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***Research paper***

# Comparison of Gas Assisted Hybrid EDM, Rotary EDM and Conventional EDM Processing of High Carbon High Chromium Die Steel

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**Abstract**

The high carbon high chromium die steel is most widely used in various industrial applications. However, effective machining of high carbon-chromium die steel is extremely difficult due to its high hardness and stiffness. In the present work, comparative analysis of Gas Assisted Hybrid EDM (GAHEDM), Rotary EDM (REDM), and Conventional EDM processes have been done with respect to process responses like electrode wear ratio (EWR), material removal rate (MRR), and surface roughness (SR). Experimentation has been done to the study influence of process factors like discharge current, pulse on time, duty cycle, tool rotation and discharge gas pressure on MRR, EWR and SR. Further, from a comparative study, it has been observed that high MRR, low EWR and low SR are obtained in GAHEDM process in comparison of REDM and EDM processes. Analysis of surface morphology reveals that the formation of recast layer and cracks on the surface are fewer in number on work piece machined by GAHEDM process with respect to specimen machined with REDM and EDM processes. The results show that the use of compressed helium gas in GHEDM process has a positive impact on the machining performance. This process may be used for industrial machining operation.

***Keywords***: *Dielectric, MRR, EDM, EWR, Helium.*

## 1. Introduction

Electric Discharge Machining (EDM) is non-conventional machining process that remains as one of the most versatile process for machining of metals having high level of hardness and which are hard to machine using conventional machining techniques [1]. The widely used dielectric fluid in conventional EDM process is commercial kerosene oil.

Although, EDM has numerous advantages over other conventional machining processes but it has limitation of low material removal rate (MRR) and high tool wear rate (TWR). Various researchers have used different techniques and approaches to overcome this limitation.

Ramani and Cassidenti [2] used helium and helium gases as dielectrics in dry electrical discharge drilling. They showed that this method resulted in a low tool wear rate (TWR) and comparatively better surface finish than oil based EDM process. Although, MRR by this process was found to be lower than conventional EDM process. Kunieda et al. [3, 4] showed that high velocity gas flow through tool electrode reduced debris reattachment after a spark and thus considered it as effective in flushing. The debris reattachment was much lower for a thin walled tube and this increased the MRR. It was also shown that the tool wear rate (TWR) was negligible in dry EDM. MRR was found to increase when oxygen gas was used. The results suggested that the heat generated by oxidation was responsible for the increased MRR.

Yu et al. [5] performed groove milling and three-dimensional milling by using dry EDM process. They employed high velocity oxygen gas through rotary tubular tool electrode. Further, they compared the performance of dry EDM process with conventional EDM and conventional EDM milling. They found that dry EDM milling resulted in better electrode wear ratio in comparison of other two processes considered. Further, comparative analysis shows that the machining performance of dry EDM was better than conventional EDM process. However, the machining performance of dry EDM was lower than conventional EDM process. Soni et al. [6] observed an interesting phenomenon when rotary motion was provided to tool electrode. The same was verified by Mohan et al.[7] in their experimentation. They observed that the whirl condition due to rotary action helped to remove the evaporated materials from inter-electrode gap which consequently improved the flushing efficiency as well as MRR. Kuppan et al. [8] explored the effect of electrode rotation while EDM drilling of Inconel 718. Their findings revealed that MRR was notably affected by non-electrical parameters like tool rotation and electrical parameters i.e. discharge current and duty cycle. They observed that surface roughness (SR) reduced with an increase in pulse on time. Koyano et al. [9] studied effect of gas bubbles by varying the hydrostatic pressure on EDM performance. The results indicated that bubbles containing gas enhanced the flushing performance of EDM process. Aliakbari and Baseri [10] investigated the rotary EDM and studied effect of prominent electrical parameters on process output viz. EWR, MRR and SR.

Their observations depicted that EWR, MRR and SR were notably affected by electrode rotation, pulse duration, discharge current and tool electrode geometry. They stated that the improvement in process output (EWR, MRR and SR) was attributed due to use of multiple hole rotary tool electrode. Recently, Plaza et al. [11] investigated the effect of helical shaped electrode on EDM performance during deep hole machining of Ti6Al4V. Their findings suggested that the use of helical shaped electrode enhanced the flushing action resulting in an improvement in MRR, EWR and machining time. Further, they showed that as compared to solid tool the use of helical tool significantly reduced machining time. Singh and Pandey [12] studied the effect of air assisted multi-hole tool electrodes during machinability of EDM process. They found the application of air assisted multi-hole tool improve the MRR and reduced the EWR with respect to solid rotary tool electrodes under same machining conditions. Yoshida et al [13] studied the effect of supplied of oxygen gas in dielectric liquid in EDM operation. They observed that when oxygen is dissolved in dielectric liquid and supplied in electrodes gap machining performance improve significantly.

