2nd International Conference on Mechanical Engineering Research (ICMER 2013) IOP Publishing
IOP Conf. Series: Materials Science and Engineering **50** (2013) 012062 doi:10.1088/1757-899X/50/1/012062

Electrical discharge machining (EDM) of Inconel 718 by using copper electrode at higher peak current and pulse duration

S Ahmad[a] and M A Lajis[b]
Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400, Parit Raja, Batu Pahat, Johor, Malaysia

Email: [a]said@uthm.edu.my, [b]amri@uthm.edu.my

Abstract. This experimental work is an attempt to investigate the performance of Copper electrode when EDM of Nickel Based Super Alloy, Inconel 718 is at higher peak current and pulse duration. Peak current, I_p and pulse duration (pulse on-time), t_{on} are selected as the most important electrical pulse parameters. In addition, their influence on material removal rate (MRR), electrode wear rate (EWR), and surface roughness (Ra) are experimentally investigated. The ranges of 10 mm diameter of Copper electrode are used to EDM of Inconel 718. After the experiments, MRR, EWR, and Ra of the machined surfaces need to be measured in order to evaluate the performance of the EDM process. In order to obtain high MRR, higher peak current in range of 20A to 40A and pulse duration in range of 200µs to 400µs were used. Experimental results have shown that machining at a highest peak current used of 40A and the lowest pulse duration of 200µs used for the experiment yields the highest material removal rate (MRR) with value 34.94 mm^3/min, whereas machining at a peak current of 20A and pulse duration of 400µs yields the lowest electrode wear rate (EWR) with value -0.0101 mm^3/min. The lowest surface roughness (Ra) is 8.53 µm achieved at a lowest peak current used of 20A and pulse duration of 200µs.

1. Introduction

Nickel based super alloy, Inconel 718 is one of the most difficult-to-machine material which attributed to its ability to maintain hardness at elevated temperature and consequently it's very useful for hot working environment. Formation of complex shapes by this material along with reasonable speed and surface finish is not possible in traditional machining. This alloy is characteristically difficult to machine due to its poor thermal properties, high toughness, high hardness, and high work hardening rate. Usually, a nonconventional machining method like electrical discharge machining (EDM) is chosen for machining Inconel 718 in order to overcome such limitations. However, due to the great physical properties of Inconel 718, the cutting process for this material is become an issue in order to improve the speed of machining process. This alloy has attracted many researchers because of its increasing applicability and the machinability of aerospace alloys will continually decline as service demands increase in order to satisfy the demand for higher temperature capability for structural engine alloys [1,2].

For several decades, EDM has been an important for manufacturing process. It has proved for the machining of super-tough, electrically conductive materials such as the aerospace materials that are difficult to machine by conventional methods [3-6]. The main influence to the machining in EDM will be determined by electrical parameters such a current, pulse duration and voltage, and material properties of work piece and electrode like the material's melting temperature, as well as its electrical and thermal conductivity [7].

Copper became the metallic electrode material of choice for EDM due to its high in electrical and thermal conductivity properties. Copper can produce very fine surface finishes, even without special polishing circuits [8]. Bharti et al. [9] explained the machining characteristics of die-sinking EDM on Inconel 718 with copper as tool electrode. He found that the discharge current is the most influential input parameter on each performance measure. Discharge current and pulse-on-time are identified as common influencing parameters for MRR, Ra and EWR. According to Kuppan et al. [10], the MRR and Ra increases with the increase in peak current for EDM of Inconel 718. The effect of pulse duration is insignificant on MRR because long pulse duration can decrease the MRR. However, result from an experiment done by Kumar et al. [11] when EDM of Inconel 718 shows that an Increase in pulse duration up to 750µs has improves MRR. The primary objective in EDM of materials is always having higher material removal rate (MRR) in order to improve the productivity. Thus, by using higher peak current and pulse duration in this experimental work, hopefully capable to increase the performance and productivity of EDM Inconel 718.

