An experimental investigation on electrochemical discharge peripheral surface grinding process

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KEYWORDS

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Alumina-Reinforced-Epoxy-Nanocomposite,
MRR,
R_a,
Hybrid Machining.

ABSTRACT

Polymer nanocomposites have become the best possible materials to replace metals and alloys. However, the available options for the machining processes for these materials are very limited due to their electrically non-conductive nature. Electrochemical discharge peripheral surface grinding (ECDPSG) process can be a potential machining process for such materials. Therefore, in the present work, an attempt has been made to investigate the performance of ECDPSG process in terms of MRR and R_a. The two types of wheel (metallic non-abrasive wheel and metal-bonded abrasive wheel), have been used to machine alumina-reinforced-epoxy-nanocomposite. It has been found that at lower wheel rotation, MRR using the metallic non-abrasive wheel is more than the MRR using a metal-bonded abrasive wheel. However, this difference between MRR obtained using both wheels decreased with the increase in wheel rotation. R_a has been found less using metal-bonded abrasive wheel at all respective wheel rotations.

1. Introduction

Nowadays, advancements in machining processes have become necessary, along with the development of new materials. Electrochemical discharge machining (ECDM) is one of the potential machining processes used by researchers for making features in electrically non-conductive advanced materials. The configurations of experimental setup have been developed based on requirements. For example, the experimental setup of drilling-ECDM has been developed to make holes/cavities (Singh & Dvivedi, 2018) milling-ECDM has been developed to make channels (Hajian et al., 2018) traveling wire-ECDM has been developed to make straight cut in electrically non-conductive materials (Yadav et al., 2020).

Apart from these developments, researchers have been trying to utilize the advantage of abrasion by mixing abrasives in electrolyte (Yang et al., 2006), and using abrasive coatings on tool. Ladeesh & Manu, (2019) used abrasive coated tool for drilling a hole in electric non-conductive material; and they termed the process grinding aided-electrochemical discharge drilling. The performance of the process in terms of MRR was improved. Liu et al. (2013) developed an experimental setup for grinding-ECDM. They used the face of cylindrical tool for machining of metal matrix composite (Al_2O_3 particulate reinforced aluminium 6061 alloy), and found that the grinding action removed a recast layer of material deposited on the machining surface. Hence, the average surface roughness (R_a) was ten times lesser than that of the specimen machined using ECDM alone (Liu et al., 2013).

Thus the combination of grinding with ECDM process has proven its potential in enhancing the performance of the process. This process can be called as electrochemical discharge grinding (ECDG) process. ECDG process employs thick metal disc as a tool for making finished channel in electrically non-conductive materials. ECDG process works on the similar parametric conditions as ECDM process.

Researchers used ECDM process for dressing of the grinding wheel (Schöpf, et al., 2001). Hence, in ECDG process, the need of dressing of grinding wheel is eliminated, which is an additional advantage of the process.

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Based on the wheel and workpiece shape and interaction, the four potential configurations of ECDG process can be: electrochemical discharge peripheral surface grinding, electrochemical discharge face surface grinding, electrochemical discharge peripheral cylindrical grinding, and electrochemical discharge face cylindrical grinding (Singh et al, n. d.)

From the above literature, very few works have been found related to electrochemical discharge grinding process. Hence, the prime objective of the present work is to explore the possibilities for the first configuration mentioned in the previous paragraph, i.e., electrochemical discharge peripheral surface grinding (ECDPSG) process. In this study, the two types of wheel (metallic non-abrasive wheel and metal-bonded abrasive wheel) have been used for ECDPSG process for machining of alumina-reinforced-epoxy-nanocomposite. The performance of the process has been compared in term of material removal rate (MRR) and average surface roughness (R_a) three levels of supply voltage and wheel rotation.