Having gone through these existent processes available, it was observed that MRR in dry- EDM was poor than oil based EDM. However, tool wear and surface finish were observed better than conventional EDM. Hence, in order to extract the benefits of oil EDM as well as dry EDM, the present work aims to develop a hybrid process of EDM employing both liquid (kerosene) and gas (compressed helium gas) as dielectrics during die-sinking EDM process. In this experimental exploration, compressed gas was supplied through an eccentric-three hole tool, to study the effect of both liquid and gas as dielectrics on EDM performance. The effect of different process factors viz. discharge current, pulse duration, duty cycle, tool rotation and discharged gas pressure have been used to study behavior of MRR, EWR and SR. A comparative analysis of Gas Assisted Hybrid EDM (GAHEDM), Rotary EDM (REDM) and conventional EDM has also been performed in the following sections.

## 2. Experimentation

The experimentation was carried out on carbon chromium die steel having dimension of 15x15x10 mm. The work piece, considered for the study, had a hardness of 45HRC. Table 1 shows chemical composition of selected specimen. In order to ensure effective transfer of heat from tool tip a tool of diameter of 8 mm and 70 mm length were chosen. Figure 1 show the schematic setup mounted on EDM machine. Figure 2 presents the view of tool used during experimentation.

The gas assisted die sinking EDM with an eccentric hole tool was performed on EDM machine. The machining time was fixed to be 15 min. during experiments. Hydrocarbon based oil (Kerosene) was employed as dielectric medium. For the experimental work, four controllable process factors viz., pulse-on time, discharge current, duty cycle and tool rotation were selected. The values of these factors were decided on the basis of trial experimentation and the capability of machine.

**Table 1:** Chemical composition of specimen

| C | Si | Cr | Mn | Fe |
|---|---|---|---|---|
| 1.35 | 0.70 | 0.90 | 0.30 | Rest |

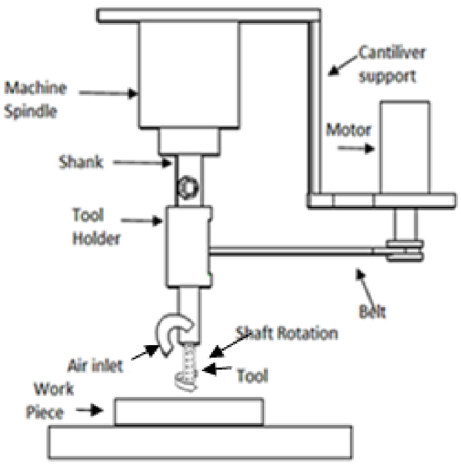



**Fig. 1:** Schematic of the experimental setup.

**Fig. 2:** Pictorial view of tool

Table 2 shows machining parameters range used during present work. For experimentation, open circuit voltage was kept at 60V. For experimentation with GAHEDM process, gas pressure was kept constant at 12mm of Hg. Table 3 shows the summary of test conditions.

**Table 2:** Process factors used in present work

| Machining Parameter | Range |
|---|---|
| Discharge Current ($I_p$) ($A$) | 3-7 |
| Pulse on Time ($T_{on}$) ($\mu s$) | 100-500 |
| Duty Cycle ($DC$) | 0.52-0.76 |
| Tool Rotation Speed ($N$) | 100-900 |

The electrode wear ratio was evaluated as proportion of wear weight of tool to wear weight of specimen,

$$Electrode\ wear\ rate = \frac{Wear\ weight\ of\ tool}{Wear\ weight\ of\ specimen} \text{x } 100 \quad (1)$$

The material removal rate was evaluated as proportion of wear weight of specimen to total machining time [17],

$$Material\ removal\ rate\ (mg/min) = \frac{Wear\ weight\ of\ the\ specimen}{Machining\ time} \quad (2)$$

Specimens and tool electrodes were cleaned with acetone after every experiment. Electronic weighing machining was utilized to evaluate the weight drop of electrodes. A portable SR tester Mitutoyo (Model: SJ 201P) was used to quantify the SR of the machined work piece.

