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Interaction Effect of Depth of Cut, Back Rake Angle and Rock Properties on Temperature of Single Polycrystalline Diamond Compact Cutter

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ABSTRACT

The single polycrystalline diamond compact (PDC) cutter's performance is affected by temperature during rock cutting process. The study towards understanding the factors and its interaction affecting the cutter's temperature is essential prior to cutting process optimization. Thus, this study aims to investigate the effect of various cutting parameters and its interaction on the temperature of a single PDC cutter. A series of test was conducted in a lathe machine which utilized facing operation to cut the rock samples at 0.5 to 1.5 mm depth of cut and back rake angle of 5° to 15°. Two types of rock being tested in this study were Indiana limestone and Carthage marble. The analysis of variance (ANOVA) output indicated that cutting parameters and rock properties and its interaction have a significant effect on cutter's temperature except for interaction between back rake angle and rock properties. Increasing the depth of cut and decreasing back rake angle has resulted in increasing temperature. The temperature of the single PDC cutter is higher when cutting Carthage marble than Indiana limestone. Combination of low back rake angle and high depth of cut producing maximum temperature. It is also validated that the data developed from the mathematical model having a difference of 5% as compared to the experimental data obtained using similar parameters which indicates that the results are reliable and can be forwarded in the future study.

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NOMENCLATURE

mD	Millidarcy	s	second
MPa	Megapascal	T_{cm}	Temperature for Carthage marble
mm	Millimetre	T_{il}	Temperature for Indiana limestone
°C	Degree Celcius		

1. INTRODUCTION

Polycrystalline diamond compact (PDC) cutter brazing onto the PDC's bit and cut the rock formation during a drilling operation in the oil and gas industry. Rate of penetration, weight on bit and torque are the parameters that were controlled and affecting the bit's performance [1]. On the other hand, the depth of cut, back rake angle, cutting speed and spindle rate are the parameters affecting the performance of single PDC cutter that directly correlates with PDC bit. It has been proven that the rock cutting theories produced in single PDC cutter study which was verified through analytical and numerical models applied in industry and improved the drilling operation [2]. The temperature which is one of the uncontrolled factors affecting the bit's performance suggested to be considered when conducting a single PDC cutter study, respectively.

The generated temperature at the cutter-rock interface during rock cutting affecting the cutting performance of a single PDC cutter [3, 4]. Various studies have been conducted by researchers to investigate the relationship

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between rock cutting process with rock properties discussed in literature [5-9]; but, did not evaluate the temperature response. Meanwhile, studies to evaluate the effect of various cutting parameters on temperature have been conducted using experimental work and simulation analysis [2-4]. However, one can find that the data obtained from the experiment are more accurate as compared to the calculated temperature from the simulation [4]. The inaccuracy of the results happened due to simplification of calculation solution which is unacceptable in the complicated circumstance in the 'real' rock cutting. Thus, it is essential to employ the best temperature measuring technique in order to improve the accuracy and reliability of the temperature measurement in the experiment [2].

During rock cutting, the temperature of single PDC cutter was measured using thermocouple due to the principle of the Seebeck where dissimilar metals such as copper and iron are connected between one end to the other [10]. The wire is connected from thermocouple to the signal conditioning circuitry. The voltage is produced when the area between the measurement and reference junction is heated [11]. The magnitude of the produced voltage indicates the difference between the temperature at the junction with the thermocouple connectors and the data logged in the computer software [12].

Che et al. [3] used a thermocouple technique to measure the temperature of a single PDC cutter by placing the thermocouple at five locations on the PDC cutter surface to increase the accuracy of the measurement. The same technique is also used by Wilson and Vorono [13]. Both studies [3, 13] agreed that the temperature was the highest when the thermocouple is positioned at the edge of the PDC cutter (the interface area between cutter and rock). These findings proved that the heat was mainly generated at the cutter rock interface and suggested to be the area of measurement for this study. However, these studies did not include the effect of a parameter such as rock properties on the temperature response of a single PDC cutter.

In the previous literature [13-16] depth of cut, back rake angle and rock properties are reported to have a significant effect on single PDC cutter performance such as cutting force and mechanical specific energy. However, the effect of these parameters on temperature is not much explored. Thus, it is the objective of this study to evaluate the effect of various cutting parameters on the temperature of single PDC cutter during rock cutting process.

This article is organized as follows: Section 2 described the materials; rock sample and cutter, experimental setup and design of experiment used in this study. Section 3 portrayed the obtained result and analysis of temperature mechanism in single PDC cutter test, analysis of variance, the effect of various cutting parameters on temperature and validation of the mathematical model, followed by brief conclusion drawn in section 4.

2. MATERIALS AND METHODS

2. 1. Research Methodology Figure 1 shows the flowchart of this study which is divided into three sections. The first section involves the development of experimental setup and the selection of the materials consist of PDC cutters and rock samples; Carthage marble and Indiana limestone, and cutting parameters consist of depth of cut, back rake angle and rock properties based on comprehensive literature review.

The second section includes the application of design of experiment in lathe rock cutting to obtain the temperature responses. The final section involves the analysis of the interaction effect between cutting parameters on temperature. Finally, the mathematical models obtained from an ANOVA output were validated. The experimental result was compared to the predicted result from the obtained mathematical model.