2. Experimental details

In this study, Nickel base super alloys, Inconel 718 were selected as the material for the work piece (specimens 40mm x 30mm x 10mm) and Copper as a tool electrode with diameter of 10mm. The experiments were carried out on a standard CNC EDM machine, *Sodick AQ55L* with positive electrode polarity. The EDM experimental conditions and parameters are summarized in table 1.

Table 1. Experimental conditions and parameters.

Parameters	Levels
Work piece material	Inconel 718
Tool electrode	Copper
Peak Current, I_p (A)	20, 30, 40
Pulse duration, t_{on} (µs)	200, 300, 400
Pulse interval, t_{off} (µs)	Based on 80% duty factor
Voltage, V	120
Electrode polarity	Positive
Dielectric fluid	Kerosene
Depth of cut	3mm

Before experimentation, the work piece top surface was flattened using a surface grinding machine. The initial weight of the work piece and electrode was weighed using a 0.1mg accuracy digital weight balance. The work piece was held on the machine table using a fixture shown in figure 1. The time taken for machining and the weighed of work piece and electrode after machining are noted. All the gathered information from machining time, mass loss after machining process for both tool electrode and work piece were used to determine the values of MRR and EWR.

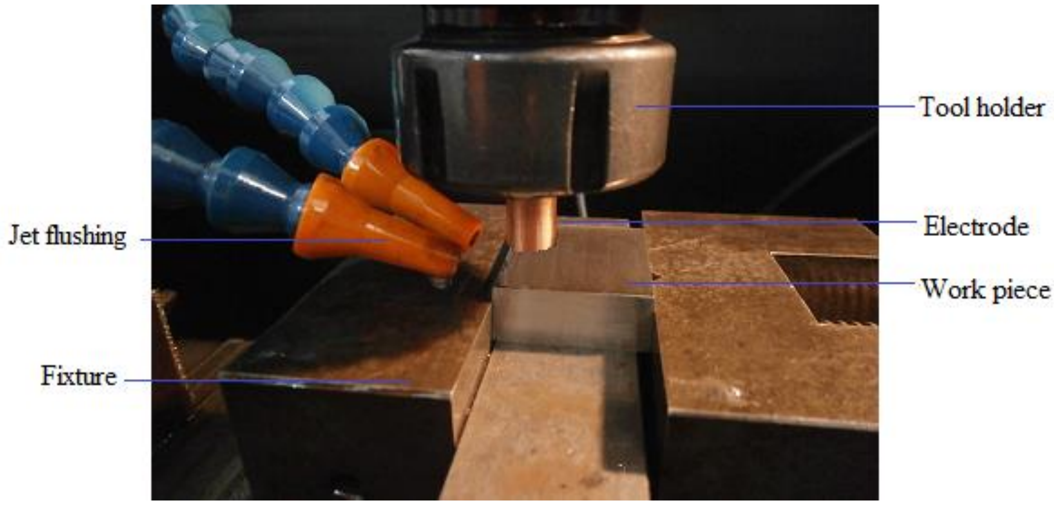


Figure 1. Experimental setup before machining.

The MRR and EWR were calculated using the equation (1) and (2). The surface finish was measured in terms of arithmetic mean roughness (Ra in μm). Ra was measured in the top of machining surface using Mitutoyo's surf test instrument SJ-400. In this research, a constant duty factor was used for the purpose of maintaining machining efficiency. The formula for duty factor is stated in equation. (3).

$$\text{MRR (mm}^3\text{/min)} = \frac{\text{Mass loss of workpiece (g)}}{\text{Density of work piece (g/mm}^3\text{) x machining time (min)}} \quad (1)$$

$$\text{EWR (mm}^3\text{/min)} = \frac{\text{Mass loss of electrode (g)}}{\text{Density of electrode (g/mm}^3\text{) x machining time (min)}} \quad (2)$$

$$\text{Duty factor (\%)} = \frac{\text{Pulse duration (}\mu\text{s)}}{\text{Pulse duration (}\mu\text{s) + pulse interval (}\mu\text{s)}} \quad (3)$$

3. Result and discussion

Table 2 shows the experimental results for EDM of Inconel 718 by using copper electrode.

