Machining Performance of Green Electrical Machining

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Abstract

The aim of this study is to develop a novel green electrical machining (GEM) using gas media immersed in deionized water. The developed process can fulfill the environmentally friendly issue and satisfy the demand of high machining performance. The experiments were conducted by this developed GEM process to investigate the effects of machining parameters on machining characteristics in terms of material removal rate (MRR), electrode wear rate (EWR), and surface roughness. Firstly, the experiments were conducted to assess the feasibility of the new developed GEM process. Moreover, the main GEM process parameters such as machining polarity, peak current, pulse duration, as well as the gas supply conditions like compressed pressure were varied to evaluate effects on machining characteristics for SKD 61 steel. A high frequency digital oscilloscope was used to detect the discharge waveforms during the machining to evaluate the effects of various machining media on gap stability, and the surface morphologies were observed by a scanning electronic microscope (SEM) to determine the influences of electrical discharge energy on the surface integrities. The developed GEM process revealed the potential to obtain a stabilizing machining progress with excellent machining performance and environmentally friendly feature. As the experimental results shown, the MRR increased with peak current, pulse duration, and compressed air pressure. In addition, the EWR went up with peak current, and the EWR declined as further extending the pulse duration at large peak current. The surface roughness went up with peak current, as well as the machined surface revealed a coarser feature when the peak current was set at high value.
Keywords: Green electrical machining, Machining performance, Gas media, Deionized water, Surface roughness

1. Introduction

Dielectric fluid like kerosene exhibits excellent machining performance, so it is widely employed in common electrical discharge machining (EDM) applications. Using kerosene as the dielectric fluid for EDM would result in the undesirable problems in terms of fire hazard, air pollution, and environmental damage. Therefore, to develop a reliable dielectric media with both excellent performance and environmentally friendly feature is urgently necessary, and then an automatic operation scheme with safety regime will be realized. The concept of EDM performed in gas media was proposed by Kuneida and his coworkers in 1997 [1]. The molten materials generated in EDM process was ejected from machining area by a gas jet with high pressure. In their work, the removal efficiency of molten material was improved by using a hollow electrode, which passed the high compressed air into machining gap to prevent the machined surface from producing excessive thickness of recast layer. If the molten material could not be removed completely, it would re-solidify and adhere on the machined surface to deteriorate the surface quality and reduce the machining efficiency. The benefits to EDM associated with jetting and intake modes of gas supply have been studied [2]. Their experimental results reported that the air supplied in intake mode presented a better machining precision. The technique of EDM in gas media has also been used to explore the machining feasibility in wire electrical discharge machining (WEDM) [3]. Yu et al. [4] studied the potential of EDM in gas media for machining tungsten carbides; the experimental results confirmed that the tungsten carbides could be machined by EDM milling in gas media using uniform tiny electrodes. Curodeau et al. [5] investigated the effects of EDM in gas media on surface modification and surface finishing by using a thermoplastic composite electrode for mold manufactures. In addition, Zhang [6] incorporated ultrasonic vibration with EDM to build a hybrid process of EDM with ultrasonic machining (USM), and the ejection efficiency of machining debris could be facilitated for EDM in gas media by using such a hybrid machining system. According to the previous investigation [7], the compressed gas jet can be regarded as the machining media to maintain the stabilization of discharge sparks consecutively generating in the machining gap and to expel the molten material in the EDM process. However, the gas media within the discharge gap had less constriction, and the molten materials lack of dielectric explosion to eject form the machined surface. If the molten materials expelled incompletely, the remainder would recast and adhere on the machined surface at the end stage of EDM. Thus, the machining precision and surface quality would be deteriorated by producing thick recast layer and abundant debris adhered. This investigation proposed a new GEM process using gas media immersed in deionized water. The constriction of gap and the debris ejection could be improved due to the machining zone filling with the liquid such as deionized water. The liquid supplied into machining zone could enhance the debris evacuation and cooling effect to obtain the process stability and surface quality during the process.. The technique of GEM process associated with environmental issues can be treated, and the benefits related to industrial applications of GEM process can be also promoted.

2. Experimental Method

2.1 Experimental Materials

The workpiece material adopted SKD 61 steel, widely used in die and mold manufacturing industries with the dimensions of 10 mm×10 mm×10 mm. The specimens were initially milled and ground to guarantee the parallelism for each experiment. Table 1 lists the chemical composition of the SKD 61 steel. The electrode material was employed electrolytic copper, which is the most common material used as tool electrode in EDM industries. The electrode was shaped into a tube form with 50 mm length as well as 5 mm inner and 8 mm outer diameters. In addition, the front face of electrode was ground using 600, 800, and 1200 mesh grit of emery paper on a plate to guarantee the surface finishing and the flatness of each electrode at the same level. Table 2 shows the essential properties of electrolytic copper. In this investigation, the GEM process would be conducted with gas immersed in deionized water. Therefore, the machining media consisted of deionized water and gas media. The compressed and dehumidified air was employed as the gas media, which was adjusted by a pressure control valve and was delivered through the tube electrode to machining gap of GEM process.