**Table 3:** Experimental test conditions

| Expt. No. | Discharge Current ($I_p$), A | Pulse on time (μs) | Duty Cycle (DC) | Tool Rotation (rpm) |
|---|---|---|---|---|
| 1 | 5 | 300 | 0.76 | 500 |
| 2 | 7 | 300 | 0.64 | 500 |
| 3 | 5 | 500 | 0.64 | 500 |
| 4 | 5 | 300 | 0.64 | 500 |
| 5 | 5 | 300 | 0.64 | 300 |
| 6 | 5 | 100 | 0.64 | 500 |
| 7 | 5 | 300 | 0.52 | 500 |
| 8 | 3 | 300 | 0.64 | 500 |
| 9 | 5 | 300 | 0.64 | 900 |

Analysis of variance (ANOVA) has been performed based on experimental outcome of the test. The contribution (%) of each factor and error on output factor determine by value of variance of error ($v_e$) and sum of squares for regression as obtained from ANOVA table.

$$\Delta Y = t_{\alpha/2}; DF\sqrt{V_e} \tag{3}$$

Where $\Delta Y$ stand for the error in response, $DF$ designate for degree of freedom. The level of confidence interval is denoted by $\alpha$ and its value is taken as 0.05. The variance of error of the anticipated process responses are denoted by $V_e$. The evaluated error has been indicated in the following plots by employing the errors bars.

## 2.1 Effect of Process Factors on MRR

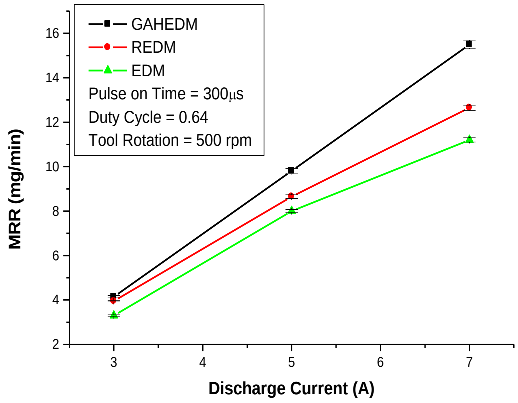
The effect of discharge current, pulse duration, duty cycle and tool rotation on MRR have been presented below.

Figure 3(a) depicts influence of discharge current on MRR for GAHEDM, REDM and EDM processes. It can be observed that for the all three processes, MRR become better with an enhancement in discharge current. This can be reasoned because of a rise in discharge energy in machining region which resulted in greater extent of melting and evaporation of work piece [12]. It can be deduced that MRR is more in GAHEDM process in comparison to REDM and conventional EDM process. It may be due to gas assisted eccentric-hole tool with rotation improves flushing efficiency of molten material from machining gap and hence molten metal is removed from the inter electrode gap more effectively.

Figure 3(b) depicts influence of pulse-on time on MRR for GAHEDM, REDM and EDM processes. It can be deduced from plot that MRR decreased with enhancement in the pulse duration for GAHEDM and REDM processes. Moreover, MRR increased with increase in the pulse duration for conventional EDM process. Because of tool rotation, the plasma channel is expanded at higher pulse on time value. Hence, magnitude of energy is decreased. So less melting and evaporation of specimen occurred, and reduced MRR is produced at longer pulse-on time [7, 14] for GAHEDM and REDM processes. Further it can be deduced from figure that MRR is high with GAHEDM than the REDM process.

Figure 3(c) presents effect of duty cycle on MRR for GAHEDM, REDM and EDM processes. It can be deduced that MRR enhanced with a rise in duty cycle. This can be reasoned that magnitude of spark energy increases with an increase in duty cycle which results in more melting and vaporization of workpiece [19]. From graph it can be percivd that MRR is high with GAHEDM process than REDM and conventional EDM processes. It is probably due to the injection of compressed gas through rotary eccentric hole tool which results a faster removal of the eroded particles. This result in effective flushing of debris from inter electrodes gap.

From graph (refer Figure 3(d)) it is observed that MRR increases with an increase in tool rotation and then decreases for all three processes. This is due to the reason that scale of centrifugal force rises with a rise in tool rotation which results in better evacuation of debris from inter electrodes gap and hence MRR is increased [12,13]. Further an increase in tool speed stirred up the plasma channel resulting in a decrease in the energy density. This results in reduced MRR.