Table 2. MRR, EWR, and Ra of EDM Inconel 718.

Peak Current, A	Pulse duration, μs	MRR, mm^3/min	EWR, mm^3/min	Ra, μm
20	200	18.6097	-0.0034	8.53
20	300	16.6653	-0.0058	9.72
20	400	14.7250	-0.0101	10.44
30	200	32.7401	0.0391	13.39
30	300	31.3544	0.0098	13.46
30	400	30.3742	-0.0050	14.04
40	200	34.9412	0.0438	14.27
40	300	31.4583	0.0079	14.07

40	400	30.5636	0.0030	14.61

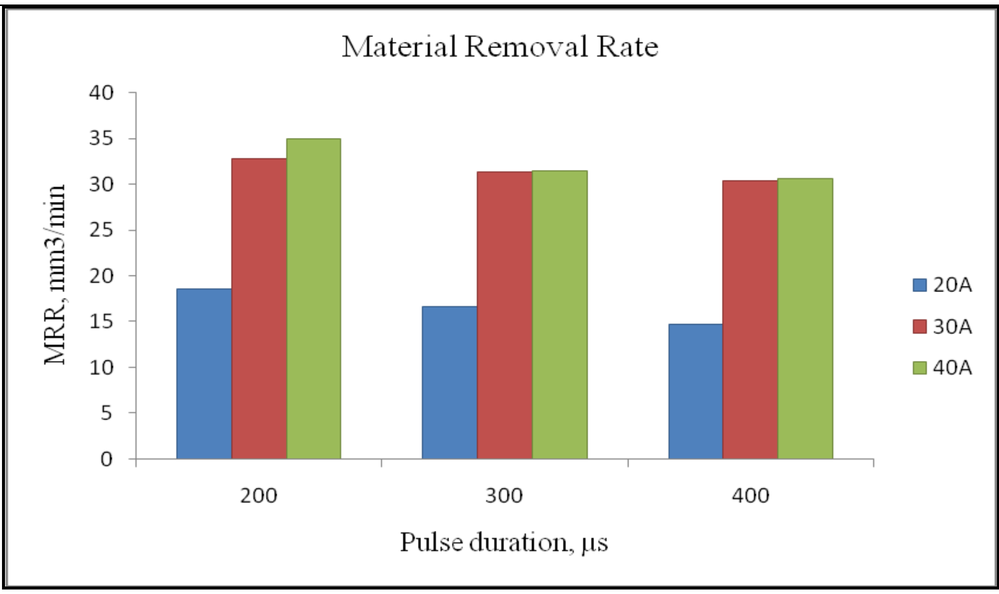


Figure 2. Effect of peak current and pulse duration on MRR.

3.1. Peak current and pulse duration against MRR

The effect of peak current and pulse durations on the MRR is shown in figure 2. It is shown that the peak current affects the MRR significantly. An increased in peak current MRR increase for all setting of pulse duration. MRR increases with the increase in peak current due to the increases of the energy per pulse causes temperature raises sharply that leads to rapid melting of work piece material at sparking area. However, higher pulse duration decreased MRR for all peak current used. With a pulse duration longer than 200µs, the MRR start decreases because of the exceeding value of pulse interval. High ignition delay due to high pulse interval in each cycle reduces the machining rate at a constant machining efficiency [12]. The highest MRR is achieved at 40A of peak current and 200µs of pulse on with value approximately 34.94mm^3/min.