2. Working of ECDPSG Process

The basic principle of material removal in ECDPSG is similar to the ECDM process (Fig.1). Two conditions are necessary for the occurrence of a spark. First, the ratio of the immersed surface area of the cathode to anode should be at least 1:100 (Fascio et al., 2004). Second, the supply voltage should be more than a critical value (minimum voltage required for the breakdown of the gas film). The electrochemical reactions are responsible for hydrogen gas generation at the cathode and oxygen gas at the anode. When the supply voltage reaches the critical value, the gas film forms around the cathode (i.e., metal disk in this case) and isolates cathode from the electrolyte. This gas film works as dielectric (in electric discharge machining). The discharge occurs as a spark within the gas film on increasing supply voltage further than a critical value. The workpiece has been placed in a sparking zone. Hence, the heat energy of the spark increases the temperature of the localized area of the workpiece to a very high temperature leading to the melting and vaporization of the workpiece.

When the metallic non-abrasive wheel (MNAW) is used as a tool electrode, melting and vaporization occurs simultaneously, and then ejection of molten material takes place, which is responsible for material removal from the workpiece during machining. This process is called electrochemical discharge peripheral surface non-abrasive grinding (ECPSNAG). On the other hand, when metal-bonded abrasive wheel (MBAW) is used as a tool electrode, melting, vaporization, and ejection along with abrasion is responsible for material removal from the workpiece surface. This process is called electrochemical discharge peripheral surface abrasive grinding (ECDPSAG).

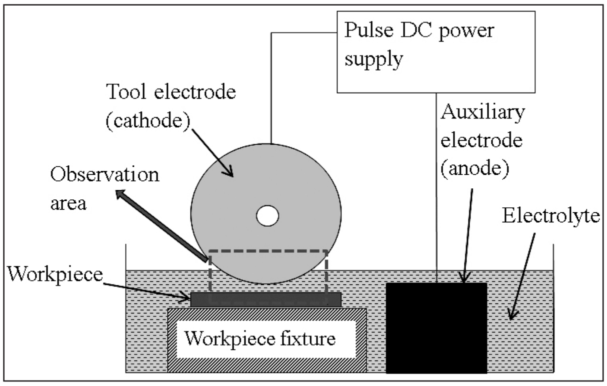

Fig. 1. Schematic diagram of ECDPSG process.

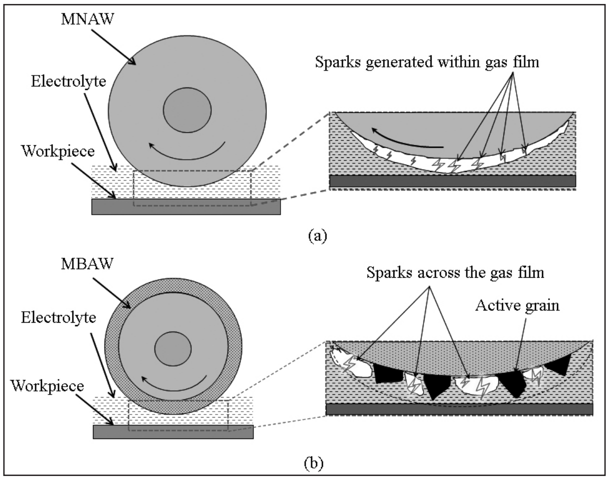

Fig. 2. Wheel and workpiece interaction
(a) ECDPSNAG process, (b) ECDPSAG process.

3. Materials and Methods

The experiments have been performed at an indigenously developed experimental setup of ECDPSG process. The basic units of an experimental setup of ECDPSG process are a mechanical unit, electrical unit, electronic unit, and machine user interface. Figure 3 shows a block diagram of the experimental setup of ECDPSG process and the interrelationship of each unit. Here, arrows indicate the flow of information and electricity. Figure 4 shows the photographic view of the mechanical unit, which consists of a machining

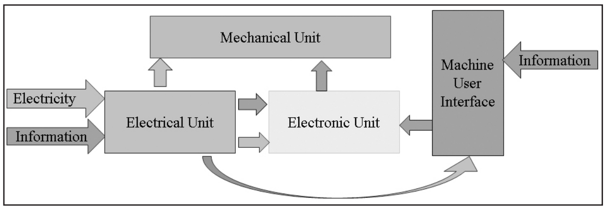

Fig. 3. Block diagram of experimental setup of ECDPSG process with the electricity flow and information flow.