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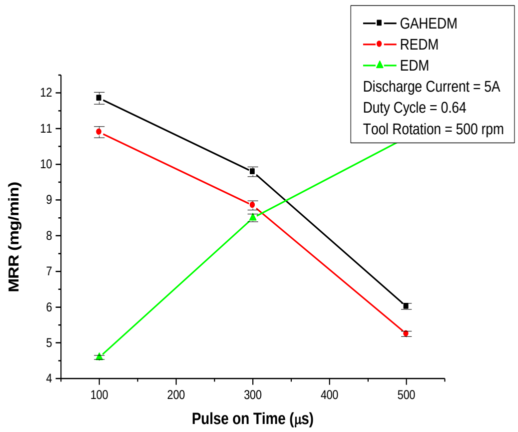


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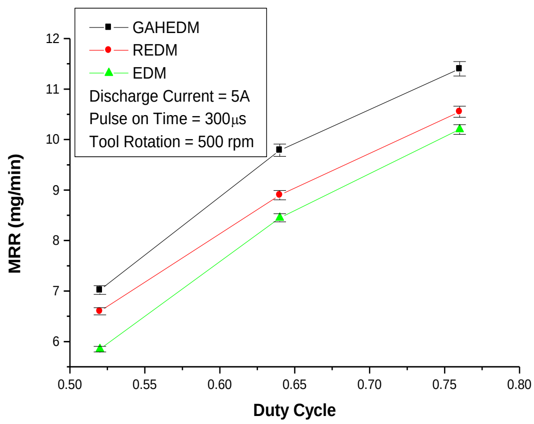


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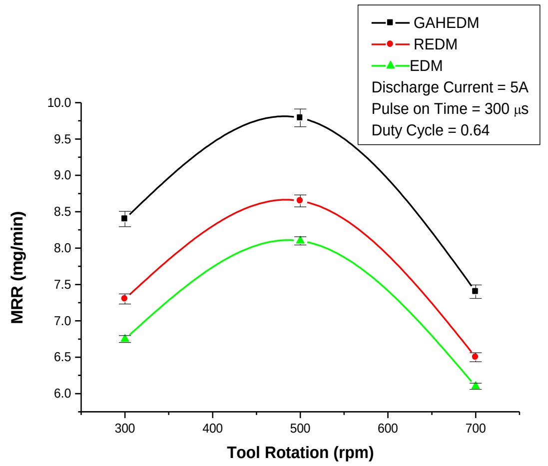
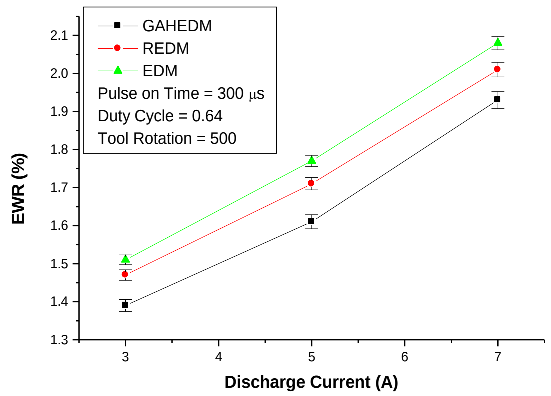



(d)

**Fig. 3:** Influence of (a) discharge current (b) pulse on time (c) duty cycle (d) tool rotation on MRR

## 2.2 Effect of Process Factors on EWR

Figure 4 (a) depicts the effect of discharge current on EWR for GAHEDM, REDM and EDM processes. In all the three processes EWR improves with an increase in discharge current. This is probably due to reason that magnitude of discharge energy increases with an enhancement in current resulting in more melting and evaporation of electrode [16, 17]. Further, it can be seen from the plot that EWR reduced with GAHEDM process than the REDM and conventional EDM processes. This was probably due to reason that when compressed helium gas passes through rotary eccentric hole electrode it reduces the tool tip temperature significantly. This results in formation of smaller crater on tool surface, hence EWR is reduced.

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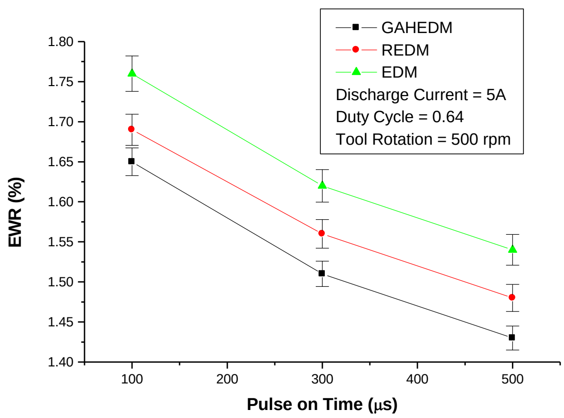