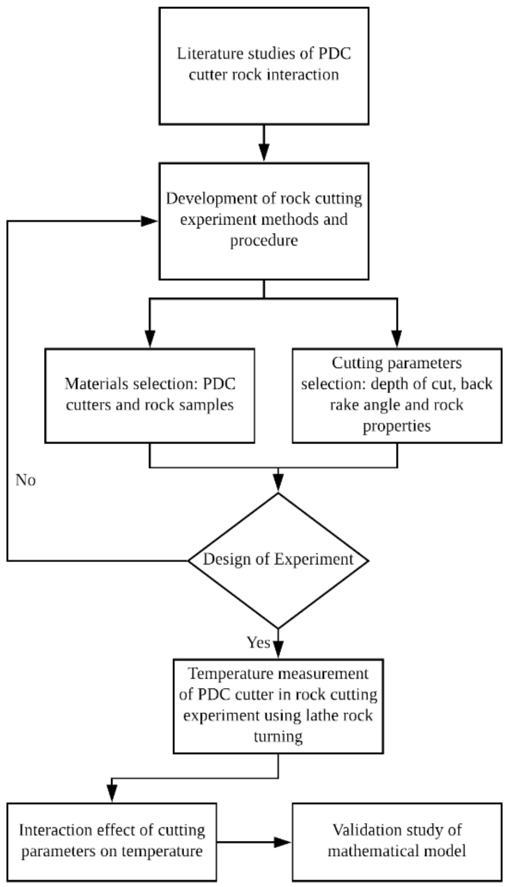

Figure 1. Research flowchart

2. 2. Materials In this experiment, Indiana limestone and Carthage marble of cylindrical shape with 101.6 mm diameter and height are used as rock samples as shown in Figure 2. The samples provided by Kocurek Industries Inc. with physical properties given in Table 1. The selection of these rocks based on distinguished strength and hardness and expected to be one of the factors affecting the temperature of single PDC cutter. The hardness of these rocks is classified by Wang et al. [17] where Indiana limestone and Carthage marble are fairly hard and hard rock, respectively.

PDC cutters used in this study were manufactured by Glynn Technical Diamonds had a dimension of 13.4 mm diameter and 8.0 mm height as shown in Figure 3. The single PDC cutter built by 6 mm thick carbide substrate and 2 mm thick diamond (chamfered at 45° chamfered with 0.6 mm length).

2. 3. Experimental Setup Figure 4 shows the single PDC cutter test conducted using electronic centre lathe 2-axis by Harrison A400 Alpha having 7.5 kW spindle and a maximum spindle speed of 2500 rpm.

In this study, the temperature of the PDC cutter is measured using K-type thermocouple which connected to DAQ system instruments consist of DEWESoft®

Figure 2. One of the rock samples for Indiana limestone (left) and Carthage marble (right) used in rock cutting experiment

TABLE 1. Physical properties of the two rock samples

Property	Indiana Limestone	Carthage Marble
Formation	Mississippian	Permian
Permeabilty (mD)	4.000	0.007
Porosity (%)	14	5
Unconfined compressive strength (MPa)	34.47	137.90
Rock hardness classification [17]	Fairly hard rock	Hard rock

Figure 3. Single polycrystalline diamond compact (PDC) cutter

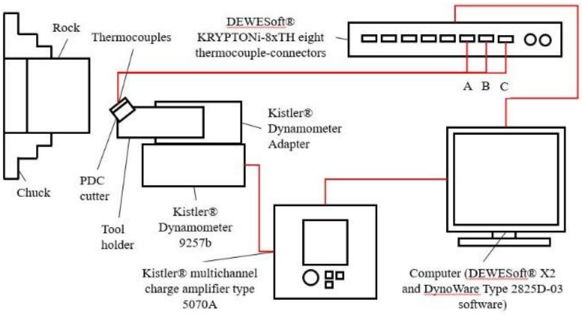

Figure 4. Schematic diagram of temperature measurement

KRYPTONi-8xTH multichannel charge amplifier and DEWESoft® X2 software. This thermocouple can measure a range of temperature between -200°C to 1372°C. The measurement of PDC cutter temperature started when the thermocouple heated during the cutting process. Then, the thermocouple sends the signal to the amplifier to be processed by setting the maximum sampling rate, 100 Hz, to produce more temperature data points. Thus, the higher accuracy of temperature measurement can be obtained. The software is used to visualize the temperature reading in time (s) vs temperature (°C) graph.

2. 4. Design of Experiment Design of experiment has been numerously utilized by researchers to study the significant effect of parameters on interest response output as discussed in literature [18-21]. Analysis tool such as ANOVA is beneficial to validate the adequacy of the mathematical model and the corresponding significance of each tested parameters under the assumption of 95% confidence [22]. In this study, the two-level factorial design was employed to study the significant effect of depth of cut, back rake angle and rock properties while setting the temperature of PDC cutter as a response. The parameters design and range of depth of cut, back rake angle and rock properties are summarized in Table 2.

Other parameters such as spindle speed and feed rate were kept constant at 750 rpm and 0.15 mm/rev, respectively. It should be notable that the constant

TABLE 2. Parameters design in single PDC cutter

Factors	Symbol	Coded Level	
		Low (-1)	High (+1)
Depth of Cut (mm)	A	0.5	1.5
Back Rake Angle (°)	B	5	15
Rock Properties	C	Indiana limestone	Carthage marble

surface speed mode is not applied in this facing operation due to the limitation of the lathe machine. The constant surface speed mode is used to ensure constant cutting speed throughout the cutting process. When it is not applied, the cutting speed is changing during the rock cutting process as the diameter of the rock sample being cut is reduced, which can be proved by using cutting speed formula as shown in Equation (1). This is in agreement with a similar finding reported by Che et al. [3].

$$V_c = \frac{\pi * D * n}{1000} \quad (1)$$

Where Vc represents the cutting speed (m/min), D represents the diameter of the rock sample (mm) and n represent spindle speed (rev/min).

These selected ranges of parameters are made by considering of comprehensive literature of previous study [13-16]. Thus, the lower range depth of cut and back rake angle is selected. Design expert software is used to develop the design of the experiment of this study.

3. RESULTS AND DISCUSSION

A set of single PDC cutter test was performed at low depth of cut and back rake angle by cutting different rock properties consist of Indiana limestone and Carthage marble rock samples. The set of tests were randomized and repeated thrice in order to perform a significance test, increase the sensitivity of the statistical test, and ensure the independence of experimental errors [23]. Overall, there were 24 sets of runs to complete the matrix and the suggested combinations of the run, as well as the temperature result, is portrayed in Table 3.

