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The 15th International Conference on Quality in Research (15th QiR 2017)

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Selected, peer reviewed paper from the
15th International Conference on
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Edited by

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Preface

On behalf of the organizing committee, it was a great pleasure for us to welcome you to the 15th International Conference on Quality in Research (QiR) 2017 to be held in Bali, Indonesia on July, 24 – 27, 2017. This biennial event was co-organized with the Faculty of Engineering Universitas Udayana and Politeknik Negeri Bali.

The main theme for the year conference is "Science, Technology and Innovation for Sustainable World". Under this theme the conference focused on the innovative research and contribution in science and technology toward achieving sustainable world. In line with this theme, it is our utmost pleasure to present you with research papers in material-related field which were presented at QiR 2017 in the International Symposium on Materials, Metallurgy, and Chemical Engineering.

The QiR 2017 brought together national and international academicians, researchers, executives, government, industrial and business officials, practitioners and leaders to present and discuss a vast range of engineering, architectural designs and community development based on green and smart technology. QiR had been growing, since its first event two decades ago, into our flagship academic event with international reputation. This year, we received almost 1000 submissions from more than 26 countries. Along with our events in conjunction, more than 500 oral and poster presentations were scheduled with more than 700 participants gather in the event.

On behalf of QiR 2017 committee, we would like to thank all of our speakers, participants, contributors, partners and professional associations for their generous contributions. We also would like to acknowledge the support from our International Advisory Board members and distinguished reviewers. Last but not least, a special thanks to our local co-organizer, Universitas Udayana and Politeknik Negeri Bali.

We wish all of you a productive and rewarding conference, also a pleasant and memorable stay in Nusa Dua, Bali, Indonesia.

Thank you and we hope to see you in QiR 2019.

Ardiyansyah, PhD.
General Chair of QiR 2017 Organizing Committee

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The Effects of Dielectric Fluid Viscousity on Chips Formation Rate and Electrode Wear Rate in Electrical Discharge Machining of SKD 61 Steel

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Keywords: EDM; Jatropha Curcas; Metal Removal; Tool Wear; Viscousity.

Abstract. Electrical Discharge Machining (EDM) is a machine for cutting workpieces with thermal energy derived from electrical spark from tool (cathode) to workpiece (anode). As EDM process requires a dielectric fluid in the cutting operation, the characteristics of the dielectric fluid play an essential role for obtaining excellent cutting. Jatropha curcas has been demonstrated for use as a dielectric fluid in EDM process. However, the drawback is that the Rate of Metal Removal (RMR) is lower than that of generally-used dielectric fluid in industry. We consider that the cause is a much higher viscousity of the jatropha curcas. This study was conducted to investigate the characteristics of a new dielectric fluid mixture of jatropha curcas and kerosene. Kerosene was used in the mixture to reduce the viscousity of the jatropha curcas since the kerosene has a much lower viscousity. The measurement of the viscousity of the fluid mixture was performed using an Ostwald viscousimeter. Evidently, when the jatropha curcas mixed with the kerosine the viscousity of the mixture is lower than that of the pure jatropha curcas. The effects of the viscousity of the fluid mixture were investigated by measuring the RMR and Tool Wear Rate (TWR). The RMR and TWR were determined by calculating the difference in the weight of the workpiece and the tool, respectively, before and after the cutting for a certain cutting interval. The measurements were carried out for eleven different concentration of the fluid mixture by varying the current of 15 and 21 Amp, with replication of 3 times. As the result, the energy released during the cutting process affects the values of TWR and RMR. It was also found that in contrast to the effect on TWR, the RMR was not influenced by the viscousity of the mixture.

Introduction

Jatropha curcas, as an esterification product, can be used as dielectric fluid because its breakdown voltage is higher than kerosene [1, 2]. However, its RMR is still low [3]. One of the probable culprit for this is the high viscousity of jatropha curcas. This condition will complicate the disposal of chips formed during the cutting process, which in turn the cutting process will be disrupted due to the short circuit. To overcome the problem, the tool should perform a pumping motion in the gap between the workpiece and the tool so that the non-productive time increases. Since the kerosene has higher fluidity, the jatropha curcas was mixed with kerosine (EDM-85) so that the mixture of has higher fluidity than that of pure jatropha curcas. The purpose of this study is to investigate the effects of the viscousity of the dielectric fluid mixture on Rate of Metal Removal (RMR) and Tool Wear Rate (TWR).

Methodology

The outline of the study is shown in the flow diagram in Figure 1. In this study, the EDM process mainly consists of a SKM ZNC SERIES T50 EDM machine, 10 mm diameter copper rod electrodes, and SKD 61 steel as the workpiece. Current used for the process were 15 and 21 Amp with pulse-on time and pulse off-time of 20 μs each. Flushing was employed by an injection type.

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The amount of chips formed and the wear of the electrode were determined by weighing the workpiece and electrode, respectively, before and after the cutting test, as well as recording the actual machining time. The dielectric fluid used was a mixture of jatropha curcas with kerosene (EDM-85). The chosen concentrations of jatropha curcas were 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100%. Measurements of the viscosity were performed by using Ostwald viscousimeter. The data obtained from the measurement were the fall time. The fall time was affected by the viscousity of the tested fluid. High dilution will allow the fluid to flow, or *fall*, leaving the ball-shaped test glass. Jatropha curcas has a viscousity of 29.57 cSt [1], which is higher than the viscousity of kerosene (2.12 cSt). Therefore, the mixing of both fluids will produce a certain viscousity.