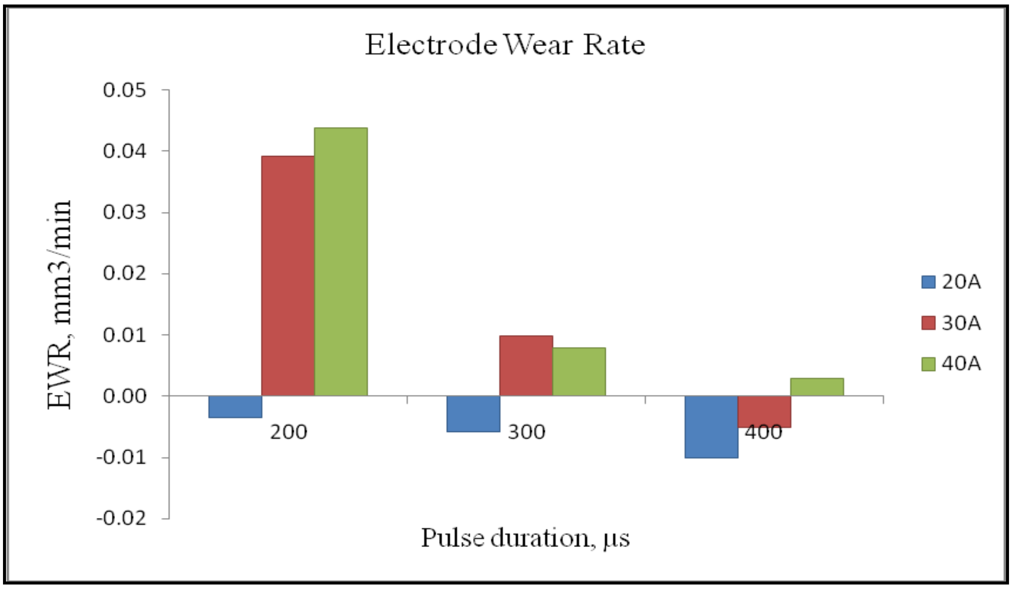
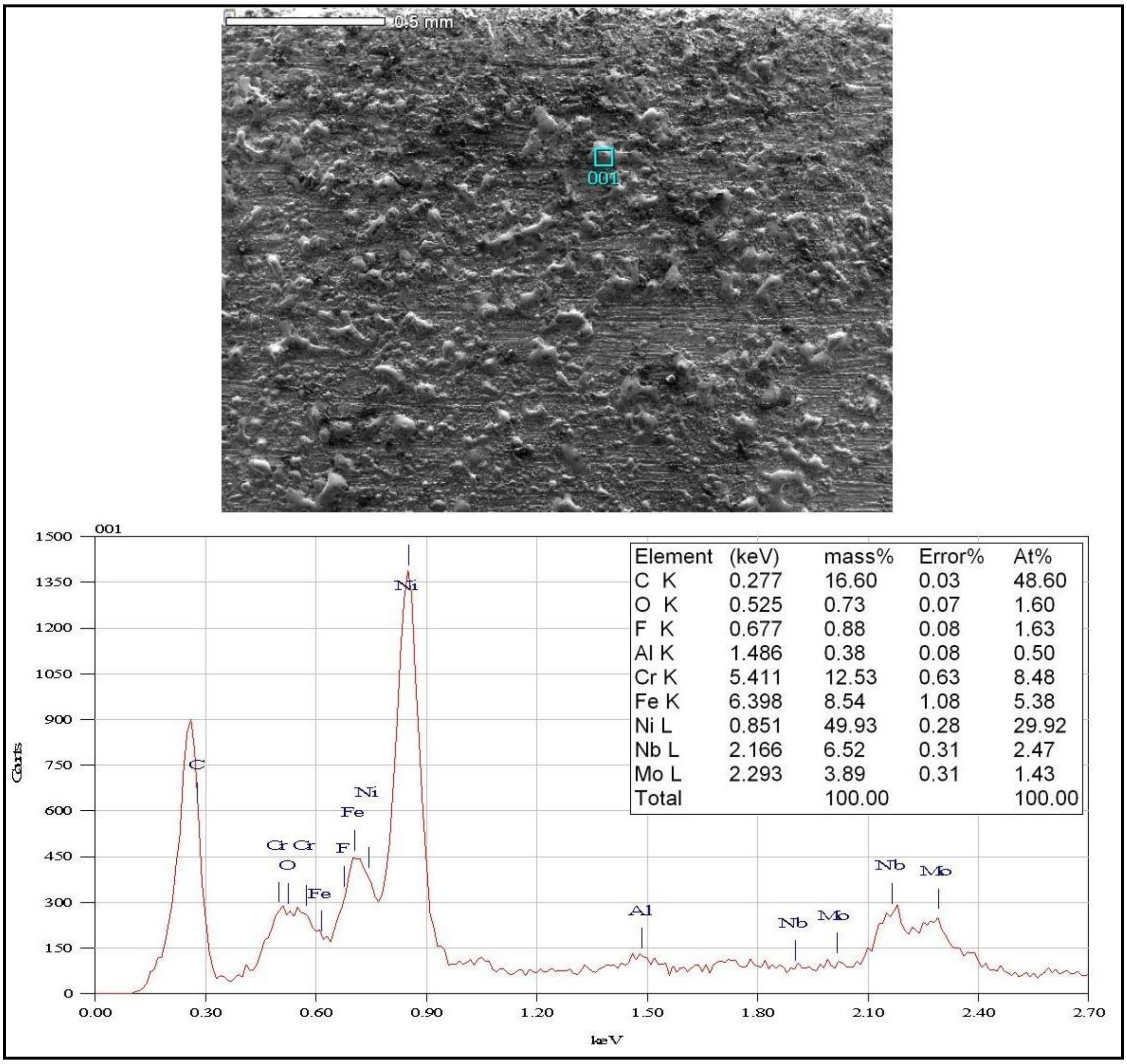


