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Preliminary Study on Slotted-Electrical Discharge Diamond Face Grinding of Metal Matrix Composite

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Abstract – **Metal matrix composites (MMCs) are highly required in field of advanced engineering. Due to the abrasive nature of the reinforcements into matrix, machining of the MMCs is yet a challenge for manufacturing industries. In this paper, a new hybrid machining process named as slotted-electrical discharge diamond face grinding (S-EDDFG) has been proposed for machining of the end surface of the electrically conductive hard and brittle materials. The performance of the developed process has been tested on EDM machine with application of the compound grinding wheel. The role of discharge voltage, current, pulse on-time, pulse off-time and wheel RPM has been investigated on MRR and Ra during machining of the Al/SiC composite. The experimental results show that MRR increases and Ra value decreases with increase of the wheel RPM due to enhances in the flushing efficiency of the dielectric.**

Keywords: **Electrical Discharge Machining (EDM) Electrical Discharge Grinding (EDG), Electrical Discharge Diamond Grinding (EDDG), Metal Matrix Composites (MMCs)**

I. Introduction

Metal matrix composites (MMCs) are having high demand in the field of automobile and aerospace due to the their unique properties such as low weight to high strength ratio, high wear resistance, high corrosive resistance as compared to the convention engineering materials [1-3]. These materials are consisting two distinct phases i.e. one of the soft materials such as metals or alloys known as matrix and other is very hard material like ceramics known as reinforcing material. The commonly used matrix materials are: aluminium, copper, tin and brass while reinforcing materials are: silicon carbide (SiC), boron carbide (B4C), titanium carbide (TiC), aluminium oxide (Al_2O_3) and zirconium oxide (ZrO_2).

Due to presence of the two distinct properties of materials (soft matrix and hard ceramics), the machining of the MMCs is a much difficult issues for the advanced manufacturing industries. The hard and brittle ceramic particles lead to increase of the high tool wear and high cutting forces while soft matrix material leads to the thermal residual stresses and built edge formation on the tip of the cutting tool when machining by cutting techniques are applied for machining of these difficult to machine materials i.e. MMCs. Even though the strength of MMCs depends upon percentage volume of the reinforcing materials and higher percentage volumes of reinforcement means higher strength and wear resistance. But simultaneously the machining of MMCs becomes more and more difficult for industries.

Among various non-traditional machining processes, electrical discharge machining (EDM) is a more acceptable process for machining of the difficult to machine electrically conductive hard and brittle materials such as super alloys, carbide alloys, heat treated alloys, MMCs and ceramics [4-7]. The performance of the EDM process is better that the abrasive jet machining and laser beam machining [8, 9]. However, it suffers with several inherent problems such as slow productivity, formation of recast layer, surface cracks and high specific energy consumption [10-12]. To minimize the limitations of the EDM process, several researchers were replaces the stationary tool electrode used in EDM process with rotating disc wheel. Such developed process is known as electrical discharge grinding (EDG) process [6, 11, 13-15]. Even though, to remove the recast layer and micro-cracks, the post process operation such as grinding has been required after EDM process. Keeping the concept of the grinding after EDM process, a new hybrid machining named as slotted-electrical diamond discharge grinding (S-EDDG) has been proposed.

S-EDDG process is a novel process for machining of the difficult to machine materials such as semiconductor, ceramics, composites, poly crystalline diamond, glass etc. It is developed by combining the two machining processes i.e. slotted-diamond grinding (S-DG) and slotted-electrical discharge grinding (S-EDG) as shown in the Fig. 1. Generally, S-DG process is more beneficial for grinding of the soft materials like aluminium, copper, brass, MMCs and the materials which lead wheel loading problem during grinding [16, 17]. On other hand, the S-EDG process is much beneficial for machining of the hard and brittle materials such as ceramics [18-20]. Keeping these concept, a compound wheel has been developed, which is capable to perform S-DG and S-EDG processes during machining when the performance of the process is tested on the EDM machine. The developed hybrid machining process of S-DG and S-EDG is known as S-EDDG process.

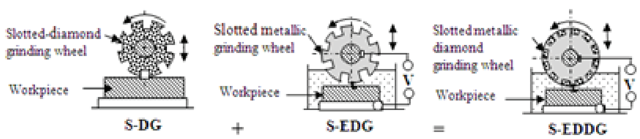

Fig. 1 Details combinations of the S-EDDG process

The mechanism of material removal of S-EDDG process has been explained in the Fig. 2. In this process, material has been removed by individual effects of the spark erosion and abrasive abrasion, which occurs alternatively due to rotation of the compound wheel [21]. In this process, the spark has been generated between workpiece and metallic portion of the compound wheel, when DC pulse power supply has been applied to the EDM machine. Due to this, high temperature (8000^{0}C) has been generated during pulse on-time. As a result, the workpiece material is melted and softened below the melt zone. The molten material is removed during pulse off-time of EDG process and such phenomenon has been repeated till the entire peripheral length of metallic portion. After completion of the EDG action, the grinding process starts and large number of diamond particles make contact with the soften workpiece surface. Due to this, the soften layer with recast layer and micro-cracks has been removed by abrasive abrasion of the diamond particles. These two phenomenons are repeated alternatively during machining and material removal is the equal to the sum of the separate vale of removal by S-EDG and S-DG processes.