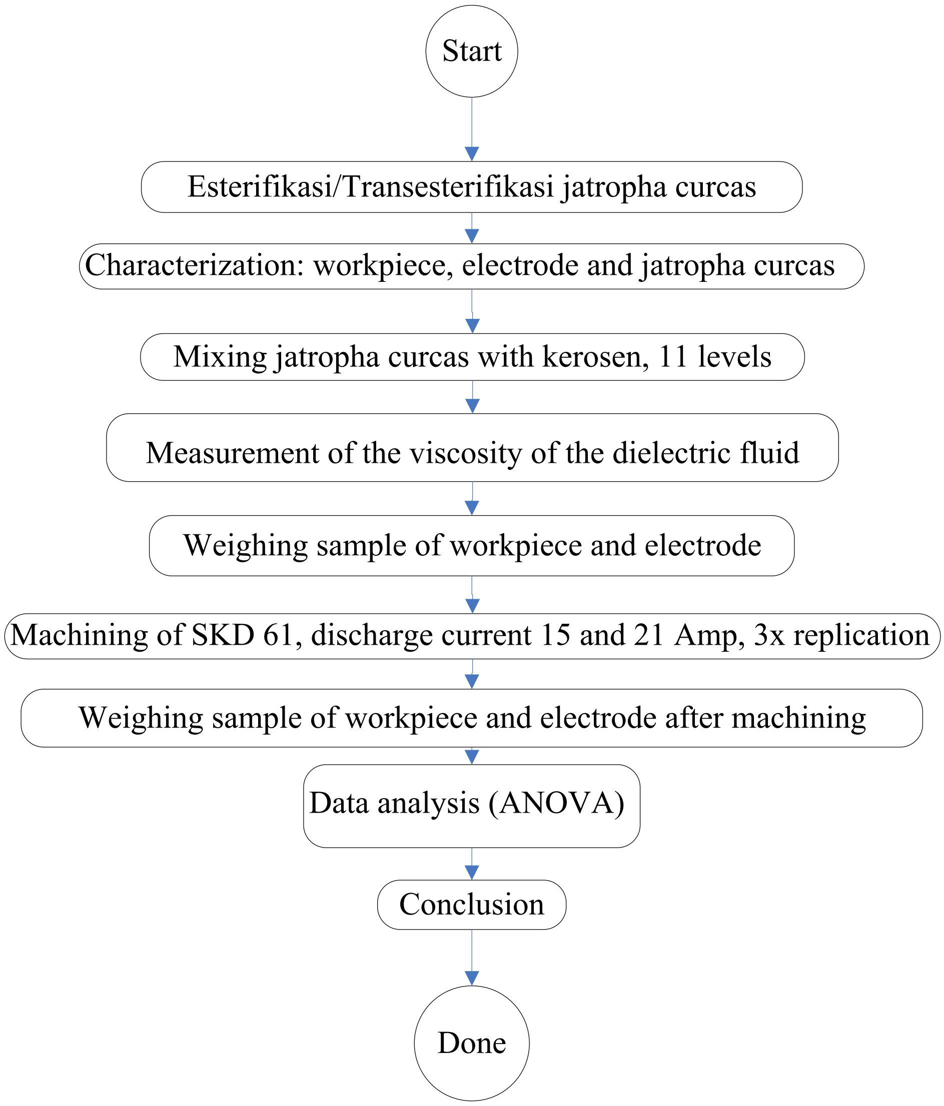

Figure 1. Flowchart of research work.

Workpiece in the form of rod steel with the diameter of 30 mm were cut into 66 samples with a thickness of 5 mm by using a flat grinding machine. For pairing the 66 samples of the workpiece, the 66 electrodes were cut from copper rods with the diameter of 10 mm and length of 15 mm.

Results and Discussion

Viscousity of Dielectric Fluid. One role of the dielectric fluid flow is to flush the debris away from the gap between the electrodes and the workpiece. From the fall time data, the viscousity of the dielectric mixture can be calculated by using Eq. (1)[5]. The calculation results are shown in Table 1. As shown in the table, when the concentration of jatropha curcas increases, the viscousity of the dielectric fluid also increases.

$$\eta_2 = \eta_1 \,.\, \rho_2/\rho_1 \,.\, t_2/t_1 \qquad (1)$$

where,
η : Viscousity [cPs]
t : Time [s]
ρ : Density [g/cm^3]

Table 1. Viscosity of eleven dielectric fluid mixture measured with Ostwald viscousimeter.

Sample ID	Composition [%]		Time	η [cPs]
	Jatropha curcas	Kerosene	[s]	
1	10	90	1.97	1.88
2	20	80	2.06	1.97
3	30	70	2.31	2.20
4	40	60	2.44	2.33
5	50	50	3.19	3.04
6	60	40	3.66	3.49
7	70	30	4.03	3.84
8	80	20	4.80	4.58
9	90	10	5.50	5.25
10	100	-	6.85	6.53
11	-	100	1.38	1.32

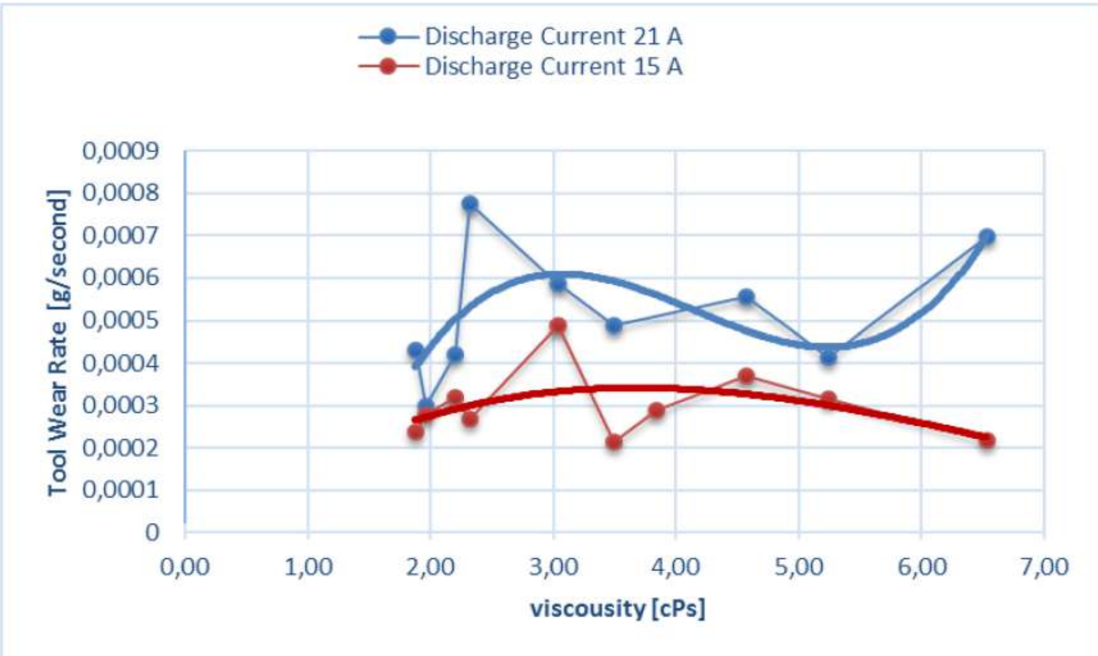

Figure 2. The plots of Tool Wear Rate (TWR) against the viscousity of the dielectric fluid mixture for the current of 15 dan 21 Amp.

Effect of Viscosity on TWR. Figure 2 shows the plots of TWR against viscousity for the current of 15 and 21 A. As shown in the figure, the TWR is higher for higher current. The trend for the TWR from the viscousity of 1.88 to 3.04 cPs (or concentration from 10 to 50%) on both current is equally increasing and then decreasing after the viscousity of 3.04 cPs. However, for 21 Amp current, the TWR increases beyond 80% concentration.

With ANOVA method, the calculation and the interpretation are shown as follows,
ANOVA: Tool Wear Rate (TWR) versus Concentration JC-EDM; Current

Factor	Type	Levels	Values
Concentration JC:EDM	fixed	11	0; 10; 20; 30; 40; 50; 60; 70; 80; 90; 100
Current	fixed	2	15; 21

Table 2. Analysis of Variance for TWR, using Adjusted SS for Tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Consentration JC-EDM	10	0.0000061	0.0000061	0.0000006	3.32	0.003
Current	1	0.0000026	0.0000026	0.0000026	13.91	0.001
Concentration JC-EDM*Current	10	0.0000062	0.0000062	0.0000006	3.35	0.003
Error	44	0.0000081	0.0000081	0.0000002		
Total	65	0.0000229				
S = 0.000429058 R-Sq = 64.69% R-Sq(adj) = 47.83%						

Interpretation of the Output for the Factorial Design:
The output shows a description of the factors that there are 11 levels for the concentration factor of JC-EDM and 2 levels for the current factor. The level for the factor of JC-EDM concentration is 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% and the level for the current factor is 15 and 21 Amp. As shown in Table 2, there are 2 factors and 1 interaction, so there are 3 hypotheses that must be formulated that is hypothesis test to determine: (i) the influence of JC-EDM concentration, (ii) the influence of the current, and (iii) the influence of interaction between JC-EDM concentration and the current.