Figure 3. Effect of peak current and pulse duration on EWR.



Element	(keV)	mass%	Error%	At%
C K	0.277	16.60	0.03	48.60
O K	0.525	0.73	0.07	1.60
F K	0.677	0.88	0.08	1.63
Al K	1.486	0.38	0.08	0.50
Cr K	5.411	12.53	0.63	8.48
Fe K	6.398	8.54	1.08	5.38
Ni L	0.851	49.93	0.28	29.92
Nb L	2.166	6.52	0.31	2.47
Mo L	2.293	3.89	0.31	1.43
Total		100.00		100.00

Figure 4. EDS analysis of the copper electrode surface after EDM (I_p = 20A, t_{on}=400µs).

3.2. Peak current and pulse duration against EWR

The effect of peak current and pulse durations on the EWR is shown in figure 3. The higher peak current resulting an increasing in EWR for constant pulse duration. High discharge current leads to high spark energy causes more material removal from work piece and tool electrode which in effect increases the EWR. EWR decrease when increasing of pulse duration for each of peak current used respectively. This is because of deposition of carbon on tool electrode at a high temperature for a longer pulse on time. The negative value for the lowest EWR is indicating that the electrode is deposited by the carbon is more compare to the wear of electrode. Longer pulse duration tends to increase the possibility of carbon deposition on the electrode surface, which function as wear resistant layer for copper electrode and helps to decrease the electrode tool wear. The lowest EWR is approximately -0.01mm^3/min at 20A of peak current and 400µs of pulse duration. A dissolved metal from the work piece also revealed deposited on the copper electrode. This is proved by the EDS test as shown in figure 4. The increment in the electrode weight after machining can be explained with this deposition effect. The similar result also found by Kang and Kim [13].