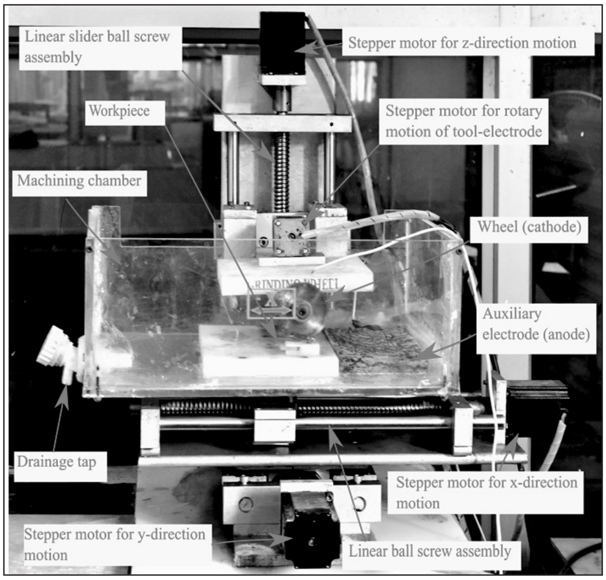

Fig. 4. Photographic view of mechanical unit of ECDPSG process.

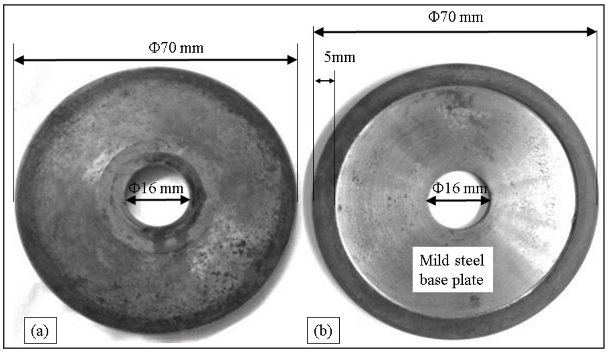

Fig. 5. Photographs (a) metallic non-abrasive wheel, and (b) metal-bonded abrasive wheel.

chamber, tool attachment unit, motion-providing units, and workpiece holding unit.

Figure 5 (a) shows metallic non-abrasive wheel of bronze, Figure 5 (b) shows the metal-bonded abrasive wheel (D80/100M100M) having bronze bonded diamond layer of 5 mm thickness on mild steel base plate. The outer diameter of both wheels is same.

The experiments were performed on self-prepared alumina-reinforced-epoxy-nanocomposite workpiece at tabulated experimental conditions

Table 1
Experimental details.

Fixed parameters	**Symbol**	**Values**
Feed rate (in x-direction) (mm/min)	f_w	0.5
Pulse-off time (µs)	T_{OFF}	500
Electrolyte		Aq. NaOH
Electrolyte concentration (g/l)	E_C	100
Pulse-on time (µs)	T_{ON}	1000
Variable input parameters		**Levels**
Supply voltage (V)	V_S	55 V, 60 V, and 65 V
Wheel rotation (rpm)	N_S	3 rpm, 4 rpm, and 5 rpm
Performance parameters		
MRR	mg/min	
R_a	µm	

in Table 1. Performances of ECDPSNAG process and ECDPSAG process in terms of MRR and R_a, have been compared. MRR has been calculated from Eq.1, where, w_b and w_a are weights (g) of the workpiece (measured using a digital microbalance, accuracy 10 µg, CAS India Private Limited) before and after machining, respectively, and t_m is machining time (minutes). R_a was measured by surface roughness tester (accuracy 0.1 µm, SURTRONIC-25 model, Taylor Hobson Ltd., UK).

$$MRR\ (mg/min) = \frac{w_b - w_a}{t_m} \times 10^3 \qquad ....(1)$$

The variation of MRR and R_a with wheel rotation at different supply voltage conditions for both configurations of ECDPSG process, i.e., ECDPSNAG process and ECDPSAG process, have been analyzed, and results are explained in section 4.