Slotted-electrical discharge diamond face grinding (S-EDDFG) is a new configuration of the S-EDDG process for machining of the end surface of the cylindrical workpieces. For this purpose, a compound wheel has been developed, which face surface is utilized for spark erosion and abrasion purposes. To develop the compound wheel, the face surface of the metallic disc (MS) wheel (diameter=30 mm) has been

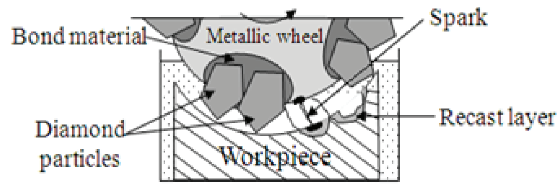

Fig. 2 Mechanism material removal of S-EDDG process

cut into equal number of slots with equal dimensions. The numbers of slots are equal to the number of metallic portions, which is also called as metallic tooth. The slots between two teeth are completely field with vitrified bonded diamond abrasives (grit number=80) and finally get a circular wheel (diameter=30 mm), which face surface has been utilized for machining. The actual photographic view of the developed compound wheel is shown in the Fig. 3.

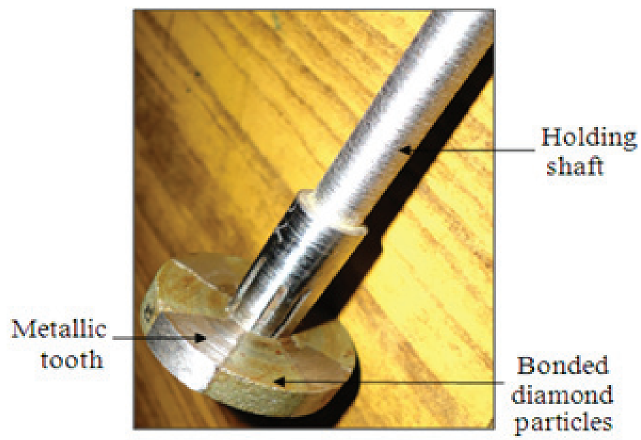

Fig. 3 Developed compound grinding wheel

II. Experimental Study

For experimental study, Ecoline ZNC EDM machine (model: ZNC 320) has been used. At the vertical column of EDM machine, a separate attachment of rotary unit has been mounted for rotating the compound wheel with the help of DC motor, V-belt and V-pulley. The gap between workpiece and wheel is maintained by servo mechanism of existing EDM machine. The workpiece and grinding wheel are continuously dipped into dielectric fluid (EDM oil) during machining. The photographic view of actual experimental setup has been shown in the Fig. 4.

In present study, role of discharge voltage, current, pulse on-time, pulse off-time and wheel RPM has been investigated on MRR and Ra during machining of the Al/SiC workpiece (diameter=30 mm). For measuring the weight before and after machining, a digital micro-weighing balance (model:

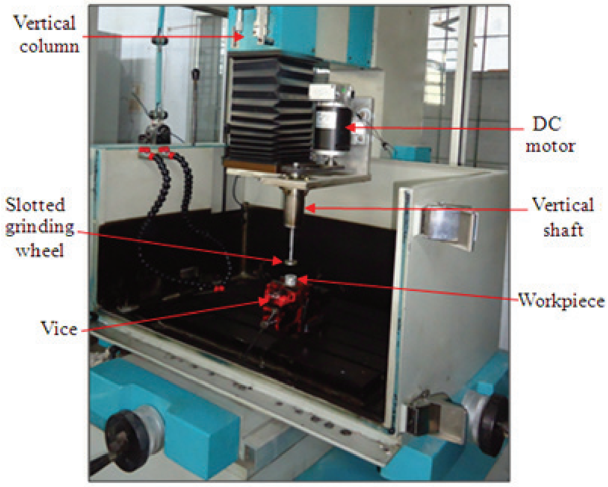

Fig. 4 Photographic view of experimental setup

CAUW-D) has been used. A digital surface measuring instrument (model: Surtronic-25) has been used to measure the Ra value of machined surface.