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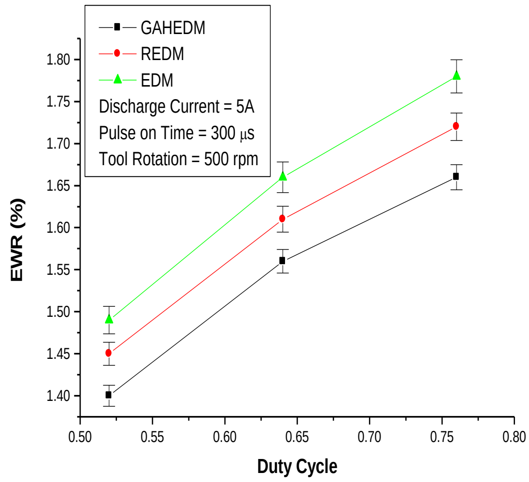


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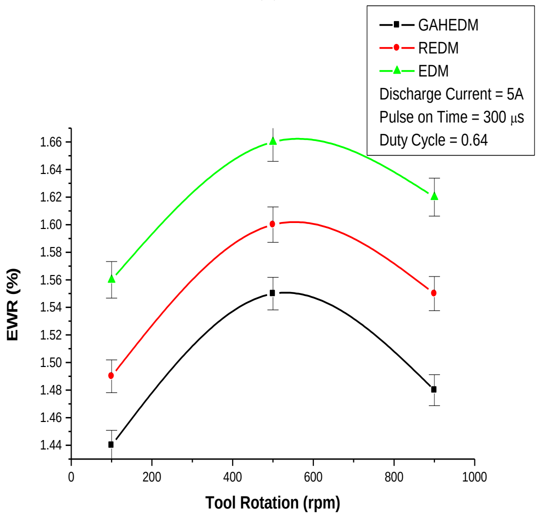



(d)

**Fig. 4:** Influence of (a) discharge current (b) pulse on time (c) duty cycle (d) tool rotation on EWR

Figure4 (b) presents influence of pulse on time on EWR for GAHEDM, REDM and EDM processes. It is observed from figure that the tool wears decreases with an increase in pulse duration for GAHEDM, REDM and EDM processes. This is reason because at higher pulse duration, carbon as a result of breakdown of hydrocarbon (dielectric) is deposited on tool surface. This deposited layer increased tool wear resistance [15]. Further, from figure it can be seen that EWR is less in GAHEDM process than REDM and EDM processes. It is most likely because when compressed gas passes through the tool, it cools surface of the tool which results in lesser melting of the tool and hence EWR is reduced.

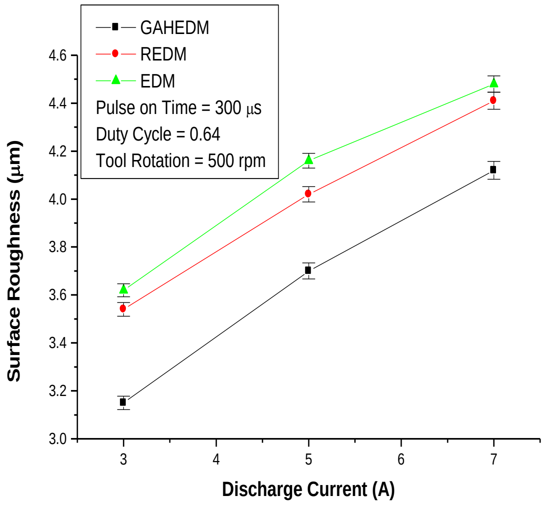
It can be deduced from Figure 4(c) that EWR rises with an increase in duty cycle for all the three processes. The magnitude of energy increases with an increase in duty cycle and this result in an increased EWR [17]. Further, it can be seen that EWR reduced in case of GAHEDM process than REDM and EDM processes. It is likely because the use of eccentric hole rotary tool in case of GAHEDM process with liquid cum gaseous dielectric enhances flushing efficiency which effectively carries away the eroded particles and heat.

Figure 5 (d) reveals that EWR improves with increase in tool rpm for both processes. Because of an increase in tool rpm, magnitude of centrifugal force is increased. Under the influence of increased centrifugal forces, the deposited black carbon is removed from tool surface [15]. This resulted in an increased EWR.

## 2.3 Effect of Process Factors on SR

Figure 5(a) shows influence of discharge current on SR during GAHEDM, REDM and EDM processes. From the graph it is seen that for all the three processes SR increases with an increase in discharge current. The spark density of discharge increased with a rise in current which causes a deeper crater and resulted in an increased surface roughness.