Table 1 Chemical composition of SKD 61 steel.

Element	C	Si	Mn	Cr	Mo	V
wt.%	0.32-0.42	0.8-1.2	<0.5	4.5-5.5	1.0-1.5	0.8-1.2

Table 2 Essential properties of electrolytic copper.

Essential properties	Descriptions
Specific gravity (g/cm^3)	8.94
Melting range (°C)	1065-1083
Thermal conductivity (W/m·K)	388
Specific heat (J/kg·K)	385
Thermal expansion coefficient (1 /℃)	16.7×10^{-6}
Electrical resistivity (Ω·cm)	1.7×10^{-6}

2.2 Experimental Equipment and Procedure

In this investigation, a commercial type (Model CR-6C, CREATOR) of transistor controlled die-sinking EDM machine was used. The GEM experiments were performed to explore the feasibility of SKD 61 steel using compressed air immersed in deionized water as the machining media. Moreover, the effects of machining variables on machining characteristics of GEM process were determined. The air pressure was controlled by a precision pressure control valve, the regulated gas media were passed to the machining zone through the pipe and the tube electrode. The deionized water was infused into a self-built tank and maintained at 50 mm height over the electrical spark spots during the EDM process. The molten materials were rapidly expelled by the gas jet from the machining zone. The constraint of the machining gap was ameliorated by the deionized water, and the GEM stability could be improved to enhance the machining efficiency. The details of gap action by compressed air jet are depicted in Fig.1.

The machining characteristics such as material removal rate (MRR, mm^3/min), electrode wear rate (EWR, mm^3/min) and surface roughness (Ra/μm) were chosen to evaluate the effects of the machining parameters of GEM process with gas media immersed in deionized water. Moreover, a high frequency oscilloscope was connected to the two terminals (tool and workpiece) to detect the waveforms of discharge current and voltage during the GEM process, and then the discharge waveforms were utilized to gauge the gap stability of GEM process with gas media immersed in deionized water. In addition, the surface integrity was also observed by a scanning electron microscope (SEM) to evaluate the influences of machining parameters on the variation of surface topography.

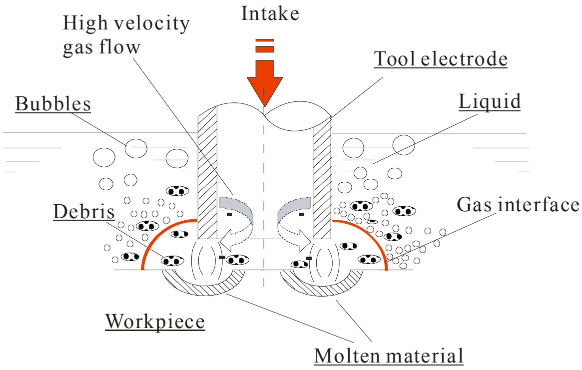

Fig.1 Details of gap with compressed air jet.

2.3 Experimental Condition

The essential GEM parameters such as peak current (I_p), pulse duration (τ_p), types of machining media (type), pressure of air jet (AP) were varied to explore their effects on machining characteristics. The machining elapsed time was set at 30 min for each experiment. The detail experimental condition is listed in the Table 3.

Table 3 Experimental conditions.

Working conditions	Descriptions
Workpiece	SKD 61
Electrode	Electrolytic copper
Polarity	Positive (+): Cu(+), SKD61 (-)
No-load voltage	260 V
Servo reference voltage	40 V
Peak current	5, 10, 15, 20 A
Pulse duration	250, 500, 750, 1000 μs
Duty factor	0.5
Dielectric fluid	Air (Compressed), Deionized water
Air pressure	0, 0.1, 0.3, 0.5 MPa
Working time	30 min