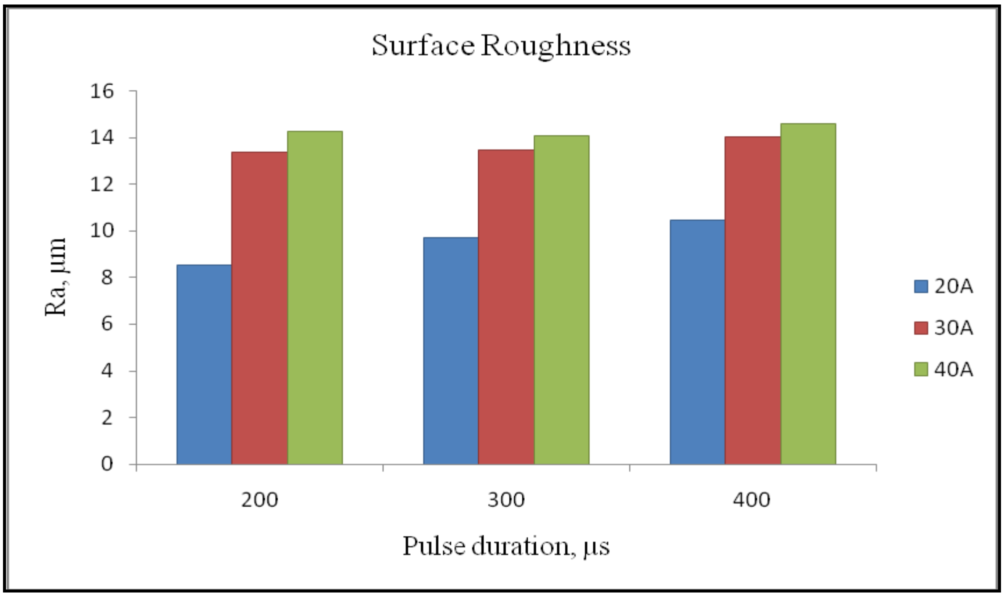


Figure 5. Effect of peak current and pulse duration on Ra.

3.3. Peak current and pulse duration against Ra

Figure 5 shows the effect of peak current and pulse durations on surface roughness of Inconel 718. Ra increases with the increase in discharge current and pulse duration. Figure 6 shows the differences in crater size for the lowest and highest Ra. When the discharge current is high, then the spark intensity are more, as a result, a larger crater depth on the surface of the work piece are produced, hence Ra is high. Pulse duration also strongly influences the Ra. An increase in pulse duration results in proportional increase in spark energy and consequently melting boundary becomes deeper and wider, and hence increases the roughness value [14]. The lowest Ra with value of 8.53µm is achieved at a peak current of 20A and pulse duration of 200µs.