Test for the hypothesis on the effect of concentration of JC-EDM on TWR.
Hypothesis
H_o: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10} = \alpha_{11}$ (Concentration of JC-EDM does not affect the value of TWR)
H_1: At least there is one pair of $\alpha_i \neq \alpha_j$ where $i \neq j$ (Concentration of JC-EDM affects the value of TWR)

From the output, the statistical test F results in the concentration of JC-EDM is 3.32 and p-value is 0.003. Therefore, the decision is to reject Ho, i.e. JC-EDM concentration affects the value of TWR because p-value = 0.003 < α = 0.05.

Test for the hypothesis on the effect of current on TWR.
Hypothesis
H_o: $\beta 1 = \beta 2$ (current does not affect the value of TWR).
H_1: $\beta 1 \neq \beta 2$ (current affects the value of TWR)

From the output, statistical test F for current is 13.91 with p-value = 0.001 < α = 0.05. Therefore, the decision is to reject the initial hypothesis stating that current does not affect the value of TWR. So, the conclusion is that the current factor has a significant influence on the value of TWR.

Test for the hypothesis on the effect of interaction between factors on TWR.
Hypothesis
H_o: $(\alpha\beta)_{ij} = 0$ (Interaction between factors does not affect on the value of TWR).
H_1: $(\alpha\beta)_{ij} \neq 0$ (Interaction between factors affects on the value of TWR).

From the output, the statistical test F = 3.35 with p-value = 0.003 < α = 0.05. The decision is to reject Ho that the interaction between factors affects the value of TWR. Figure 3 shows the plot of the Main Factor which shows that 70% concentration of JC-EDM and 21 Amp current significantly influence the value of TWR.

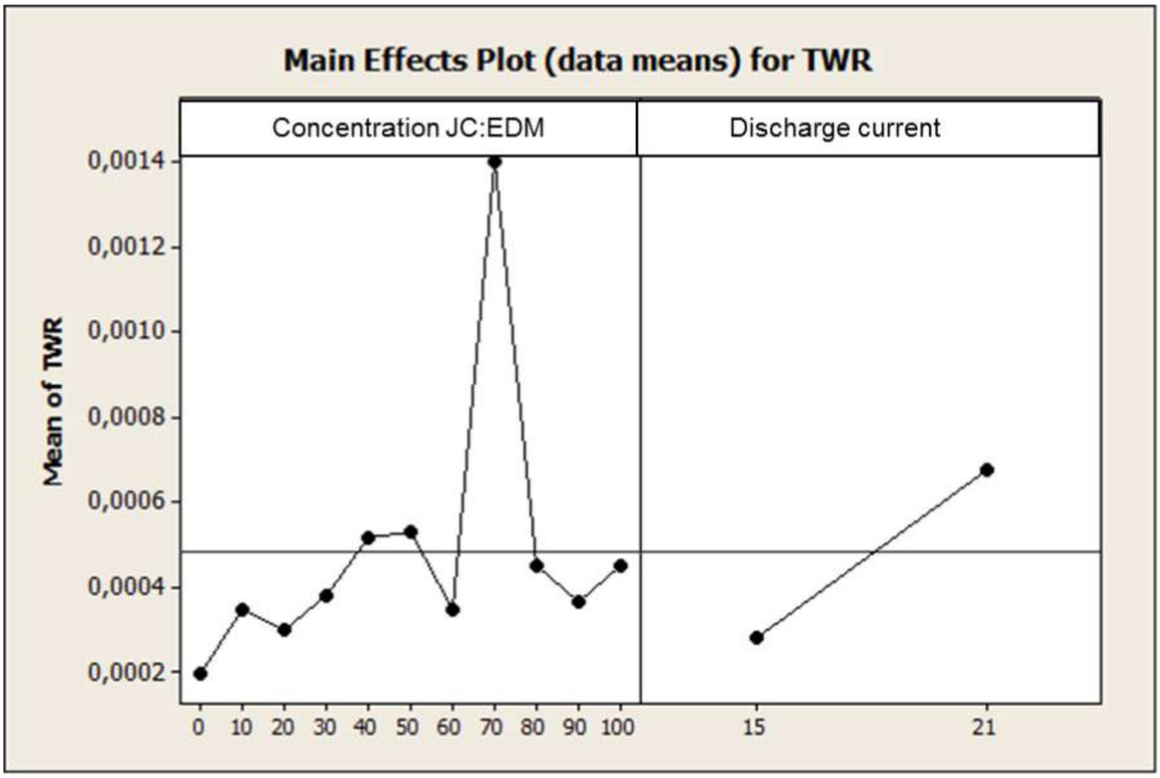

Figure 3. The plot of Main Factor.

Effect of Viscousity on RMR. Figure 4 shows the effect of the viscousity of the dielectric fluid on RMR. Previous studies [1, 3, 4] have also shown that the dominant factor on RMR is the current. The higher the current, the higher the RMR. This is because of the higher energy released for the melting of the material. As seen in Figure 4, for 20 Amp current the RMR increases until levelling off at 60% concentration. One interesting find is that for all concentrations the RMR is higher than that of EDM-85. On the contrary, for 15 Amp current, the RMR decreases with concentration. However, the RMR is higher than that of the treatment with pure kerosene for concentration up to 50%. Different characteristics for RMR change for both currents may be due to the spreading of energy to move the metal atoms contained in jatropha curcas becomes more evenly when the energy is increased.