4. Results and Discussions

Experiments were carried out successfully on the in-house developed experimental setup of ECDPSG process. The observed results are presented in the graphs.

4.1. Material removal rate (MRR)

Figure 6 shows the comparison between MRR obtained in ECDPSNAG process and ECDPSAG process at three levels of wheel rotation (3 rpm, 4 rpm, and 5 rpm). The comparison has been made for different supply voltage conditions and shown by Region I (V_S= 55V), Region II (V_S= 60 V), and Region III (V_S= 65V).

Here, it can be noted that in Region I (V_S=55 V), Region II (V_S=60 V), and Region III (V_S=65 V), at lower value of wheel rotation (3 rpm), the MRR in ECDPSNAG is 81.64 %, 32.27 % and 31.71 % more than the MRR in ECDPSAG process, respectively. At a lower wheel rotation (3 rpm), the sparks observed in ECDPSNAG process are more prominent than the spark produced in ECDPSAG process. This is because the exposure of the conductive surface area of the wheel in ECDPSNAG process is more than in ECDPSAG process. Therefore, the melting of the material is more in ECDPSNAG process than ECDPSAG process. As a result, for the same pulse-off time, more molten material is ejected from the melting zone in ECDPSNAG process.

In Region I (V_S=55 V), when wheel rotation increases from (4 rpm to 5 rpm), the difference between the MRR obtained from both processes decreases. This is because as wheel rotation increases, abrasion participates in removal of re-solidified material on the workpiece surface in ECDPSAG process. A similar explanation is valid for MRR at higher wheel rotation (5 rpm) in Region II (V_S=60 V) and Region III (V_S=65 V).

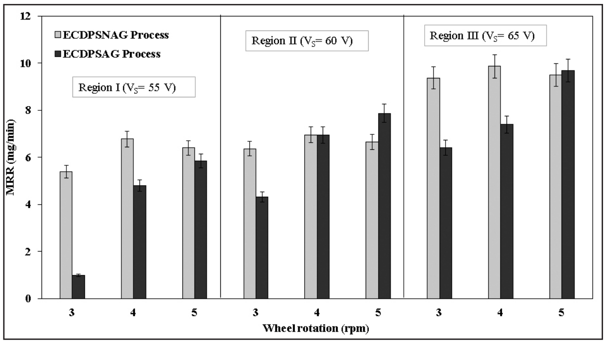

Fig. 6. Comparison between the MRR obtained in ECDPSNAG process and ECDPSAG process at different wheel rotation and different supply voltage condition keeping other parameters constant at E_C=100 g/l, T_{ON}=1000 µs, T_{OFF}= 500 µs.

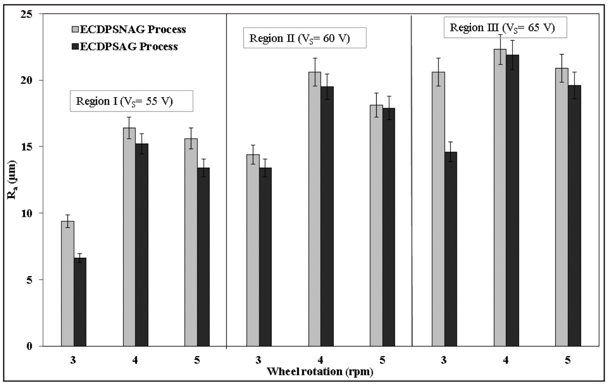

Fig. 7. Comparison between the R_a obtained in ECDPSNAG process and ECDPSAG process at different wheel rotation and different supply voltage condition keeping other parameters constant at E_C=100 g/l, T_{ON}=1000 µs, T_{OFF}= 500 µs.

4.2. Average surface roughness (R_a)

Figure 7 shows the comparison between R_a obtained in ECDPSNAG process and ECDPSAG process at three levels of wheel rotation (3 rpm, 4 rpm, and 5 rpm). The comparison has been made for different supply voltage conditions and shown by Region I (V_S= 55V), Region II (V_S= 60 V), and Region III (V_S= 65 V).