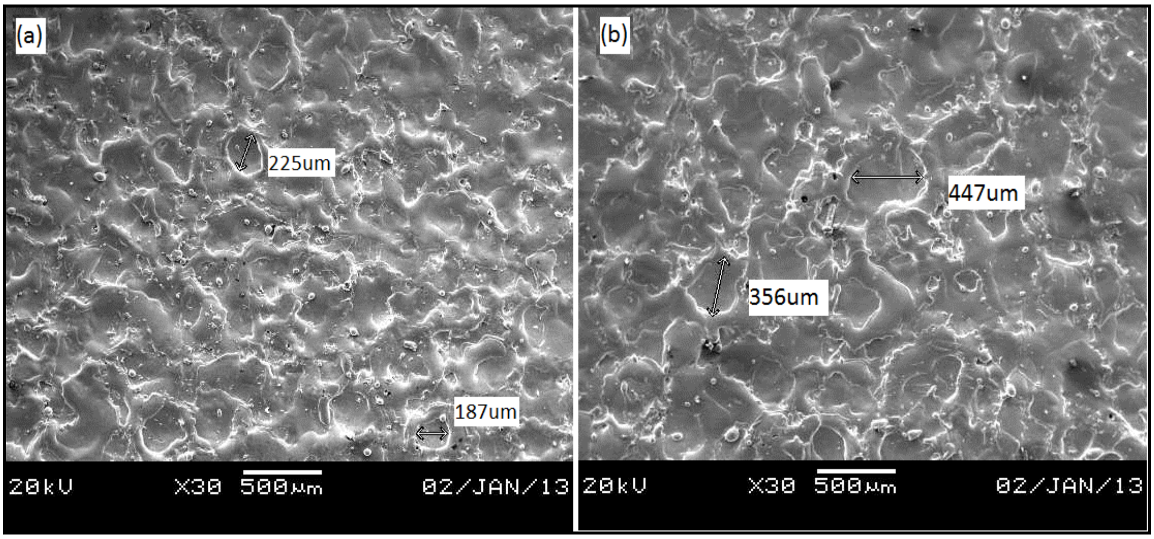


Figure 6. SEM images of the crater size diameter of Inconel 718 after EDM; a) lowest Ra (I_p=20A, t_{on}=200µs), b) Highest Ra (I_p=40A, t_{on}=400µs).

4. Conclusion

Material removal rate is the most important performance measure in this study. In order to improve productivity in EDM machining of Inconel 718, the higher peak current and pulse duration up to 40A and 400µs respectively are used. The conclusion can be made the peak current is the most influence parameter for achieving high MRR while for pulse duration it shows insignifant for improving MRR when EDM of Inconel using Copper electrode. For electrode wear rate, the longer pulse duration used may improved the EWR but affect adversely when higher peak current used. For surface roughness, lowest peak current and the lowest pulse duration is suggested in order to achieve good surface finish.

Acknowledgements
The authors would like to thank the Universiti Tun Hussein Onn Malaysia (UTHM) and Ministry of Higher Education (MOHE) for financial support under the Exploratory Research Grant scheme (ERGS) Vot 0886.

References

[1] Ezugwu E O 2005 Key improvements in the machining of difficult-to-cut aerospace superalloys *International Journal of Machine Tools & Manufacture* **45** 1353-67
[2] Rajesha S, Sharma A and Kumar P 2011 On Electro Discharge Machining of Inconel 718 with Hollow Tool *Journal of Materials Engineering and Performance* 1-10
[3] Tzeng Y-f 2008 Development of a flexible high-speed EDM technology with geometrical transform optimization *Journal of Materials Processing Technology* **203(1–3)** 355-64
[4] Khan M A R, Rahman M M, Kadirgama K, Maleque M A and Ishak M 2011 *J Mech Eng Sci* **1** 16
[5] Kumar S and Singh R 2010 *Inter J Automot Mech Eng* **2** 181
[6] Rupinder Singh and Bhupinder Singh 2011 *Inter J Automot Mech Eng* **3** 239
[7] Lee S H and Li X P 2001 Study of the effect of machining parameters on the machining characteristics in electrical discharge machining of tungsten carbide *Journal of Materials Processing Technology* **115(3)** 344-58
[8] Kern R 2008 Techtips Sinker Electrode Material Selection *EDM Today* (July/August 2008 Issue)
[9] Bharti P S Maheshwari S and Sharma C 2010 Experimental investigation of Inconel 718 during die-sinking electric discharge machining *International Journal of Engineering Science and Technology* **2(11)** 6464-73
[10] Kuppan P, Rajadurai A and Narayanan S 2008 Influence of EDM process parameters in deep hole drilling of Inconel 718 *International Journal Advance Manufacturing Technology* **38** 74-84
[11] Kumar A, Maheshwari S, Sharma C and Beri N 2011 Analysis of machining characteristics in additive mixed electric discharge machining of nickel-based super alloy Inconel 718 *Materials and Manufacturing Processes* **26(8)** 1011-18
[12] Hamid F E A and Lajis, M A 2012 High performance in EDM machining of AISI D2 hardened steel *Advanced Materials Research* **500** 259-65
[13] Kang S and Kim D 2003 Investigation of EDM characteristics of nickel-based heat resistant alloy *Journal of Mechanical Science and Technology* **17(10)** 1475-84
[14] Patel K M, Pandey P M and Venkateswara R P 2009 Surface integrity and material removal mechanisms associated with the EDM of Al2O3 ceramic composite *International Journal of Refractory Metals and Hard Materials* **27(5)** 892-899