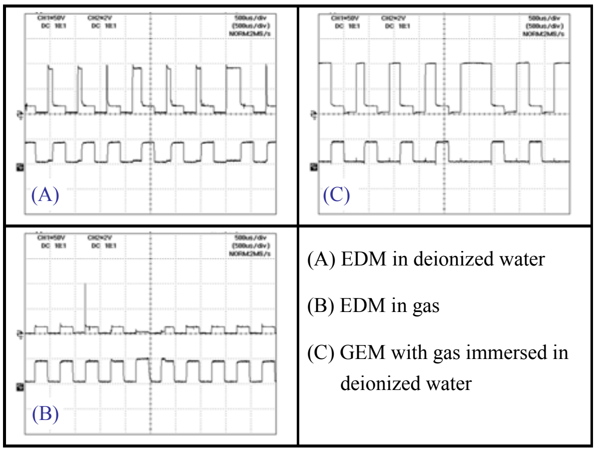

Fig.2 Discharge waveforms by using various machining media. (I_p=10 A, τ_p=250 μs, AP=0.5 MPa)

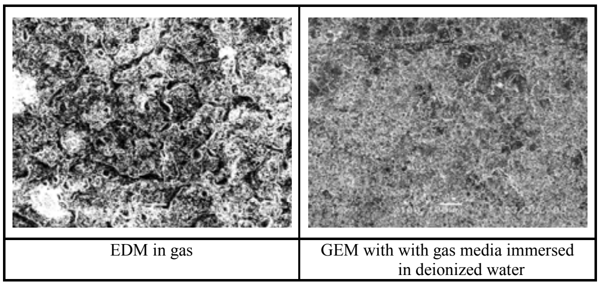

Fig.3 Comparison of surface morphologies obtained from EDM in gas and GEM with gas media immersed in deionized water. (I_p=10 A, τ_p=250 μs, AP=0.5 MPa)

3. Results and Discussion

3.1 Effects of Machining Media

Fig.2 shows the discharge waveforms obtained from using various machining media. As the experimental results shown, both deionized water and GEM with gas media immersed in deionized water revealed that the isolation of the EDM gap conditions could recover rapidly. In contrast, the gap condition of EDM in gas media recovered to initial dielectric state was incomplete. Although the number of spark pulse revealed an increasing trend, the pulse train almost classified as arcing state, when the machining media of EDM were using gas media. As a consequence, the stability of gap condition for electrical discharges could not maintain appropriately and the spark concentration generated easily during the EDM process. Fig.3 depicts the comparison of surface morphologies obtained from EDM in gas and GEM process with gas media immersed in deionized water under the same EDM condition. It is evident that the machined surface generated by GEM with gas media immersed in deionized water was finer and more uniform than that by EDM in gas. The dielectric recovery of GEM with gas media immersed in deionized water was fast and easy, and then the gap status could maintain at a more suitable circumstance in EDM process. Moreover, the space constraint could be promoted and the cooling capability was enhanced, when the deionized water was filled in the machining zone. The molten materials were removed more completed during EDM process. Thus, the GEM with gas media immersed in deionized water could keep the electrical discharge progress more stable and could obtain a fine finishing machined surface.

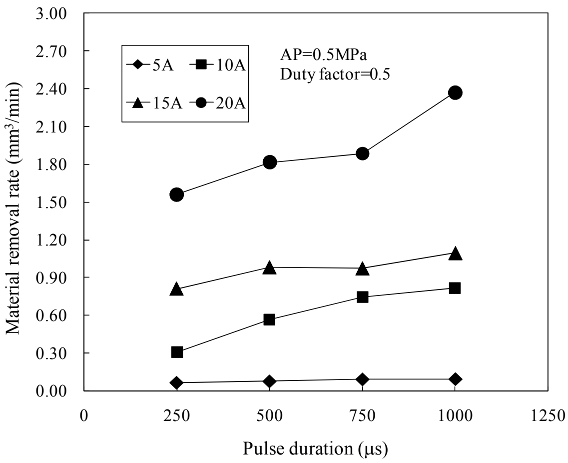

Fig.4 Comparison of MRR in GEM with gas media immersed in deionized water under various peak currents and pulse durations.

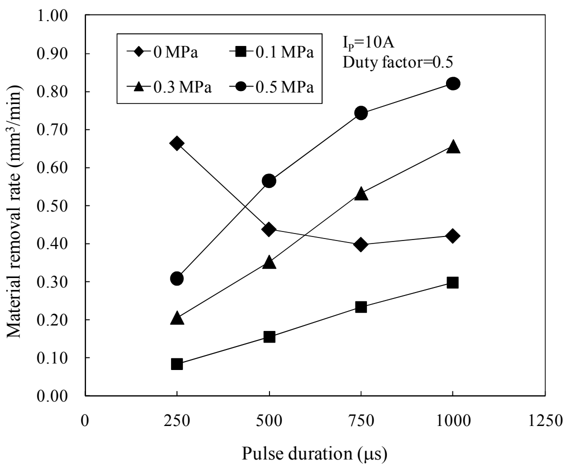

Fig.5 Comparison of MRR in GEM with various gas jet pressures and pulse durations.