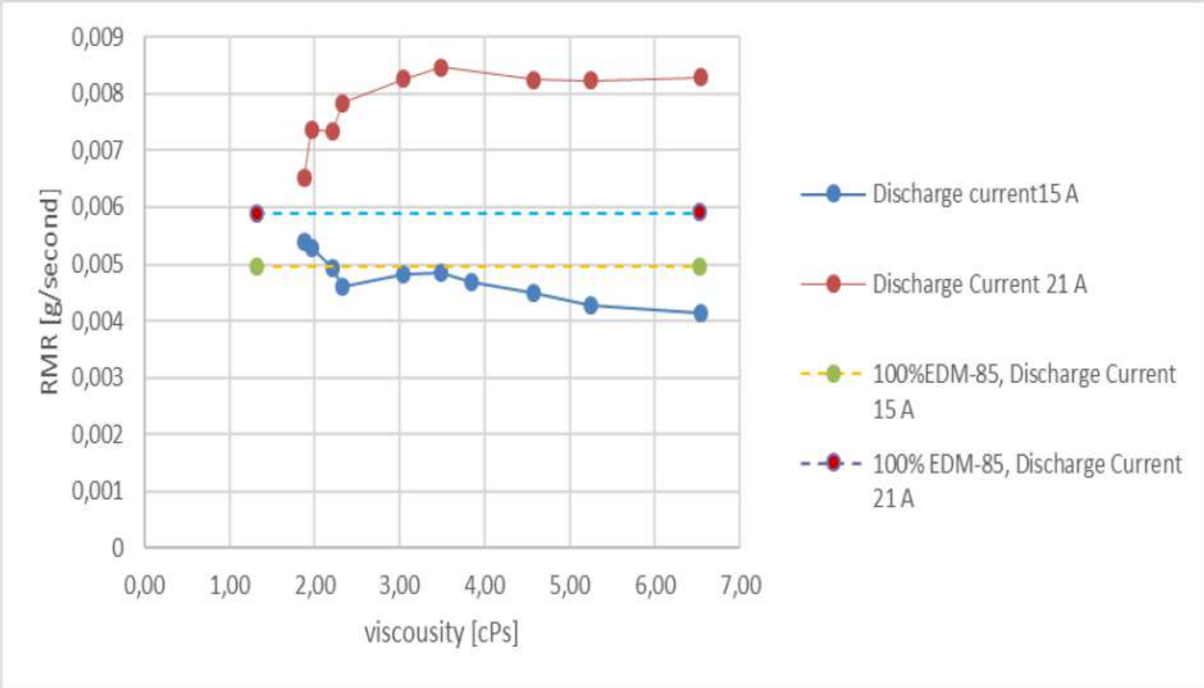

Figure 4. The plots of Rate of Metal Removal (RMR) against the viscousity of the dielectric fluid mixture for the current of 15 dan 21 Amp.

For statistical analysis, with ANOVA method, the calculation and interpretation are as follows,

Factor	Type	Levels	Values
Concentartion JC-EDM	fixed	11	0; 10; 20; 30; 40; 50; 60; 70; 80; 90; 100
Current	fixed	2	15; 21

Table 3. Analysis of Variance for RMR, using Adjusted SS for Tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Concentration JC-EDM	10	0.0001287	0.0001287	0.0000129	1.26	0.284
Current	1	0.0002303	0.0002303	0.0002303	22.50	0.000
Concentration C-EDM*Current	10	0.0001453	0.0001453	0.0000145	1.42	0.204
Error	44	0.0004505	0.0004505	0.0000102		
Total	65	0.0009549				
S = 0.00319964 R-Sq = 52.82% R-Sq(adj) = 30.31%						

Interpretation of the Output for the Factorial Design:
The output shows a description of the factor that there are 11 levels for the concentration factor of JC-EDM and 2 levels for the current factor. The level for the factor of JC-EDM concentration is 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% and the level for the current factor is 15 and 21 Amp. As shown in Table 3, there are 2 factors and 1 interaction, so there are 3 hypotheses that must be formulated that is hypothesis test to determine: (i) the influence of JC-EDM concentration, (ii) the influence of the current, and (iii) the influence of interaction between JC-EDM concentration and the current.

Test for the hypothesis on the effect of concentration of JC-EDM on RMR.
Hypothesis
H_o: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10} = \alpha_{11}$ (Concentration of JC-EDM does not affect the value of RMR).

H_1: At least there is one pair of $\alpha_i \neq \alpha_j$ where $i \neq j$ (Concentration of JC-EDM affects the value of RMR)).

From the output, the statistical test F results in the concentration of JC-EDM is 1.26 and p-value is 0.284. Therefore, the decision is to accept Ho, i.e. JC-EDM concentration does not affect the value of RMR because p-value = 0.284 > α = 0.05.

Test for the hypothesis on the effect of current on RMR.

Hypothesis

H_o: $\beta_1 = \beta_2$ (current does not affect the value of RMR).

H_1: $\beta_1 \neq \beta_2$ (current affects the value of RMR)

From the output, statistical test F for current is 22.5 with p-value = 0.00 < α = 0.05. Therefore, the decision is to reject the initial hypothesis stating that current does not affect the value of RMR. So, the conclusion is that the current factor has a significant influence on the value of RMR.

Test for the hypothesis on the effect of interaction between factors on RMR.

Hypothesis

H_o: $(\alpha\beta)_{ij} = 0$ (Interaction between factors does not affect on the value of RMR).

H_1: $(\alpha\beta)_{ij} \neq 0$ (Interaction between factors affects on the value of TWR).

From the output, the statistical test F = 1.42 with p-value = 0.204 > α = 0.05. The decision is to accept Ho that the interaction between factors does not affect the value of RMR. In addition, the concentration of 70% JC-EDM or the viscousity of 3.84 cPs for 21 Amp current has a significant effect on the RMR, as shown in Figure 5.

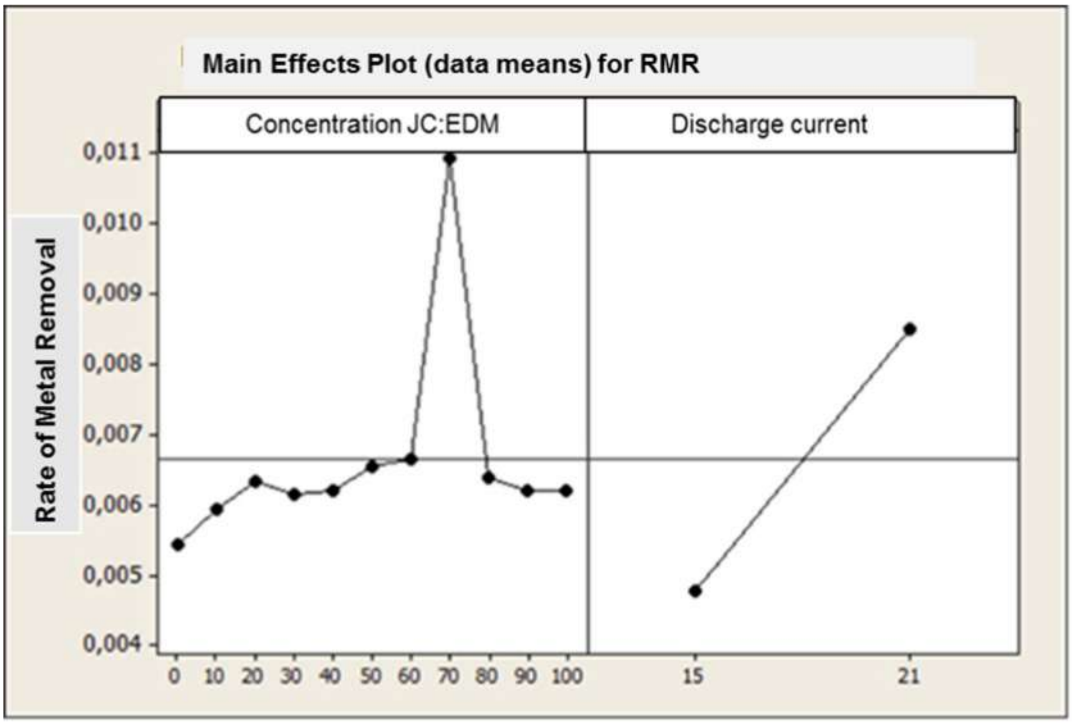

Figure 5. The Plots of RMR against concentration and current.