This section starts with the discussion on mechanism of temperature during this rock cutting experiment. After all the results are obtained, ANOVA approach is used to evaluate the relation effects between factors on temperature [14]. It is also used to obtain mathematical models in predicting the response [24]. Then, the interaction effect between depth of cut, back rake angle and rock properties on temperature are analyzed. Supplementary rock cutting experiment was performed to validate predicted models and discussed in section 3.4.

3. 1 Discussion on Temperature Mechanism of Single PDC Cutter Test

The mechanism of temperature during PDC cutter cutting rock samples was analyzed from temperature (°C) vs time (s) graph as shown in Figure 5. It was found that a similar trend in the graph but with different magnitude was captured for all sets of the tests.

The mechanism of temperature is analyzed according to the two phases identified in this study. In phase 1, the temperature rises approximately after 12 seconds which show the rock cutting has started. Approximately after 17 seconds, the temperature reached its maximum value at 118.98 °C.

Based on the rock cutting principle, when the cutter starts to cut the rock sample, the heat generated from the friction of cutter-rock interaction was dissipated to both cutter and rock sample including the chips removed [2]. This condition caused the temperature rises rapidly and the maximum temperature was recorded. During this period, there is more volume of chips removed due to high cutting speed and the majority of the heat dissipated to the chips.

In phase 2, when the cutter moved towards the centre of the rock sample, the cutting speed is reduced and there was less volume of rock to be cut. Subsequently, the cutting process is completed and there is no more rock sample to be cut. Thus, it is understood that all the heat generated dissipated only at the PDC cutter where the thermocouple was placed to measure the temperature. After the maximum point, the temperature decline gradually which indicated that the PDC cutter began to

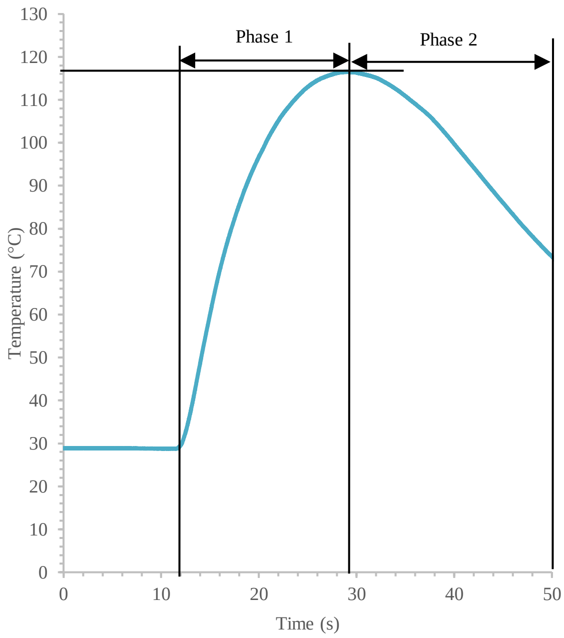

Figure 5. Temperature (°C) vs Time (s) graph captured from DEWESoft® X2 software

TABLE 3. Temperature result of design parameters applied in single PDC cutter test

Run	Depth of Cut (mm), A	Back Rake Angle (°), B	Rock Properties, C	Temperature (°C)
1	1.5	5	Carthage marble	214.68
2	1.5	5	Carthage marble	209.91
3	0.5	15	Carthage marble	121.02
4	0.5	15	Indiana limestone	66.96
5	0.5	5	Carthage marble	130.21
6	1.5	15	Indiana limestone	100.86
7	0.5	5	Indiana limestone	94.19
8	0.5	15	Indiana limestone	69.58
9	1.5	15	Carthage marble	179.38
10	1.5	5	Indiana limestone	120.25
11	1.5	5	Carthage marble	205.66
12	0.5	5	Carthage marble	131.52
13	0.5	5	Indiana limestone	92.04
14	1.5	5	Indiana limestone	118.98
15	0.5	5	Carthage marble	135.91
16	0.5	15	Carthage marble	124.63
17	1.5	15	Indiana limestone	105.88
18	1.5	15	Carthage marble	180.29
19	1.5	15	Indiana limestone	100.13
20	0.5	15	Carthage marble	125.38
21	0.5	15	Indiana limestone	62.83
22	1.5	5	Indiana limestone	119.52
23	0.5	5	Indiana limestone	80.53
24	1.5	15	Carthage marble	178.28

cool down until it returns to the ambient temperature. The result obtained agreed with previous work carried out by [3] where the temperature tends to decrease at the end of the cutting process as the interaction between cutter and rock decrease.

3. 2. Statistical Analysis ANOVA is used to analyze the interaction and significant effect between depth of cut, back rake angle and rock properties on temperature. Table 4 shows the ANOVA for temperature response. In ANOVA, factors with Prob > F less than 0.05 and large F-value are considered significant [25, 26].

Based on Table 4, Factors A, B, C, AB, AC and ABC are significant as Prob > F is 0.0001 while factors BC is insignificant because Prob > F is 0.9845. This means that only the interaction between back rake angle and rock properties did not have a significant effect on temperature.

Based on F value, the significance of the sequence of parameters and their interaction effects on the temperature response can be conveyed as: C > A > B > AC > AB > ABC > BC. Combining the interaction between factors and evaluating the effect of the interaction on temperature is considered more reliable as compared to the previous experiment [3, 13] that conducted using one factor at a time.

The model highly fitted the data and validated as the adjusted R-squared is 0.9931. The model of this study is considered acceptable when the adjusted R-squared value is approaching 1 [27]. The mathematical models for temperature response also have been obtained with a 95% confidence level. The linear regression expressions are the output of ANOVA and presented in Equations (2) and (3). This equation illustrates that the interaction between cutting parameters has a critical impact on the determination of temperature in a single PDC cutter experiment [28].