3.2 Material Removal Rate

Fig.4 shows the MRR of GEM with gas media immersed in deionized water under various peak currents and pulse durations. As the experimental results shown, the MRR went up with peak current and pulse duration. It is evident that the melting and vaporing effects agreed with the amount of discharge energy, and thus the MRR increased with the amount of discharge energy during GEM process. Fig.5 depicts the MRR with various gas jet pressures and pulse durations. It is observed that the MRR of GEM with gas media immersed in deionized water enlarged with air jet pressure and pulse duration. Generally, a high air pressure injected in the machining zone would promote the evacuation of machining debris from machining gap and would facilitate the dielectric recovery. Therefore, the stability of the progress could be improved and the surplus materials removal effects were boosted. In addition, the amount of discharge energy per single pulse was increased when the pulse duration extended. The more surplus materials could be removed at a longer pulse, so the MRR was enlarged. Moreover, it reveals different trends of MRR between the EDM conducted in liquid dielectric (air jet pressure set at 0) and GEM with gas media immersed in deionized water. As the experimental results show that the MRR obtained from liquid dielectric declined with extending the pulse duration. Consequently, the material removal efficiency highly depended on the impulsive force caused by the explosion of liquid dielectric in EDM process. It well knows that the impulsive force mainly acted at the initial stage of a pulse discharge and revealed a steep descent with the increasing of the pulse duration [8]. As the result, the MRR of EDM in liquid was dissimilar to that of GEM with gas media immersed in deionized water. The MRR of GEM with gas media immersed in deionized water augmented with the increasing of pulse duration.

3.3 Electrode Wear Rate

Fig.6 shows the EWR of the GEM with gas media immersed in deionized water under various peak currents and pulse durations. As the experimental results shown, the EWR increased with the peak current. In addition, the EWR illustrates an obviously descendant trend with prolonging the pulse duration at larger peak current (15 A, 20 A), and the EWR shows a less variation with the increasing of pulse duration at smaller peak current (5 A, 10 A). The tendency of EWR almost consisted with the MRR. In other words, the EWR and MRR enlarged as the discharge energy increased. However, the EWR exhibited a reduction with increasing of the pulse duration. It can be attributed to the expanding of the discharge channel and excellent thermal conductivity of copper material. Fig.7 depicts the EWR of the GEM with gas media immersed in deionized water under various air jet pressures and pulse durations. It is observed that varying the air jet pressure was insignificant associated with EWR for GEM with gas media immersed in deionized water. Furthermore, the EWR of the EDM in liquid (air jet pressure set at 0) was near five times larger than that of GEM with gas media immersed in deionized water. It may be that the impulsive force would be formed in the discharge gap while liquid dielectric was used as the dielectric media in EDM.

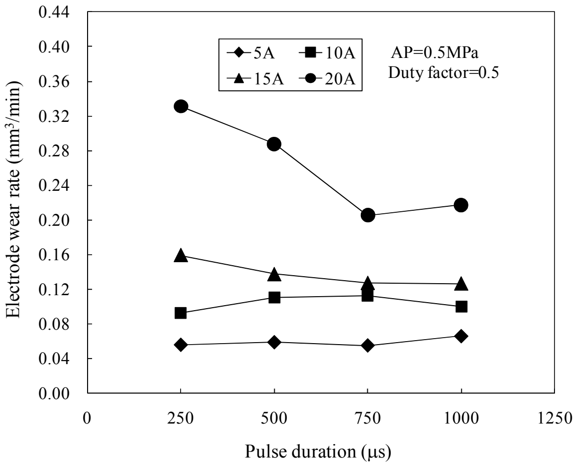

Fig.6 Comparison of EWR in GEM with gas media immersed in deionized water under various peak currents and pulse durations.

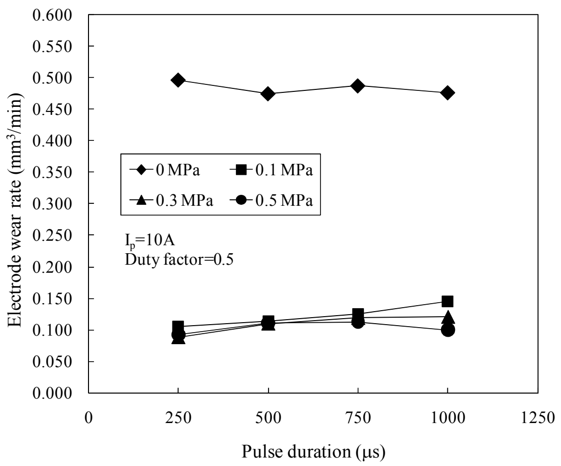

Fig.7 Comparison of EWR in GEM with various gas jet pressures and pulse durations.