Further, it can be deduced from figure that SR is less in case of GAHEDM process than REDM and conventional EDM processes. Figure 5(b) presents influence of pulse on time on SR during GAHEDM, REDM and EDM processes. From graph it may be deduced that surface finish enhance with arise in pulse duration for GAHEDM and REDM processes. It was reason because expansion of plasma channel which resulted in formation of shallow craters. Hence, surface roughness decreased with a rise in pulse on time. Further, it can be deduced from figure that SR is less in case of GAHEDM process with liquid cum gaseous dielectric than REDM process. Similar observation has been found by Chatopadhyay et al. [14] and Wang et al. [19] during their experimental investigation of rotary EDM process. Figure 5(c) depicts effect of duty cycle on SR during GAHEDM, REDM and EDM processes. From graphical representation it is observed that SR rises with an increase in duty cycle. The enhancement in duty cycle results in higher spark energy and this resulted in enhanced surface roughness. Besides this SR is less in case of GAHEDM process than REDM and conventional EDM processes.

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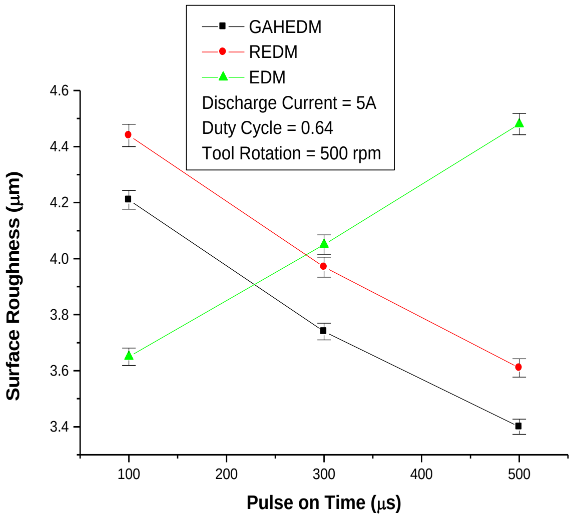


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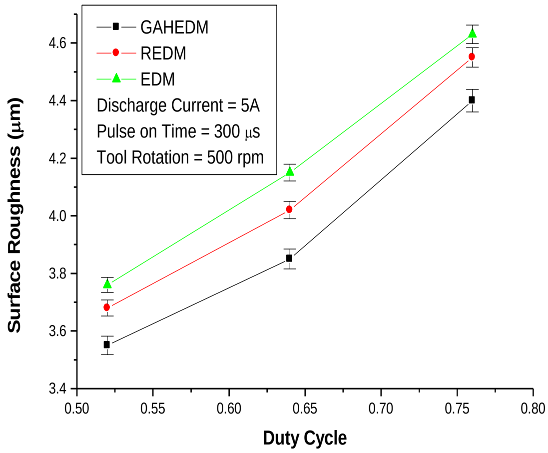


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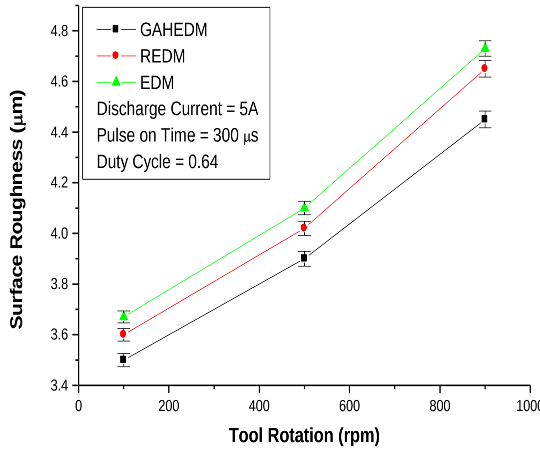
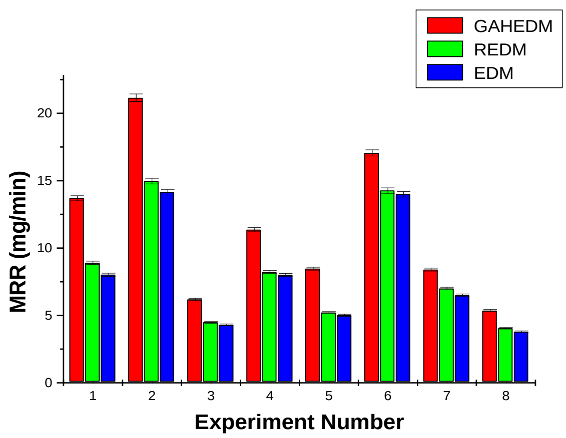



(d)

**Fig. 5:** Influence of (a) discharge current (b) pulse on time (c) duty cycle (d) tool rotation on SR

Figure 5(d) presents the influence of tool speed on SR during GAHEDM, REDM and EDM processes. It can be observed that SR starts decreasing with a rise in tool rpm. It was probably because rise in tool rpm which improved the flushing of debris and resulted in less deposition of re-melted material hence high surface roughness is obtained. Further, it can be observed from plot that SR is less in case of GAHEDM process than REDM and conventional EDM processes. The decrease in surface roughness was probably due to high heat carrying capacity of helium with effective heat reaching the work surface is less. This caused small sized crater resulting in least surface roughness among the two processes.