III. Results and Discussion

In this section, the effect of discharge voltage, current, pulse on-time, pulse off-time and wheel RPM has been investigated on MRR and Ra. All the experiments were conducted according to the one parameter at a time approach [22]. Each experiment was conducted for the 30 minutes with three repetitions to capture the variations in experimental results and their average value has been used for analysis of the data.

A. Effect of Discharge Voltage on MRR and Ra

Figure 5 illustrates the effect of the varying discharge voltage on MRR and Ra keeping other parameters at their base value such as pulse current=1 A, pulse on-time=5 µs, pulse off-time=10 µs and wheel RPM=100. It is observed that the MRR and Ra value decreases with increase of the discharge voltage. An increase of the discharge voltage leads to increase the gap between workpiece and compound wheel. Due to this, the protrusion heights of the abrasive particles become ineffective to remove the softened material during grinding process from the workpiece surface resulting MRR declines.

With an increase of the discharge voltage, spark energy increases as which the workpiece surface becomes more and more softer. Due to this, the softer workpiece material is smoothly removed by the diamond particles during grinding process as which Ra value decreases with increase of the discharge voltage.

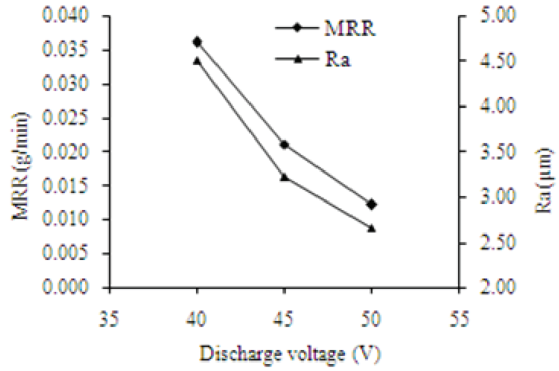

Fig. 5 Effect of discharge voltage on MRR and Ra

B. Effect of Current on MRR and Ra

Figure 6 illustrates the variation in MRR and Ra with respect to the varying current while other input parameters are kept at constant value such as discharge voltage=40 V, pulse on-time=5 µs, pulse off-time=10 µs and wheel RPM=100. It has been observed (Fig. 6) that MRR increases with increases of the current. The spark energy increases with increase of the current. Due to this, more amount of material is melted and softened below the molten material. The molten material is removed during pulse off-time while the soften material is removed by diamond particles during grinding process resulting MRR increases.

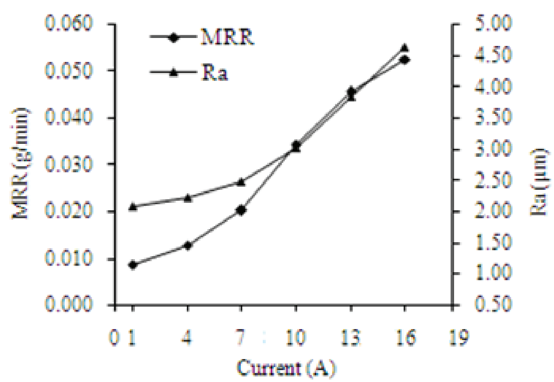

Fig. 6 Effect of current on MRR and Ra

Figure 6 also shows that the Ra value almost constant between pulse current of 1 A to 7 A. This is due to fact that smaller size of craters are formed at lower current resulting the craters marks are smoothly removed with soften material during grinding process. It has been also observed that the Ra value increases with high rate with increase of the current after 7 A. At higher current more volume of material is melted and formed bigger size of craters after ejection. Due to this, the protrusion heights of the abrasive particles become ineffective to remove the crater marks smoothly resulting Ra value increases.

C. Effect of Pulse On-Time on MRR and Ra

Figure 7 explain the variation of MRR and Ra with respect to pulse on-time at constant input parameters such as discharge voltage=40 V, current=1 A, pulse off-time=10 µs and wheel RPM=100. It has been observed (Fig.7) that MRR and Ra value increases with increase of the pulse on-time. An increase of pulse on-time means longer time for the particular spark discharge. Hence, the same amount of heat energy is transmitted into workpiece for a longer time. Due to this, more material is melted and softened as which MRR increases. Increases of the pulse on-time, the bigger size of craters are formed on workpiece process after ejection of the molten materials resulting Ra value increases. It may be also possible that the protrusion heights of abrasive particles become ineffective to smoothly machine the crater marks on workpiece surface due to the formation of the bigger size craters. As a result Ra value increases with increase of pulse on-time.