TABLE 4. ANOVA for temperature response of single PDC cutter test

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	46370.9	7	6624.41	475.47	< 0.0001
A	14951	1	14951	1073.12	< 0.0001
B	2363.74	1	2363.74	169.659	< 0.0001
C	27009.1	1	27009.1	1938.59	< 0.0001
AB	104.918	1	104.918	7.53055	0.0144
AC	1667.33	1	1667.33	119.674	< 0.0001
BC	0.0054	1	0.0054	0.00039	0.9845
ABC	274.727	1	274.727	19.7187	0.0004
Pure Error	222.917	16	13.9323		
Cor Total	46593.8	23			

$$T_{cm} = 92.7392 + 88.4850A + 0.2078B - 2.1897AB \quad (2)$$

$$T_{il} = 86.1125 + 28.0783A - 2.5048B + 0.5170AB \quad (3)$$

Where T_{cm} and T_{il} represent the temperature (°C) for Carthage marble and Indiana limestone, respectively while A is depth of cut (mm) and B is back rake angle (°).

3. 3 Effect of Cutting Parameters and Rock Properties on Temperature

Figures 6 and 7 shows the interaction effect between the back rake angle and depth of cut on temperature. Interaction effect of depth of cut on temperature is not included in other single PDC cutter studies as they used a constant depth of cut [3, 13]. It can be observed that temperature increased when the depth of cut increase from 0.5 to 1.5 mm. Based on Figure 6, a steep increase in temperature is observed using 5° and 15° back rake angle with increasing depth of cut. A similar trend was found in Figure 7.

The higher the depth of cut, the larger the contact length between the PDC cutter and the rock sample as illustrated in Figure 8. Larger contact length leads to a larger contact area between cutter-rock resulted in higher friction and increasing temperature. Energy consumption to break a fragile material is commensurate with the amount of new surface created [11]. Thus, at 1.5 mm depth of cut, more volume of rock is needed to be cut as compared to 0.5 mm depth of cut. The temperature increase as the depth of cut increase due to the increasing cross-sectional area of cut and generate more frictional heat [11]. Similar finding can be found in a study conducted by Rajabov et al. [15] where mechanical specific energy is analysed. As the depth of cut increase, the area of cut increased and put higher stresses on a PDC cutter. This significantly affects the temperature response by generating more heat at a cutter-rock interaction area of a single PDC cutter. It should be mentioned that high correlation of force to the temperature was observed in a study conducted by Wilson and Vorono [13]. Thus, the changes in magnitude of cutting force is directly proportional to the temperature changes.

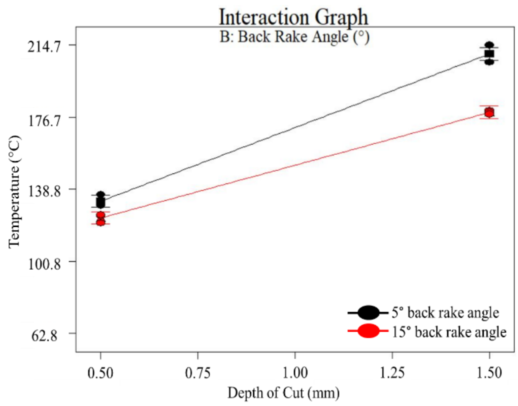

Figure 6. Interaction effect of depth of cut and back rake angle on temperature for Carthage marble

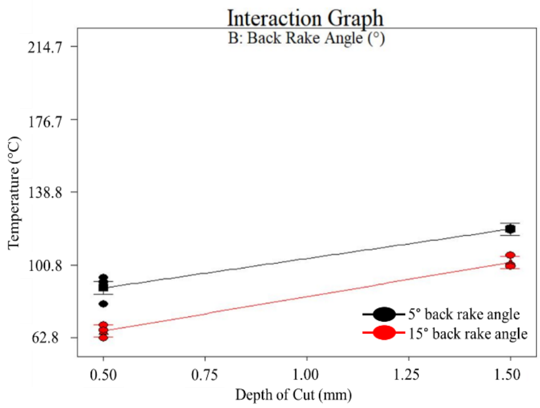

Figure 7. Interaction effect of depth of cut and back rake angle on temperature for Indiana limestone

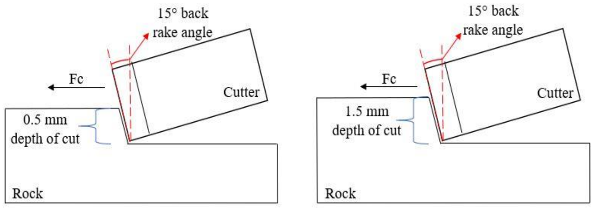

Figure 8. The cutting condition of 0.5 mm and 1.5 mm depth of cut

The interaction effect between the depth of cut and rock properties are presented in Figures 9 and 10. The temperature increases sharply when cutting Carthage marble and Indiana limestone with increasing depth of cut. It is also observed that temperature is higher when cutting Carthage marble as compared to Indiana limestone. Classified as very hard rock based on unconfined compressive strength (Table 1), the higher cutting force required to cut Carthage marble and possibly generate more heat which resulted in higher temperature as compared to cutting Indiana limestone, respectively.

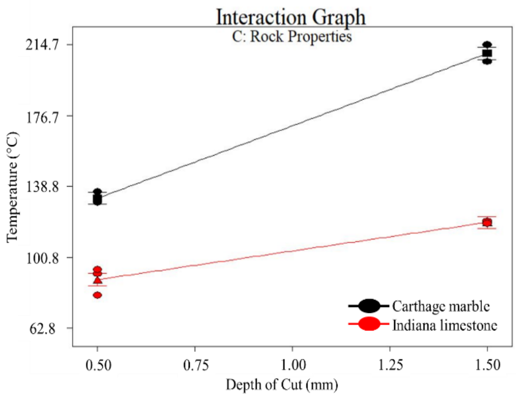

Figure 9. Interaction effect of back rake angle and rock properties on temperature for 0.5 mm depth of cut

On the other hand, Rajabov et al. [15] and Cheng et al. [29] suggested that the analysis of rock cutting cannot depend solely on the UCS of the rock and must also support with the analysis on the sedimentology of rock including rock type and its formation characteristic. Hence, the formation characteristic of Carthage marble and Indiana limestone were identified.