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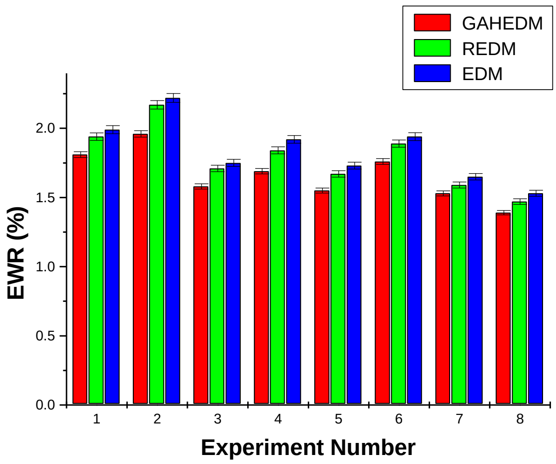


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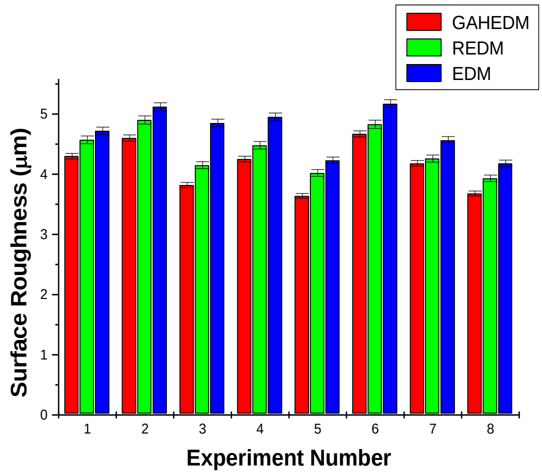



(c)

**Fig. 6:** Comparative analysis of (a) MRR (b) EWR(c) SR of two processes

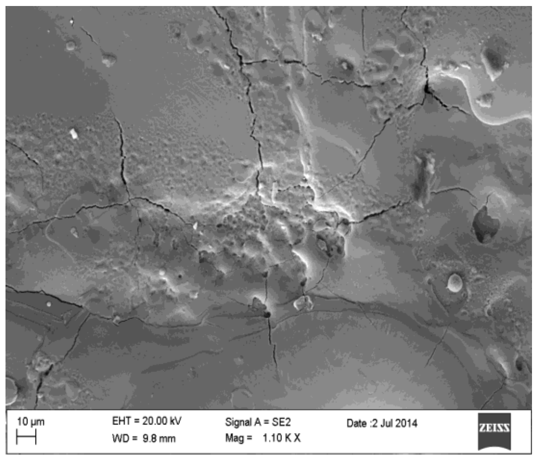
The comparison of MRR for GAHEDM, REDM and EDM machining is shown in Figure 6(a). Under same combinations of process factors, MRR is found higher in machining with GAHEDM process in comparison of REDM and conventional EDM machining. The use of compressed gas in case of GAHEDM process causes an enhancement in material vaporization due to reduction in temperature. This generates better removal of molten material, and led to less deposition of eroded particles on machined surface, resulting in a rise in MRR [18]. The use of liquid cum gaseous dielectric with eccentric-hole rotating electrode in case of GAHEDM process led to increase in MRR. Based on the results obtained, the use of liquid cum gaseous dielectric in case of GAHEDM process led to more than 71% increase in MRR for the same machining conditions.

Figure 6 (b) reveals the comparison of EWR for GAHEDM, REDM and traditional EDM machining. For the same machining conditions, EWR is found to be comparatively less in GAHEDM machining with liquid cum gaseous dielectric in comparison of REDM machining and conventional EDM machining. This was probably because temperature of electrode tip reduced by compressed helium gas which minimized the melting and vaporization of the tool electrode thereby reducing its wear. The use of liquid cum gaseous dielectric with eccentric-hole rotating electrode in case of GAHEDM process leads to a reduction of EWR. Based on the results obtained, the use of liquid cum gaseous dielectric in case of GAHEDM process led to more than 32% reduction in EWR for the same combinations of process factors in comparison of other two processes.