Figure 6 shows an interaction plots between the contributing factors. With ANOVA, the influence of each magnitude of the current can be determined.

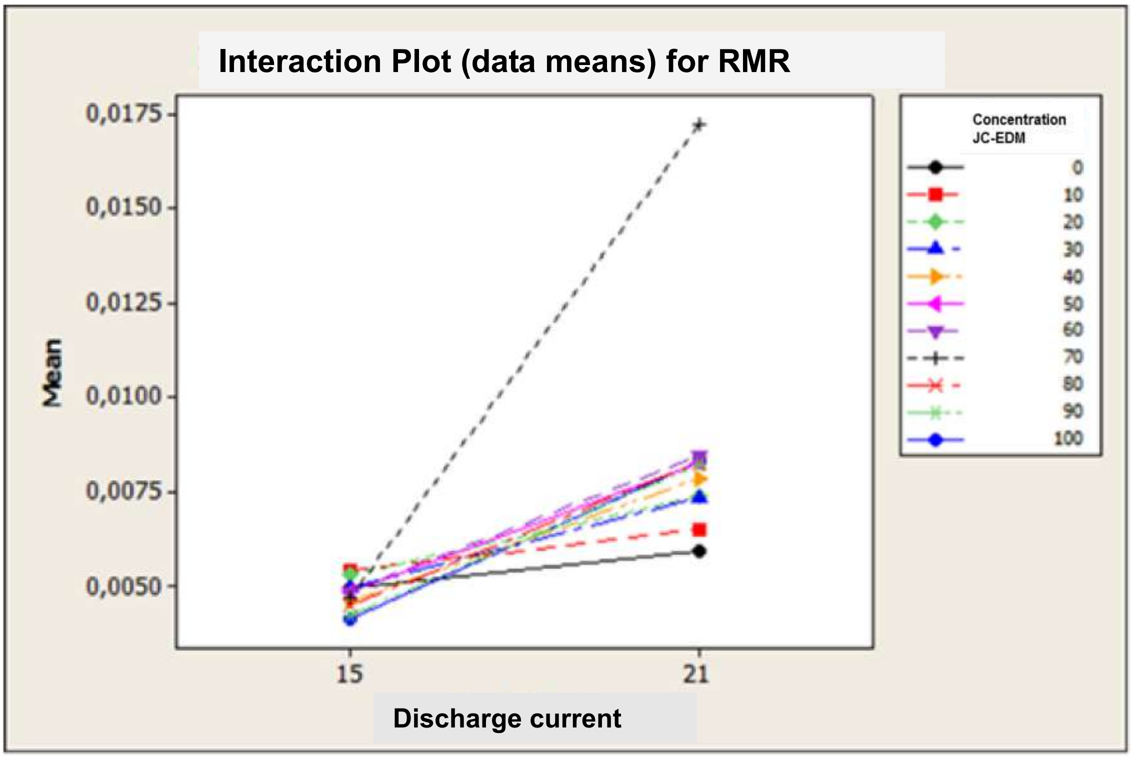

Figure 6. Plots of interaction between factors.

One-way ANOVA:

Table 4. ANOVA analysis of concentration effect on RMR with 15 Amp current.

Source	DF	SS	MS	F	P
Concentration JC-EDM	10	0.0000047	0.0000005	4.58	0.001
Error	22	0.0000023	0.0000001		
Total	32	0.0000070			
S = 0.0003205 R-Sq = 67.55%	R-Sq(adj) = 52.81%				

Table 5. ANOVA analysis of concentration effect on RMR with 21 Amp current

Source	DF	SS	MS	F	P
Concentration JC-EDM	10	0.0002693	0.0000269	1.32	0.279
Error	22	0.0004482	0.0000204		
Total	32	0.0007175			
S = 0.004514 R-Sq = 37.54%	R-Sq(adj) = 9.15%				

Interpretation of the output of the interaction plots between the factors in Table 4 and Table 5 above is:

- For 15 Amp current, there is a significant difference between the concentrations of JC-EDM to the RMR where p-value < α
- For 21 Amp current, there is no significant difference between JC-EDM concentrations of JC-EDM to the RMR where p-value > α
- The average value of RMR for 21 Amp current is higher that that of 15 Amp current.

In addition, the TWR at various concentrations when compared to the RMR, ranged from 4% to 10% with an average of 6% and 7% for 15 and 21 Amp current, respectively. Thus the higher the current level will increase the wear rate of the tool. This is also in accordance with previous studies [1,3] that the higher the current used, the heat generated in the tool is also increased which in turn will facilitate the displacement of the atoms.

Conclusions

In this study, the mixture of jatropha curcas and kerosene with various concentration were used successfully as the dielectric fluid in EDM process for cutting SKD 61 steel. The effects of the viscousity of the mixture were investigated for two different current of 15 and 21 Amp. The following points are drawn in this study :

1. The viscousity of the dielectric fluid mixture affects the value of TWR when the current used is small.
2. The viscousity of the dielectric fluid mixture does not affect the value of RMR.
3. The value of TWR and RMR depends on the energy released. Higher current results in higher TWR and RMR.
4. The EDM cutting process works normally at various viscousity of the dielectric fluid mixture, which is indicated by the much lower percentage of TWR than RMR. For the current of 15 and 21 Amp, the average value of TWR is 6% and 7% of RMR, respectively.

Acknowledgement

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by Joko Riyono FTI

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Keywords: EDM; Jatropha Curcas; Metal Removal; Tool Wear; Viscousity.

Abstract. Electrical Discharge Machining (EDM) is a machine for cutting workpieces with thermal energy derived from electrical spark from tool (cathode) to workpiece (anode). As EDM process requires a dielectric fluid in the cutting operation, the characteristics of the dielectric fluid play an essential role for obtaining excellent cutting. Jatropha curcas has been demonstrated for use as a dielectric fluid in EDM process. However, the drawback is that the Rate of Metal Removal (RMR) is lower than that of generally-used dielectric fluid in industry. We consider that the cause is a much higher viscousity of the jatropha curcas. This study was conducted to investigate the characteristics of a new dielectric fluid mixture of jatropha curcas and kerosene. Kerosene was used in the mixture to reduce the viscousity of the jatropha curcas since the kerosene has a much lower viscousity. The measurement of the viscousity of the fluid mixture was performed using an Ostwald viscousimeter. Evidently, when the jatropha curcas mixed with the kerosine the viscousity of the mixture is lower than that of the pure jatropha curcas. The effects of the viscousity of the fluid mixture were investigated by measuring the RMR and Tool Wear Rate (TWR). The RMR and TWR were determined by calculating the difference in the weight of the workpiece and the tool, respectively, before and after the cutting for a certain cutting interval. The measurements were carried out for eleven different concentration of the fluid mixture by varying the current of 15 and 21 Amp, with replication of 3 times. As the result, the energy released during the cutting process affects the values of TWR and RMR. It was also found that in contrast to the effect on TWR, the RMR was not influenced by the viscousity of the mixture.