Carthage marble originated from a metamorphic type of rock which is formed through the alteration of existing rocks at the same environment of high pressure and temperature [15, 29]. This condition produced homogeneous behaviour where grains are well cemented and interaction forces between these grains are very high. Hence, the rock becomes harder and required a larger force and induce more heat to cut through this rock.

Meanwhile, Indiana limestone created from a sedimentary type of rock formed by deposition of materials in different environments over hundreds of years [30]. This condition leads to heterogeneous behaviour of this rock where it had poor cementation between grains. Therefore, the temperature generated in cutting this rock is much lower than Carthage marble.

The interaction effect between the back rake angle and rock properties are portrayed in Figures 11 and 12. The temperature trend in these figures indicates an inverse relationship between temperature and back rake angle. But hardly any changes of temperature are observed when cutting Carthage marble and Indiana limestone with increasing back rake angle. This is possibly due to the use of a low range of back rake angle. The results show in agreement with ANOVA output of Prob>F is higher than 0.05 where interaction between rock properties and back rake angle has no significant effect on temperature.

This is possibly due to the action of frictional impact between the rock and the cutter's rake face. Increment of back rake angle leads to the decrease of force component tangent to the rake face [31]. In addition, a study conducted by Akbari et al. [32] also indicates that at

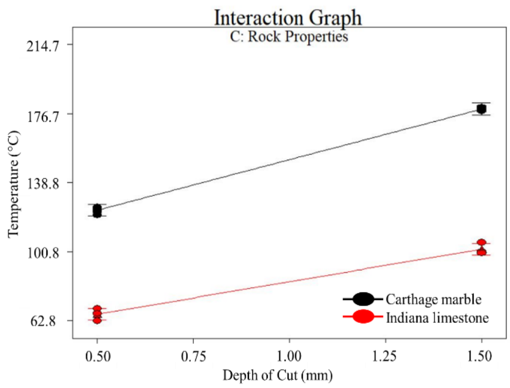

Figure 10. Interaction effect of back rake angle and rock properties on temperature for 1.5 mm depth of cut

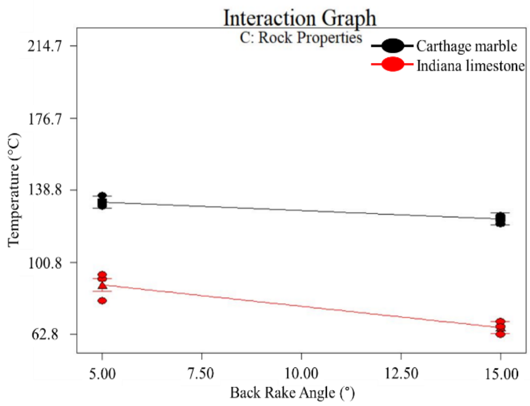

Figure 11. Interaction effect of back rake angle and rock properties on temperature for 0.5 mm depth of cu

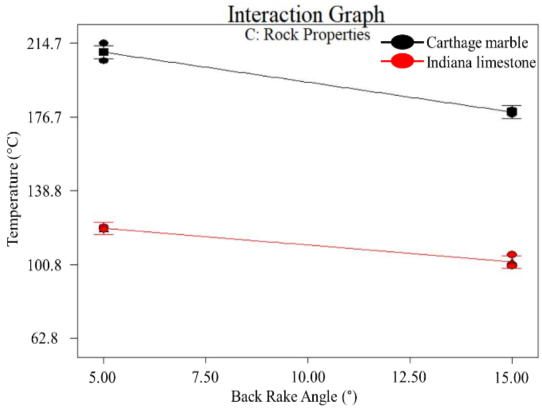

Figure 12. Interaction effect of back rake angle and rock properties on temperature for 1.5 mm depth of cut

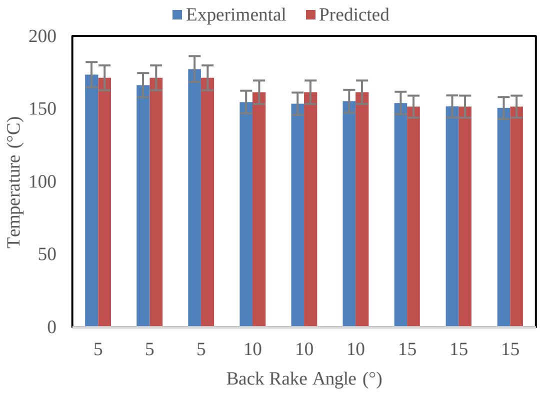

Figure 13. The experimental and predicted temperature values at a constant 1.0 mm depth of cut in Carthage marble cutting

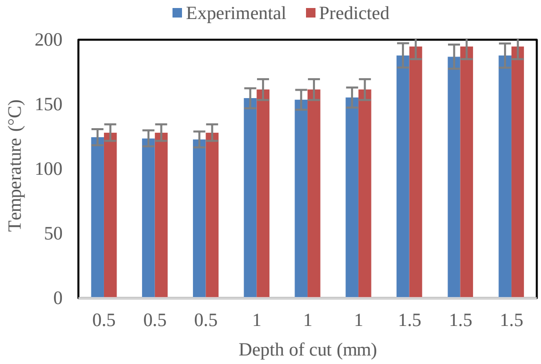

Figure 14. The experimental and predicted temperature values at a constant 10° back rake angle in Carthage marble cutting

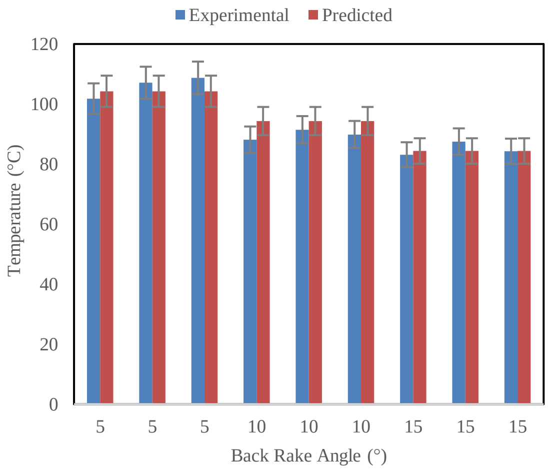

Figure 15. The experimental and predicted temperature values at a constant 1.0 mm depth of cut in Indiana limestone cutting

low back rake angle, the friction between cutter and rock is higher than cutting at high back rake angle. These findings explain the higher cutting force at lower back rake angle.