Here, it can be noted that at a lower wheel rotation (3 rpm) in Region I (V_S= 55V), Region II (V_S= 60 V), and Region III (V_S= 65 V), R_a in ECDPSNAG process is 29.78 %. 6.9 % and 29.12 % more than the R_a in ECDPSAG process. This is because, at lower wheel rotation (3 rpm) in ECDPSNAG process, the thermal energy of the spark available at the workpiece surface causes the melting of the superficial material. Some amount of the material is vaporized during melting, and some amount of the molten material is ejected during pulse-off time into the electrolyte as debris; the remaining amount of molten material re-solidifies on the workpiece surface. When the molten material is ejected from the melt pool, the craters are generated on the workpiece surface. The re-solidified material and generated craters increase the average surface roughness of the machined surface. In ECDPSAG process, although melting-vaporization, an ejection at the pulse-off time, and re-solidification of the molten material remain similar to ECDPSNAG process, the use of MBAW in ECDPSAG process removes the re-solidified molten material by abrasion action. Hence, in all regions of Figure 7 i.e., Region I (V_S=55 V), Region II (V_S=60 V), and Region III (V_S=65 V), the R_a of the machined samples obtained in ECDPSNAG process is more than the R_a of the machined samples in ECDPSAG process.

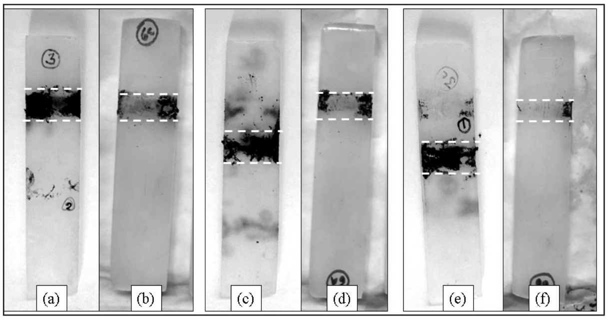

Fig. 8. Photographs of machined samples using (a) ECDPSNAG process at N_S= 3 rpm, (b) ECDPSAG process at N_S= 3 rpm, (c) ECDPSNAG process at N_S= 4 rpm, (d) ECDPSAG process at N_S= 4 rpm, (e) ECDPSNAG process at N_S= 5 rpm, and (f) ECDPSAG process at N_S= 5 rpm, keeping other parameters constant at V_S=60 volt, T_{ON}= 1000 µs, T_{OFF} = 500 µs, and E_C= 100 g/l.

Fig. 8 (a), (c) and (e) show the photographs of the machined samples obtained in ECDPSNAG process, and Fig. 8 (b), (d) and (f) show the photographs of the machined samples obtained in ECDPSAG process. It can be noted that the re-solidified material at the workpiece surface in ECDPSNAG process is more than the re-solidified material at the workpiece surface in ECDPSAG process at different levels of wheel rotation in Region II (V_S=60 V). The abrasion action helped to remove the re-solidified molten material from the workpiece surface.

5. Conclusions

Electrochemical discharge peripheral surface grinding (ECDPSG) process has been used effectively in two experimental configurations, i.e., ECDPSNAG process and ECDPSAG process for machining of alumina-reinforced-epoxy-nanocomposite. The MRR and R_a obtained in both processes have been compared at different levels of supply voltage and wheel rotation. The following conclusions are made from the present experimental study.

1. In ECDPSNAG process, obtained MRR more than that in ECDPSAG process at lower wheel rotation in all Regions.
2. The difference between MRR and R_a in the ECDPSNAG process and in ECDPSAG process decreases with increase in wheel rotation.
3. In Region II (V_S=60 V), and Region III (V_S=65 V), at higher wheel rotation, MRR is more and R_a is lesser in ECDPSAG process than MRR and R_a in ECDPSNAG process.
4. The amount of re-solidified molten material on the workpiece was reduced while increasing wheel rotation in ECDPSAG process.
5. The experimental investigation shows that ECDPSG process has potential to machine of alumina-reinforced-epoxy-nanocomposite, using ECDPSNAG and ECDPSAG process. However, better finish is observed in ECDPSAG process.

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