Introduction

Jatropha curcas, as an esterification product, can be used as dielectric fluid because its breakdown voltage is higher than kerosene [1, 2]. However, its RMR is still low [3]. One of the probable culprit for this is the high viscousity of jatropha curcas. This condition will complicate the disposal of chips formed during the cutting process, which in turn the cutting process will be disrupted due to the short circuit. To overcome the problem, the tool should perform a pumping motion in the gap between the workpiece and the tool so that the non-productive time increases. Since the kerosene has higher fluidity, the jatropha curcas was mixed with kerosine (EDM-85) so that the mixture of has higher fluidity than that of pure jatropha curcas. The purpose of this study is to investigate the effects of the viscousity of the dielectric fluid mixture on Rate of Metal Removal (RMR) and Tool Wear Rate (TWR).

Methodology

The outline of the study is shown in the flow diagram in Figure 1. In this study, the EDM process mainly consists of a SKM ZNC SERIES T50 EDM machine, 10 mm diameter copper rod electrodes, and SKD 61 steel as the workpiece. Current used for the process were 15 and 21 Amp with pulse-on time and pulse off-time of 20 μs each. Flushing was employed by an injection type.

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The amount of chips formed and the wear of the electrode were determined by weighing the workpiece and electrode, respectively, before and after the cutting test, as well as recording the actual machining time. The dielectric fluid used was a mixture of jatropha curcas with kerosene (EDM-85). The chosen concentrations of jatropha curcas were 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100%. Measurements of the viscousity were performed by using Ostwald viscousimeter. The data obtained from the measurement were the fall time. The fall time was affected by the viscousity of the tested fluid. High dilution will allow the fluid to flow, or *fall*, leaving the ball-shaped test glass. Jatropha curcas has a viscousity of 29.57 cSt [1], which is higher than the viscousity of kerosene (2.12 cSt). Therefore, the mixing of both fluids will produce a certain viscousity.

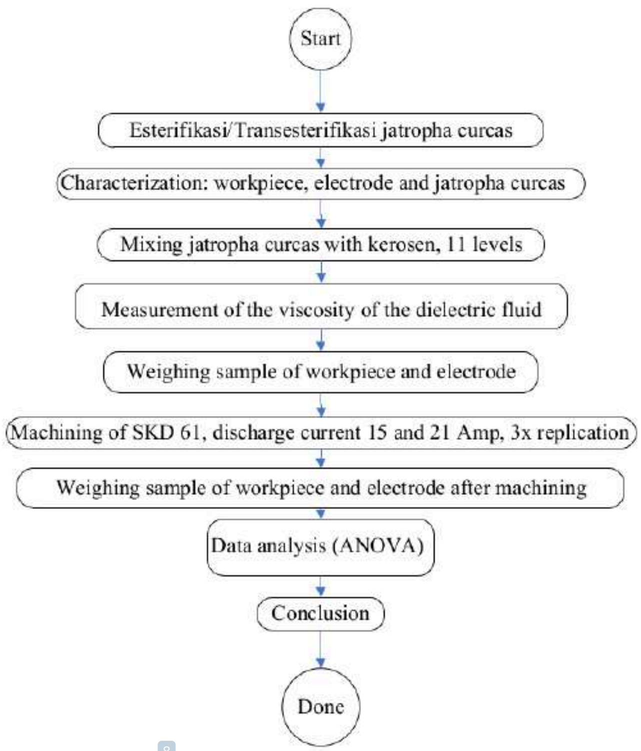

Figure 1. Flowchart of research work.

Workpiece in the form of rod steel with the diameter of 30 mm were cut into 66 samples with a thickness of 5 mm by using a flat grinding machine. For pairing the 66 samples of the workpiece, the 66 electrodes were cut from copper rods with the diameter of 10 mm and length of 15 mm.

Results and Discussion

Viscousity of Dielectric Fluid. One role of the dielectric fluid flow is to flush the debris away from the gap between the electrodes and the workpiece. From the fall time data, the viscousity of the dielectric mixture can be calculated by using Eq. (1)[5]. The calculation results are shown in Table 1. As shown in the table, when the concentration of jatropha curcas increases, the viscousity of the dielectric fluid also increases.

$$\eta_2 = \eta_1 \cdot \rho_2/\rho_1 \cdot t_2/t_1 \quad (1)$$

where,

η : Viscousity [cPs]
t : Time [s]
ρ : Density [g/cm^3]

Table 1. Viscousity of eleven dielectric fluid mixture measured with Ostwald viscousimeter.

Sample ID	Composition [%] Jatropha curcas	Composition [%] Kerosene	Time [s]	η [cPs]
1	10	90	1.97	1.88
2	20	80	2.06	1.97
3	30	70	2.31	2.20
4	40	60	2.44	2.33
5	50	50	3.19	3.04
6	60	40	3.66	3.49
7	70	30	4.03	3.84
8	80	20	4.80	4.58
9	90	10	5.50	5.25
10	100	-	6.85	6.53
11	-	100	1.38	1.32

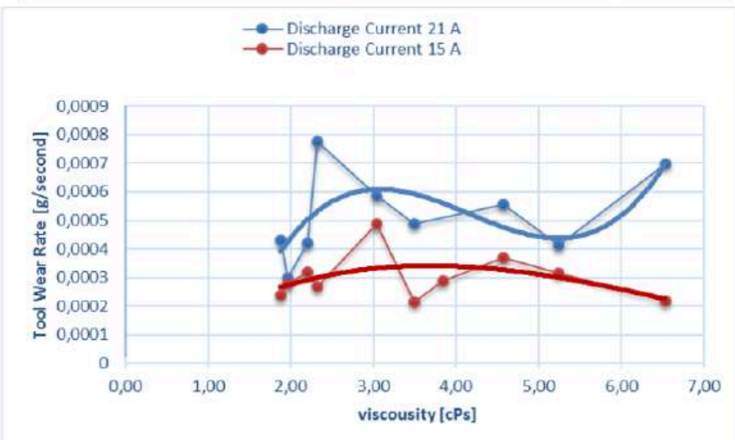

Figure 2. The plots of Tool Wear Rate (TWR) against the viscousity of the dielectric fluid mixture for the current of 15 dan 21 Amp.

Effect of Viscousity on TWR. Figure 2 shows the plots of TWR against viscousity for the current of 15 and 21 A. As shown in the figure, the TWR is higher for higher current. The trend for the TWR from the viscousity of 1.88 to 3.04 cPs (or concentration from 10 to 50%) on both current is equally increasing and then decreasing after the viscousity of 3.04 cPs. However, for 21 Amp current, the TWR increases beyond 80% concentration.