In general, Figures 6-12 show that the result is more reliable when the interaction between factors are included in the study. For example, increasing depth of cut is obvious on temperature changes when using 5° back rake angle as compared to 15° back rake angle.

This result is in agreement with Akbari et al. [32] where at low back rake angle, the friction between cutter and rock is higher than cutting at high back rake angle. Meanwhile, larger depth of cut causes the cutter to cut more cutting surface area as compared to the low depth of cut [15, 33]. Combination of the high depth of cut and low back rake angle causes the cutter's edge to cut the rock in the larger cutting area and higher friction.

3. 4. Validation of Predicted Temperature Model

The predicted values for temperature using 1.0 mm depth of cut and 10° back rake angle for Carthage marble and Indiana limestone was calculated using the linear model through Equations (2) and (3). Experimental results for Carthage marble and Indiana limestone cutting are compared with the predicted results and shown in Figures 13 to Figure 16.

It was observed that the experimental and predicted results are overlapping each other with 5% error bars and indicate the accuracy of the linear models [34]. the linear models predict the temperature of single PDC cutter with a high degree of accuracy. From these results, it can be deemed that the proposed linear model can be applied to predict the temperature of a single PDC cutter in cutting Carthage marble and Indiana limestone at low depth of cut between 0.5 to 1.5 mm and low back rake angle between 5 to 15°.

Figure 17 has portrayed the experimental data obtained in this study to show the interaction effects between depth of cut, back rake angle and rock properties on temperature. The graphs show that the temperature increased linearly with increasing depth of cut which was in agreement with Shao et al. [11]. It was also concluded

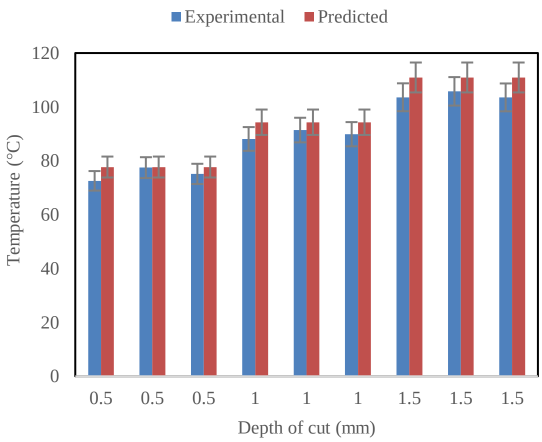

Figure 16. The experimental and predicted temperature values at constant 10° back rake angle in Indiana limestone cutting

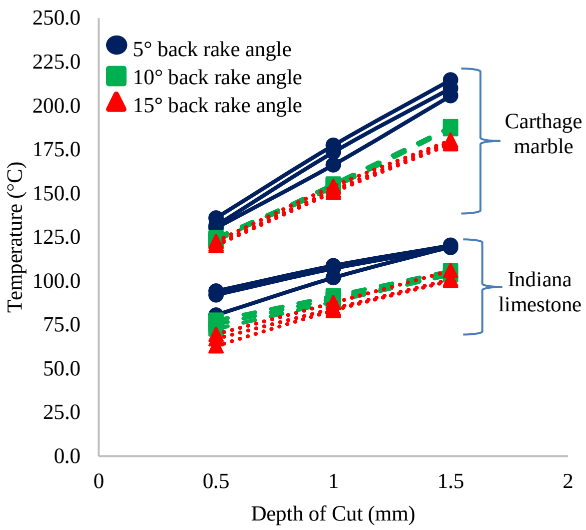

Figure 17. The comparison of all experimental interaction effects between depth of cut, back rake angle and rock properties on temperature

that the temperature exhibit by Carthage marble cutting is much higher than Indiana limestone due to different properties of Carthage marble and Indiana limestone [11, 15].

4. CONCLUSION

The rock cutting experiment was successfully conducted to evaluate the effect of back rack angle, depth of cut and rock properties and its interaction on temperature. This study contributed to the literature where the effect of low back rake angle (0.5-1.5 mm) and depth of cut (5-15°) did not evaluate in previous single PDC cutter study. It can be concluded that the depth of cut, back rake angle and rock properties have a significant effect on the temperature where Prob> F is lower than 0.05. The interaction between depth of cut and back rake angle also shows a significant effect on temperature. Another interaction between factors (depth of cut and rock properties) also indicate significant effect towards temperature. However, the interaction between back rake angle and rock properties imply insignificant changes on temperature. Nonetheless, the interaction between all factors provides a significant effect on temperature. A validation study has also been performed where a small difference (5%) between experimental and predicted data were observed. This study was limited to different formation type of rock samples; Carthage marble from metamorphic rock while Indiana limestone from sedimentary rock. The effect of different rock properties between similar formation type on temperature response is yet to be explored. Thus, it is suggested to conduct a single PDC cutter study of various rock samples from the same formation type such as sedimentary rocks.