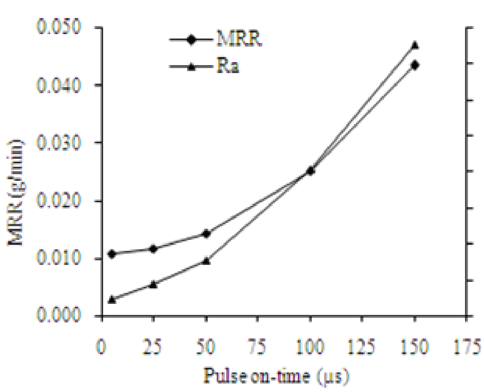

Fig. 7 Effect of pulse on-time on MRR and Ra

D. Effect of Pulse Off-Time on MRR and Ra

Figure 8 shows the variation of MRR and Ra with respect to pulse off-time at constant input parameters such as discharge voltage=40 V, current=1 A, pulse on-time=5 µs and wheel RPM=100. It has been observed (Fig.8) that MRR and Ra value increases with increase of the pulse off-time. This is due to fact that the increase of pulse off-time refers to the

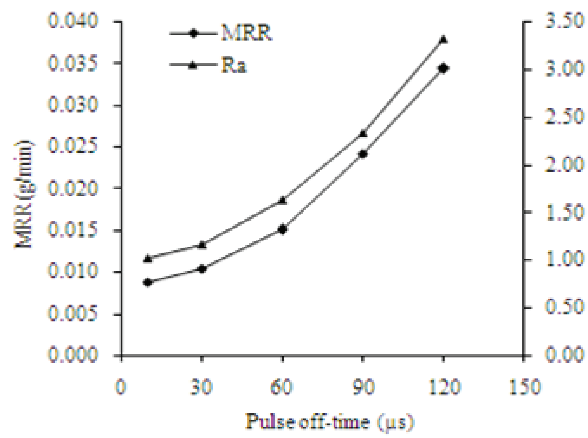

Fig. 8 Effect of pulse off-time on MRR and Ra

longer time available for the ejection of the molten material from the workpiece surface. Due to this, all the molten material is removed during pulse off-time and the softened material is removed during grinding process resulting MRR increases.

Figure 8 also shows that the Ra value increases with increase of the pulse off-time. This is due to fact that large volume of fresh dielectric enters into gap with an increase of the pulse off-time. Due to this, the softer workpiece surface becomes harder due to the quenching effect of the dielectric. As a result, the abrasive particles start blunting during grinding process as which Ra value increases.

E. Effect of Wheel RPM on MRR and Ra

Figure 9 shows the variation of MRR and Ra with respect to wheel RPM at constant input parameters such as discharge voltage=40 V, current=1 A, pulse on-time=5 µs, and pulse off-time=10 µs. Fig. 9 shows that MRR increases and Ra value decreases with increase of the wheel RPM. This is due to fact that the flushing efficiency enhances with increases of the wheel RPM, thus the molten material is completely removed and no recast layer is formed. This phenomenon leads to increase of the MRR and decrease of the Ra value.

An increase of the wheel RPM, it may be also possible that large numbers of abrasive particles make contact with workpiece surface during grinding process. Due to this, small amount of material is removed by each particle during grinding process resulting Ra value decreases with increase of the wheel RPM. It may be also possible that gap is properly cleaned and no debris accumulated into gap, thus a stable

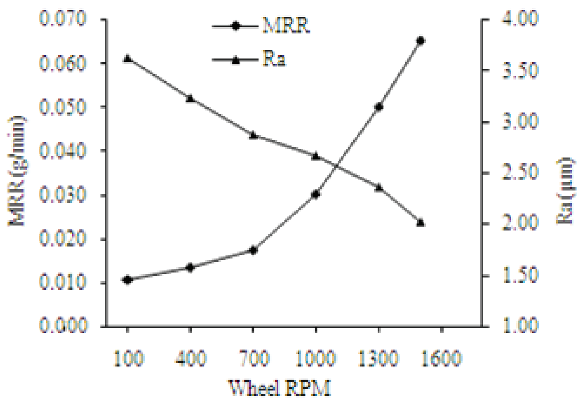

Fig. 9 Effect of wheel RPM on MRR and Ra

spark is produces during pulse on-time. This phenomenon leads to increase of the MRR and decrease of the Ra value.

IV. Conclusions

In present study a new hybrid machining process named as S-EDDFG process has been developed. The performance of the developed process has been tested on Al/SiC composite. During experimentation, the effect of discharge voltage, current, pulse on-time, pulse off-time and wheel RPM has been investigated on MRR and Ra. After experimental studies and analysis, following conclusions have been drawn:

a. Higher discharge voltage is not suitable for S-EDDFG process because the gap between workpiece and compound wheel increases with increase of the discharge voltage resulting MRR declines.

b. MRR and Ra value increases with increase of the current and pulse on-time due melting and softening of the workpiece material in large amount at workpiece surface.

c. MRR increases and Ra value decreases with increase of the wheel RPM because higher wheel PM enhances the flushing efficiency of the dielectric.

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