With ANOVA method, the calculation and the interpretation are shown as follows,
ANOVA: Tool Wear Rate (TWR) versus Concentration JC-EDM; Current

Factor	Type	Levels	Values
Concentration JC:EDM	fixed	11	0; 10; 20; 30; 40; 50; 60; 70; 80; 90; 100
Current	fixed	2	15; 21

Table 2. Analysis of Variance for TWR, using Adjusted SS for Tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Consentration JC-EDM	10	0.0000061	0.0000061	0.0000006	3.32	0.003
Current	1	0.0000026	0.0000026	0.0000026	13.91	0.001
Concentration JC-EDM*Current	10	0.0000062	0.0000062	0.0000006	3.35	0.003
Error	44	0.0000081	0.0000081	0.0000002		
Total	65	0.0000229				
S = 0.000429058 R-Sq = 64.69% R-Sq(adj) = 47.83%						

Interpretation of the Output for the Factorial Design:
The output shows a description of the factors that there are 11 levels for the concentration factor of JC-EDM and 2 levels for the current factor. The level for the factor of JC-EDM concentration is 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% and the level for the current factor is 15 and 21 Amp. As shown in Table 2, there are 2 factors and 1 interaction, so there are 3 hypotheses that must be formulated that is hypothesis test to determine: (i) the influence of JC-EDM concentration, (ii) the influence of the current, and (iii) the influence of interaction between JC-EDM concentration and the current.

Test for the hypothesis on the effect of concentration of JC-EDM on TWR.

Hypothesis
H_o: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10} = \alpha_{11}$ (Concentration of JC-EDM does not affect the value of TWR)
H_1: At least there is one pair of $\alpha_i \neq \alpha_j$ where $i \neq j$ (Concentration of JC-EDM affects the value of TWR)

From the output, the statistical test F results in the concentration of JC-EDM is 3.32 and p-value is 0.003. Therefore, the decision is to reject Ho, i.e. JC-EDM concentration affects the value of TWR because p-value = $0.003 < \alpha = 0.05$.

Test for the hypothesis on the effect of current on TWR.

Hypothesis
H_o: $\beta1 = \beta2$ (current does not affect the value of TWR).
H_1: $\beta1 \neq \beta2$ (current affects the value of TWR)

From the output, statistical test F for current is 13.91 with p-value = $0.001 < \alpha = 0.05$. Therefore, the decision is to reject the initial hypothesis stating that current does not affect the value of TWR. So, the conclusion is that the current factor has a significant influence on the value of TWR.

Test for the hypothesis on the effect of interaction between factors on TWR.

Hypothesis
H_o: $(\alpha\beta)_{ij} = 0$ (Interaction between factors does not affect on the value of TWR).
H_1: $(\alpha\beta)_{ij} \neq 0$ (Interaction between factors affects on the value of TWR).

From the output, the statistical test F = 3.35 with p-value = $0.003 < \alpha = 0.05$. The decision is to reject Ho that the interaction between factors affects the value of TWR. Figure 3 shows the plot of the Main Factor which shows that 70% concentration of JC-EDM and 21 Amp current significantly influence the value of TWR.

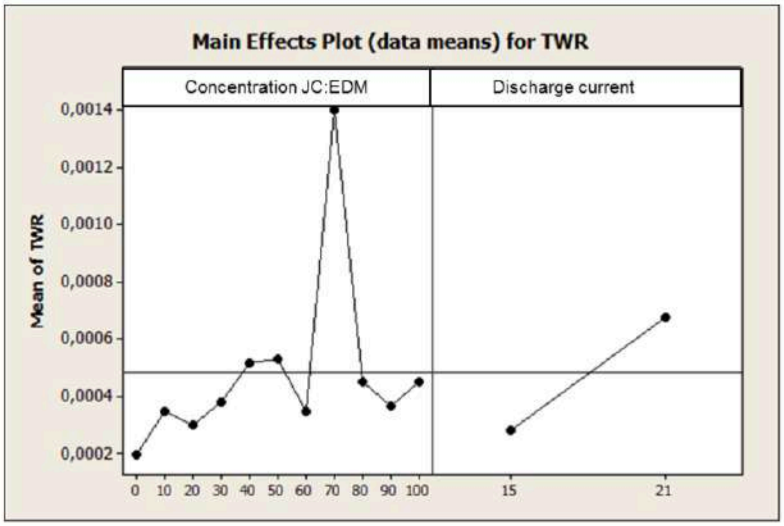

Figure 3. The plot of Main Factor.

Effect of Viscousity on RMR. Figure 4 shows the effect of the viscousity of the dielectric fluid on RMR. Previous studies [1, 3, 4] have also shown that the dominant factor on RMR is the current. The higher the current, the higher the RMR. This is because of the higher energy released for the melting of the material. As seen in Figure 4, for 20 Amp current the RMR increases until levelling off at 60% concentration. One interesting find is that for all concentrations the RMR is higher than that of EDM-85. On the contrary, for 15 Amp current, the RMR decreases with concentration. However, the RMR is higher than that of the treatment with pure kerosene for concentration up to 50%. Different characteristics for RMR change for both currents may be due to the spreading of energy to move the metal atoms contained in jatropha curcas becomes more evenly when the energy is increased.

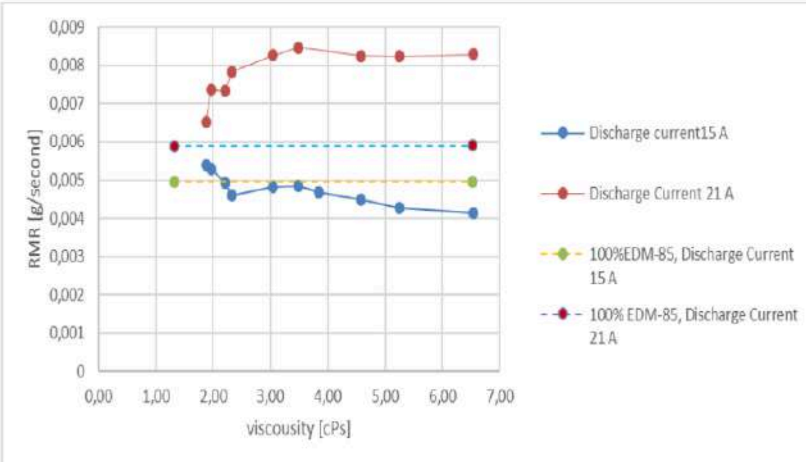

Figure 4. The plots of Rate of Metal Removal (RMR) against the viscousity of the dielectric fluid mixture for the current of 15 dan 21 Amp.

For statistical analysis, with ANOVA method, the calculation and interpretation are as follows,

Factor	Type	Levels	Values
Concentartion JC-EDM	fixed	11	0; 10; 20; 30; 40; 50; 60; 70; 80; 90; 100
Current	fixed	2	15; 21

Table 3. Analysis of Variance for RMR, using Adjusted SS for Tests.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Concentration JC-EDM	10	0.0001287	0.0001287	0.0000129	1.26	0.284
Current	1	0.0002303	0.0002303	0.0002303	22.50	0.000
Concentration C-EDM*Current	10	0.0001453	0.0001453	0.0000145	1.42	0.204
Error	44	0.0004505	0.0004505	0.0000102		
Total	65	0.0009549				
S = 0.00319964 R-Sq = 52.82% R-Sq(adj) = 30.31%						

Interpretation of the Output for the Factorial Design:
The output shows a description of the factor that there are 11 levels for the concentration factor of JC-EDM and 2 levels for the current factor. The level for the factor of JC-EDM concentration is 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% and the level for the current factor is 15 and 21 Amp. As shown in Table 3, there are 2 factors and 1 interaction, so there are 3 hypotheses that must be formulated that is hypothesis test to determine: (i) the influence of JC-EDM concentration, (ii) the influence of the current, and (iii) the influence of interaction between JC-EDM concentration and the current.