5. REFERENCES

1. Elkatatny, S., "New approach to optimize the rate of penetration using artificial neural network", ***Arabian Journal for Science and Engineering***, Vol. 43, No. 11, (2018), 6297-6304. 10.1007/s13369-017-3022-0: 10.1007/s13369-017-3022-0.
2. Che, D., Han, P., Guo, P. and Ehmann, K., "Issues in polycrystalline diamond compact cutter–rock interaction from a metal machining point of view—part i: Temperature, stresses, and forces", ***Journal of Manufacturing Science and Engineering***, Vol. 134, No. 6, (2012). 10.1115/1.4007468: 10.1115/1.4007468.
3. Che, D., Ehmann, K. and Cao, J., "Analytical modeling of heat transfer in polycrystalline diamond compact cutters in rock turning processes", ***Journal of Manufacturing Science and Engineering***, Vol. 137, No. 3, (2015), 031005. 10.1115/1.4029653: 10.1115/1.4029653.
4. Appl, F., Wilson, C.C. and Lakshman, I., "Measurement of forces, temperatures and wear of pdc cutters in rock cutting", ***Wear***, Vol. 169, No. 1, (1993), 9-24. 10.1016/0043-1648(93)90386-Z: 10.1016/0043-1648(93)90386-Z.
5. Dormishi, A., Ataei, M., Mikaeil, R. and Kakaei, R.K., "Relations between texture coefficient and energy consumption of gang saws in carbonate rock cutting process", ***Civil Engineering Journal***, Vol. 4, No. 2, (2018), 413-421. 10.28991/cej-0309101: 10.28991/cej-0309101.
6. Suryo, S.H., Bayuseno, A., Jamari, J. and Wahyudi, A.I., "Analysis of rake angle effect to stress distribution on excavator bucket teeth using finite element method", ***Civil Engineering Journal***, Vol. 3, No. 12, (2018), 1222-1234. 10.28991/cej-030952: 10.28991/cej-030952.
7. Mohammadi, J., Ataei, M., Kakaei, R.K., Mikaeil, R. and Haghshenas, S.S., "Prediction of the production rate of chain saw machine using the multilayer perceptron (mlp) neural network", ***Civil Engineering Journal***, Vol. 4, No. 7, (2018), 1575-1583. 10.28991/cej-0309196: 10.28991/cej-0309196.
8. Wang, Z., Chen, X., Xue, X., Zhang, L. and Zhu, W., "Mechanical parameter inversion in sandstone diversion tunnel and stability analysis during operation period", ***Civil Engineering Journal***, Vol. 5, No. 9, (2019), 1917-1928. 10.28991/cej-2019-03091382: 10.28991/cej-2019-03091382.

9. Bednarik, R.G., "Rock metamorphosis by kinetic energy", ***Emerging Science Journal***, Vol. 3, No. 5, (2019), 293-302. 10.28991/esj-2019-01192: 10.28991/esj-2019-01192.

10. Duff, M. and Towey, J., "Two ways to measure temperature using thermocouples feature simplicity, accuracy, and flexibility", ***Analog Dialogue***, Vol. 44, No. 10, (2010), 1-6.

11. Shao, W., Li, X., Sun, Y., Huang, H. and Tang, J., "An experimental study of temperature at the tip of point-attack pick during rock cutting process", ***International Journal of Rock Mechanics and Mining Sciences***, Vol. 107, No., (2018), 39-47. 10.1016/j.ijrmms.2018.04.044: 10.1016/j.ijrmms.2018.04.044.

12. Goldsmid, H.J., *The thermoelectric and related effects*, in *Introduction to thermoelectricity*, S.S.i.M. Science, Editor. 2016, Springer, Berlin, Heidelberg.1-7.

13. Wilson, C. and Vorono, O., "Diamond turning of granite", in Key Engineering Materials, Trans Tech Publ. Vol. 250, No., (Year), 138-146.

14. Akbari, B. and Miska, S.Z., "Relative significance of multiple parameters on the mechanical specific energy and frictional responses of polycrystalline diamond compact cutters", ***Journal of Energy Resources Technology***, Vol. 139, No. 2, (2017), 022904. 10.1115/1.4034291: 10.1115/1.4034291.

15. Rajabov, V., Miska, S.Z., Mortimer, L., Yu, M. and Ozbayoglu, M.E., "The effects of back rake and side rake angles on mechanical specific energy of single pdc cutters with selected rocks at varying depth of cuts and confining pressures", in IADC/SPE Drilling Conference and Exhibition, Society of Petroleum Engineers. (2012). DOI: https://doi.org/10.2118/151406-MS

16. Che, D. and Ehmann, K., "Experimental study of force responses in polycrystalline diamond face turning of rock", ***International Journal of Rock Mechanics and Mining Sciences***, Vol. 72, No., (2014), 80-91. 10.1016/j.ijrmms.2014.08.014: 10.1016/j.ijrmms.2014.08.014.

17. Wang, H., Lin, H. and Cao, P., "Correlation of ucs rating with schmidt hammer surface hardness for rock mass classification", ***Rock Mechanics and Rock Engineering***, Vol. 50, No. 1, (2017), 195-203. 10.1007/s00603-016-1044-7: 10.1007/s00603-016-1044-7.

18. Kazemian, M.E. and Gandjalikhan Nassab, S.A., "Thermodynamic analysis and statistical investigation of effective parameters for gas turbine cycle using the response surface methodology", ***International Journal of Engineering***, Vol. 33, No. 5, (2020), 894-905. 10.5829/IJE.2020.33.05B.22: 10.5829/IJE.2020.33.05B.22.

19. Jaafarian, M., Ebrahimi-Nejad R, S. and Kazemain, M., "Experimental investigation of energy consumption and performance of reverse osmosis desalination using design of experiments method", ***International Journal of Engineering***, ***Transactions A: Basics***, Vol. 31, No. 1, (2018), 79-87. 10.5829/ije.2018.31.01a.12: 10.5829/ije.2018.31.01a.12.

20. Noorossana, R. and Alemzad, H., "Quality improvement through multiple response optimization", ***International Journal of Engineering***, ***Transactions B: Applications***, Vol. 16, No. 1, (2003), 49-58.

