) 4.5 A, 120 mesh, 800 rpm

The effects of grinding become more pronounced at higher level of speed of tool electrode. Fig. 16 (c) and (d) shows the surfaces machined by 120 mesh tool electrode at 800 rpm. These micrographs show the thin recast layer over the machined surface of workpiece. The thickness of recast layer is more at low level of speed with medium size of abrasive particulates. These micrographs show that the effect of EDM seems to be more pronounced at lower level of grinding speed with medium size of abrasives. The EDSG process can also be observed under balanced state of grinding as well as electrical spark machining.

7 Conclusions

The experimental EDSG set up was developed to investigate the effect of gap current and rotational speed on material removal rate, electrode wear rate and surface roughness. Based on experimental results following conclusions are drawn as follows:

1) Electrical discharge surface grinding experiments reveals that MRR increases with increase in gap current and rotational speed of the tool electrode.
2) Grinding effect is more pronounced at higher rotational speeds. Above 1500 rpm MRR decreases due to gap contamination at higher speeds.
3) EWR increases with increase in gap current and rotational speed. Higher grinding speed leads to increased wear of tool electrodes at higher amperage. To yield optimum results of EWR, gap current and rotational speed should be low.
4) Surface roughness increases with increase in gap current and decreases with increase in rotational speed of the electrode. At low values of current and higher rotational speed better surface finish can be achieved by this process.
5) Grit protrusion height contributes major role in EDSG process. MRR increases with increase in size of the abrasives in composite tool electrode. Abrasives with larger sizes are having more protrusion height which contributes to remove more material from workpiece surface at higher speed.
6) APC of 10% is optimal concentration for maximum MRR at constant gap current of 3A and rotational speed of 800 rpm.
7) Micrograph analysis reveals that the thickness of recast layer is more at low level of speed with medium size of abrasive particulate, whereas its thickness reduces when machined with 60 mesh abrasive tool electrode.

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