Test for the hypothesis on the effect of concentration of JC-EDM on RMR.

Hypothesis

H_o: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = \alpha_9 = \alpha_{10} = \alpha_{11}$ (Concentration of JC-EDM does not affect the value of RMR).

H_1: At least there is one pair of $\alpha_i \neq \alpha_j$ where $i \neq j$ (Concentration of JC-EDM affects the value of RMR)).

From the output, the statistical test F results in the concentration of JC-EDM is 1.26 and p-value is 0.284. Therefore, the decision is to accept Ho, i.e. JC-EDM concentration does not affect the value of RMR because p-value = $0.284 > \alpha = 0.05$.

Test for the hypothesis on the effect of current on RMR.

Hypothesis

H_o: $\beta_1 = \beta_2$ (current does not affect the value of RMR).

H_1: $\beta_1 \neq \beta_2$ (current affects the value of RMR)

From the output, statistical test F for current is 22.5 with p-value = $0.00 < \alpha = 0.05$. Therefore, the decision is to reject the initial hypothesis stating that current does not affect the value of RMR. So, the conclusion is that the current factor has a significant influence on the value of RMR.

Test for the hypothesis on the effect of interaction between factors on RMR.

Hypothesis

H_o: $(\alpha\beta)_{ij} = 0$ (Interaction between factors does not affect on the value of RMR).

H_1: $(\alpha\beta)_{ij} \neq 0$ (Interaction between factors affects on the value of TWR).

From the output, the statistical test F = 1.42 with p-value = $0.204 > \alpha = 0.05$. The decision is to accept Ho that the interaction between factors does not affect the value of RMR. In addition, the concentration of 70% JC-EDM or the viscousity of 3.84 cPs for 21 Amp current has a significant effect on the RMR, as shown in Figure 5.

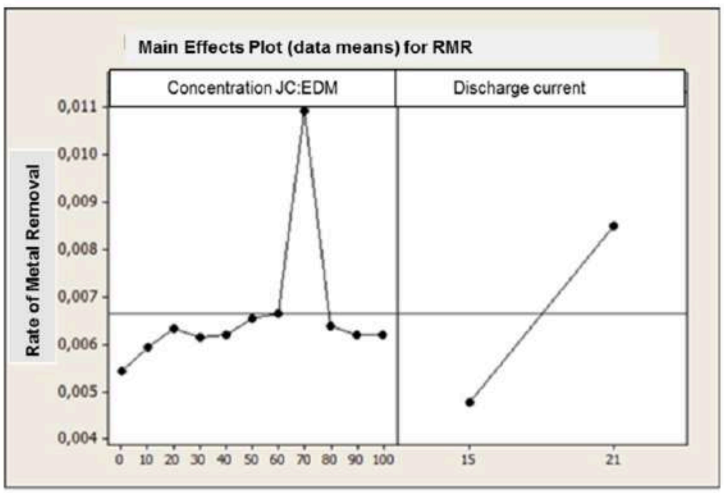

Figure 5. The Plots of RMR against concentration and current.

Figure 6 shows an interaction plots between the contributing factors. With ANOVA, the influence of each magnitude of the current can be determined.

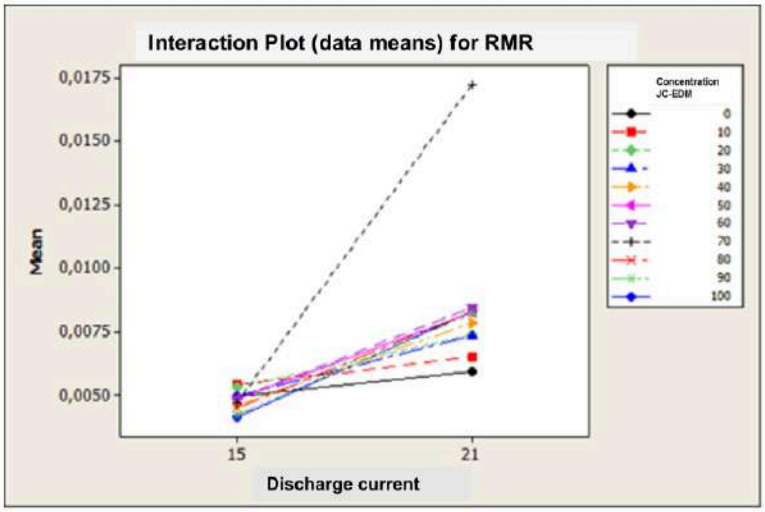

Figure 6. Plots of interaction between factors.

One-way ANOVA:

Table 4. ANOVA analysis of concentration effect on RMR with 15 Amp current.

Source	DF	SS	MS	F	P
Concentration JC-EDM	10	0.0000047	0.0000005	4.58	0.001
Error	22	0.0000023	0.0000001		
Total	32	0.0000070			
S = 0.0003205 R-Sq = 67.55%	R-Sq(adj) = 52.81%				

Table 5. ANOVA analysis of concentration effect on RMR with 21 Amp current

Source	DF	SS	MS	F	P
Concentration JC-EDM	10	0.0002693	0.0000269	1.32	0.279
Error	22	0.0004482	0.0000204		
Total	32	0.0007175			
S = 0.004514 R-Sq = 37.54%	R-Sq(adj) = 9.15%				

Interpretation of the output of the interaction plots between the factors in Table 4 and Table 5 above is:

- For 15 Amp current, there is a significant difference between the concentrations of JC-EDM to the RMR where p-value < α
- For 21 Amp current, there is no significant difference between JC-EDM concentrations of JC-EDM to the RMR where p-value > α
- The average value of RMR for 21 Amp current is higher that that of 15 Amp current.

In addition, the TWR at various concentrations when compared to the RMR, ranged from 4% to 10% with an average of 6% and 7% for 15 and 21 Amp current, respectively. Thus the higher the current level will increase the wear rate of the tool. This is also in accordance with previous studies [1,3] that the higher the current used, the heat generated in the tool is also increased which in turn will facilitate the displacement of the atoms.

Conclusions

In this study, the mixture of jatropha curcas and kerosene with various concentration were used successfully as the dielectric fluid in EDM process for cutting SKD 61 steel. The effects of the viscousity of the mixture were investigated for two different current of 15 and 21 Amp. The following points are drawn in this study :

1. The viscousity of the dielectric fluid mixture affects the value of TWR when the current used is small.
2. The viscousity of the dielectric fluid mixture does not affect the value of RMR.
3. The value of TWR and RMR depends on the energy released. Higher current results in higher TWR and RMR.
4. The EDM cutting process works normally at various viscousity of the dielectric fluid mixture, which is indicated by the much lower percentage of TWR than RMR. For the current of 15 and 21 Amp, the average value of TWR is 6% and 7% of RMR, respectively.

Acknowledgement

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The Effects of Dielectric Fluid Viscousity on Chips Formation Rate and Electrode Wear Rate in Electrical Discharge Machining of SKD 61 Steel

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