21. Kadkhodayan, M., "An investigation into the deep drawing of fiber-metal laminates based on glass fiber reinforced polypropylene", ***International Journal of Engineering***, ***Transactions C: Aspects***, Vol. 27, No. 3, (2014), 349-358. 10.5829/idosi.ije.2014.27.03c.01

22. Ranjbari, G. and Doniavi, A., "Prediction and optimization of mechanical properties of st52 in gas metal arc weld using response surface methodology and anova", ***International Journal of Engineering***, ***Transactions C: Aspects***, Vol. 29, No. 9, (2016), 1307-1313. 10.5829/idosi.ije.2016.29.09c.17: 10.5829/idosi.ije.2016.29.09c.17.

23. Hough, J.C.L., "The effect of back rake angle on the performance of small-diameter polycrystalline diamond rock bits: Anova tests", ***Journal of Energy Resources Technology***, Vol. 108, No. 4, (1986), 305-309. 10.1115/1.3231281: 10.1115/1.3231281.

24. Chamoli, S., "Ann and rsm approach for modeling and optimization of designing parameters for a v down perforated baffle roughened rectangular channel", ***Alexandria Engineering Journal***, Vol. 54, No. 3, (2015), 429-446. 10.1016/j.aej.2015.03.018: 10.1016/j.aej.2015.03.018.

25. Wang, H., Sun, J., Li, J., Lu, L. and Li, N., "Evaluation of cutting force and cutting temperature in milling carbon fiber-reinforced polymer composites", ***The International Journal of Advanced Manufacturing Technology***, Vol. 82, No. 9-12, (2016), 1517-1525. 10.1007/s00170-015-7479-2: 10.1007/s00170-015-7479-2.

26. Song, C., Li, X., Wang, L. and Shi, W., "Fabrication, characterization and response surface method (rsm) optimization for tetracycline photodegration by bi 3.84 w 0.16 o 6.24-graphene oxide (bwo-go)", ***Scientific reports***, Vol. 6, No., (2016), 37466. 10.1038/srep37466: 10.1038/srep37466.

27. Miles, J., *R squared, adjusted r squared*, in *Wiley StatsRef: Statistics Reference Online*, T.C. N. Balakrishnan, B. Everitt, W. Piegorsch, F. Ruggeri and J.L. Teugels, Editor. 2014, John Wiley & Sons.

28. Tan, Y.H., Abdullah, M.O., Nolasco-Hipolito, C. and Zauzi, N.S.A., "Application of rsm and taguchi methods for optimizing the transesterification of waste cooking oil catalyzed by solid ostrich and chicken-eggshell derived cao", ***Renewable Energy***, Vol. 114, (2017), 437-447. 10.1016/j.renene.2017.07.024: 10.1016/j.renene.2017.07.024.

29. Cheng, Z., Sheng, M., Li, G., Huang, Z., Wu, X., Zhu, Z. and Yang, J., "Imaging the formation process of cuttings: Characteristics of cuttings and mechanical specific energy in single pdc cutter tests", ***Journal of Petroleum Science and Engineering***, Vol. 171, (2018), 854-862. 10.1016/j.petrol.2018.07.083: 10.1016/j.petrol.2018.07.083.

30. Greensmith, J., "Petrology of the sedimentary rocks, Springer Science & Business Media, (2012).

31. Che, D., Zhang, W. and Ehmann, K., "Chip formation and force responses in linear rock cutting: An experimental study", ***Journal of Manufacturing Science and Engineering***, Vol. 139, No. 1, (2017), 011011. 10.1115/1.4033905: 10.1115/1.4033905.

32. Akbari, B., Miska, S., Yu, M. and Rahmani, R., "The effects of size, chamfer geometry, and back rake angle on frictional response of pdc cutters", in 48th US Rock Mechanics/Geomechanics Symposium, American Rock Mechanics Association. (2014).

33. Gerbaud, L., Menand, S. and Sellami, H., "Pdc bits: All comes from the cutter rock interaction", in IADC/SPE Drilling Conference. DOI: https://dx.doi.org/10.2118/98988-MS

34. Pratap, T. and Patra, K., "Micromilling of ti-6al-4v titanium alloy using ball-end tool", in IOP Conference Series: Materials Science and Engineering, IOP Publishing. Vol. 229, No. 1, (2017), 012011.

Persian Abstract

چکیده

عملکرد برش یکپارچه الماس چند بلوری (PDC) تحت تأثیر دما در طی فرآیند برش سنگ است .قبل از بهینه سازی فرآیند برش ، مطالعه در مورد درک عوامل و تأثیر متقابل آن بر دمای برش ضروری است .بنابراین ، این مطالعه با هدف بررسی تأثیر پارامترهای مختلف برش و اثر متقابل آن بر دمای یک برش PDC منفرد انجام می شود . یک سری آزمایش در دستگاه تراشکاری انجام شد که با استفاده از عمل روبرو ، نمونه های سنگ را در عمق 0.5 تا 1.5 میلی متر برش و زاویه شیب عقب 5 درجه تا 15 درجه برش داد .دو نوع سنگ مورد آزمایش در این مطالعه سنگ آهک هندی و سنگ مرمر کارتاژ است .تجزیه و تحلیل واریانس (ANOVA) خروجی نشان داد که پارامترهای برش و خصوصیات سنگ و اثر متقابل آن تأثیر قابل توجهی بر روی درجه حرارت برش دارد به جز برهم کنش بین زاویه شیب عقب و خصوصیات سنگ . افزایش عمق برش و کاهش زاویه شیب عقب منجر به افزایش دما می شود .دمای برش PDC منفرد هنگام برش سنگ مرمر کارتاژ بیشتر از سنگ آهک هندی است .ترکیبی از زاویه شیب کم پشت و عمق زیاد برش که حداکثر دما را تولید می کند .همچنین تأیید شده است که داده های حاصل از مدل ریاضی با اختلاف5 ٪ در مقایسه با داده های آزمایشی به دست آمده با استفاده از پارامترهای مشابه نشان می دهد که نتایج قابل اعتماد هستند و می توانند در مطالعه آینده استفاده شوند.