3.4 Surface Roughness

Fig.8 shows the surface roughness of the GEM with gas media immersed in deionized water under various peak currents and pulse durations. As the experimental results show, the surface roughness enlarged with peak current, as well as the surface roughness initially increased with pulse duration after reaching a maximum value near 750 μs, and then the surface roughness reduced with further increase in pulse duration. The amount of discharge energy intensified within single pulse when the peak current and pulse duration were increased. As a result, the discharge craters on the machined surface became wide and deep, since more surplus workpiece materials were removed in the process. Fig.9 shows the surface roughness of the GEM with gas media immersed in deionized water under various air jet pressures and pulse durations. It is observed that the surface roughness slightly enlarged with the increase in air jet pressure. Furthermore, the surface roughness obtained from the EDM in liquid situation (air jet pressure set at 0) was higher than that obtained from the GEM with gas media immersed in deionized water.

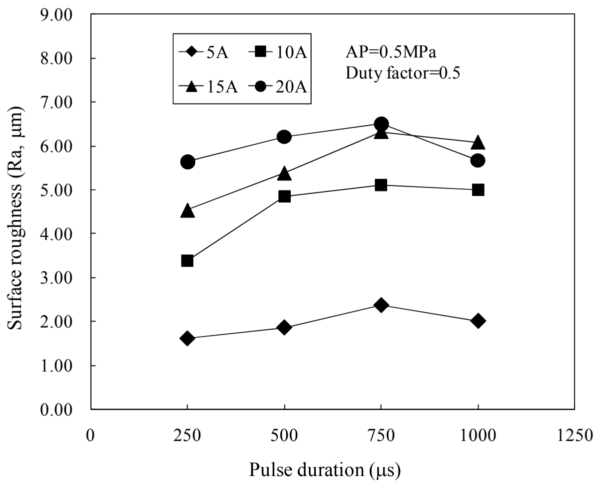

Fig.8 Comparison of surface roughness in GEM with gas media immersed in deionized water under various peak currents and pulse durations.

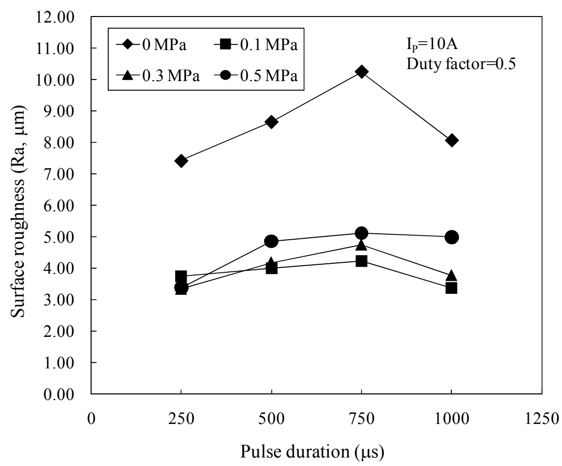

Fig.9 Comparison of surface roughness in GEM with various gas jet pressures and pulse durations.

4. Conclusions

The experimental study explored the effects of machining parameters on machining performance to investigate the feasibility of new developed GEM with gas media immersed in deionized water. According to the experimental results, the following conclusions have been drawn:

(1)GEM process with gas media immersed in deionized water could obtain a stabilized gap condition. The surface integrities were finer than that obtained from EDM in gas media.

(2)The MRR increased with peak current and pulse duration. In addition, high air jet pressure could enhance the MRR of the GEM process with gas media immersed in deionized water. When air jet pressure was set at 0 like that EDM conducted in liquid dielectric, the MRR reduce as the pulse duration extended. It was distinct from the experimental results of GEM with gas media immersed in deionized water.

(3)The EWR of GEM process with gas media immersed in deionized water went up with peak current. Moreover, the EWR revealed a trend that declined with prolonging the pulse duration. Furthermore, the EWR of EDM in liquid was obviously higher than that of GEM with gas media immersed in deionized water. The air jet pressure had insignificant influence on EWR.

(4)The SR of GEM process with gas media immersed in deionized water augmented with peak current. Furthermore, The SR increased firstly with the pulse duration, about 750 μs the SR reached a peak value, and then the SR decreased as the pulse duration further extended. The SR demonstrated a slight increasing trend with air jet pressure. Moreover, the SR of EDM in liquid (air jet pressure set at 0) was higher than that of GEM with gas media immersed in deionized water.

5. Acknowledgement

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