The comparison of SR for GAHEDM, REDM and conventional EDM machining is shown in Figure 6(c). For the same machining conditions, SR is found less in GAHEDM machining with liquid cum gaseous dielectric in comparison of REDM machining and conventional EDM machining with liquid dielectric. Helium having high heat carrying capacity the effective heat reaching the work surface is less. This caused small sized crater resulting in less surface roughness while machining with GAHEDM process. The use of liquid cum gaseous dielectric with eccentric-hole rotating electrode in case of GAHEDM process led to reduction in SR. Based on the result obtained the use of liquid cum gaseous dielectric in case of GAHEDM process led to more than 15% reduction in SR.

## 3. Surface morphology of specimen machined using GAHEDM, REDM and conventional EDM processes

Surface crack formation can be observed by SEM image (as shown in Figure 7). From figure it is observed that formation of cracks on machined specimens are less in GAHEDM process in comparison to workpiece machined using REDM and conventional EDM process. This was probably due to cooling provided by compressed gas reduces the temperature of dielectric in tool tip region. As a consequence, the temperature of the crater drops significantly. This caused a reduction in residual stress [18] underneath of machined surface and propagates less surface cracks. Further, analysis of SEM images reveals that formation of recast layers per unit area relatively found less on surface of specimens machined by GAHEDM process in comparison of specimens machined with conventional EDM process. The critical analysis of surface morphology shows that surface integrity of specimens machined with GAHEDM process found to be better than specimens machined with REDM and conventional EDM processes under the same processing conditions.

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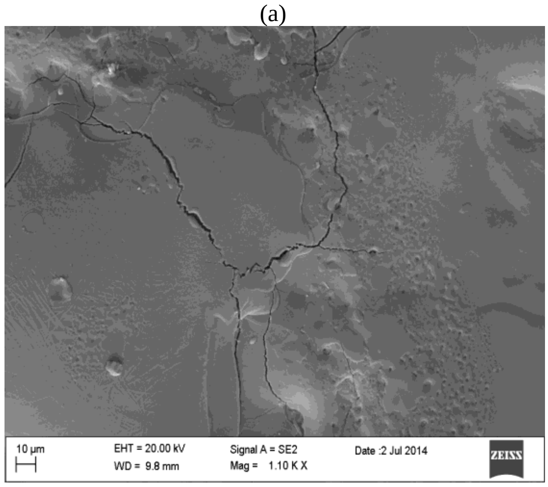


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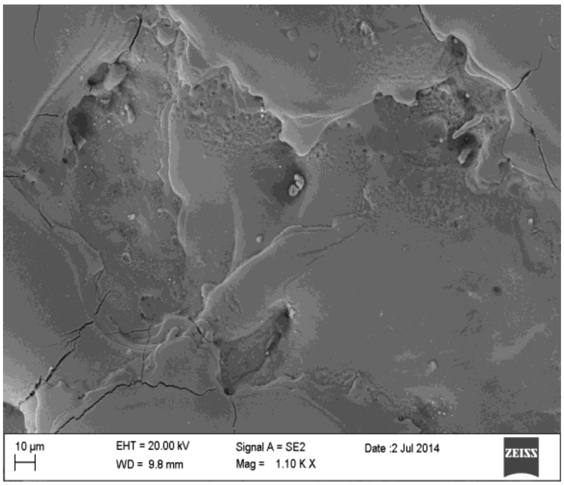


(c)

**Fig. 7:** Surface characteristic of work piece machined by (a) EDM (b) REDM (c) GAHEDM

## 4. Conclusions

In present study, a hybrid process of EDM employing both liquid (kerosene) and gas (compressed helium gas) as dielectrics has been developed successfully to machine the die steel specimens. The influence of different process factors on EDM performance of high carbon high chromium die steel has been performed. It was observed that an improve MRR, reduced EWR and low SR obtained when GAHEDM process was used as compared to REDM and conventional EDM processes, under same processing conditions.

Based on the result obtained, the use of GAHEDM process led to more than 71% rise in MRR, 32% and 15% reduction in EWR and SR respectively in comparison of traditional EDM process.

The examination of machined surface revealed that the formation of recast layers and surface cracks decreased in GAHEDM machining in comparison to conventional EDM machining. The critical analysis of surface morphology reveals that surface integrity of specimens machined with GAHEDM process found to be better than specimens machined with REDM and conventional EDM processes under the same processing conditions.

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