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Optimization of Drilling Parameters on Diameter Accuracy in Dry Drilling Process of AISI D2 Tool Steel

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Abstract

This research was carried out to determine the optimization parameter for holes diameter accuracy in dry drilling process of AISI D2 Tool Steel using Taguchi method. The objective of this project is to find the optimum condition in producing high accuracy of holes diameter. The selected spindle speeds for drilling process are 482 RPM, 550 RPM and 627 RPM. The feed rate parameters are 68 mm/min, 103 mm/min and 146 mm/min. Next parameter is the types of drill bit which consist of High Speed Steel (HSS) coated with Titanium Nitride (TiN), High Speed Steel (HSS) coated with Titanium Carbon Nitride (TiCN) and High Speed Steel (HSS) coated with Titanium Aluminium Nitride (TiAlN). The machining process will be performed on the CNC milling machine. The diameter accuracy of holes will be tested by using Coordinate Measuring Machine (CMM).

Keywords: Dry drilling; AISI D2; Tool Steel; Taguchi Method; ANOVA

INTRODUCTION

In modern manufacturing technology, there are many challenges faced by the industry in terms of dimensional accuracy and precision especially for hardened materials. Hard material such as AISI D2 Tool Steel with hardness in the range of 54-62 HRC have high strength, very high resistance to cracking and high resistance to softening and wear [1]. Drilling is a process to cut or enlarge a hole of circular cross-section in solid materials using a drill bit. Drilling may affect the mechanical properties of work piece due to the formation of low residual stresses around the holes opening and causes the work piece to become more susceptible to corrosion and crack propagation at the stressed surface [1, 2]. Several factors that can affect the quality of the drilled holes are the cutting parameters used. For instance, cutting speed, feed rate and cutting configurations which consists of tool diameter, material and geometry [2]. Dry machining has been emphasized due to the economic and environmental considerations. Although some important cutting operations are still not possible without coolants, further possibilities for dry drilling and tapping of steels are enabled by the recent approach using tools with hard coating layers topped with a lubricant layer. The chip flow is improved with a lowered coefficient of friction and minimization of cutting force with the combination of hard and soft coating layers [3]. There are many previous works study about the process parameters on the diameter accuracy in dry drilling process. However, the study focused on the effect of parameters in drilling AISI D2 tool steel is very limited. It is due to difficulties faced during machine this material [4].

There are three types of drill bit with diameter of 11mm to be used such as High Speed Steel coated with Titanium Nitride (TiN), High Speed Steel coated with Titanium Carbon Nitride (TiCN) and High Speed Steel coated with Titanium Aluminium Nitride (TiAlN). The selection of coating materials is an important task because improper selection can decrease tool life rather than uncoated tool.There are some characteristics to be considered during the selections of coating materials such as hardness. A high surface hardness is the best way to increase tool life which means the harder the material or surface, the longer the tool life span. For example, Titanium Carbon Nitride (TiCN) has a higher surface hardness compared to Titanium Nitride (TiN) according to the previous research [3,4]. This is due the addition of carbon that gives TiCN 33% hardness than TiN and changes the range from about 3000 to 4000 Vickers.

Next, wear resistance property which is the ability of coating to protect against abrasion. It is important because although a material may not be hard, the process and elements added during production may aid in the breakdown of cutting edges or forming lobes. Besides that, surface lubricant also plays an important role. A decrease of coating life or coating failure is influenced by the coefficient of friction. The higher the coefficient of friction caused the higher heat producing which leads to the problem. However, a lower coefficient of friction can greatly increase tool life. The amount of heat can be reduced by a surface that lacks coarseness or irregularities. This is because the slick surface lets the chips to slide off the tool face that results in less heat produced. A higher surface lubricant will increase speeds when compared to non-coated versions [4,5]. This will also help to fend off the work material. Oxidation temperature is the point at which the treatment starts to break down. A higher oxidation temperature shows improves success in high heat applications [6]. There are some coating materials that not as hard as TiCN at room temperature but it is more effective where the heat is generated. For example TiAlN holds its hardness at higher temperature with the help of layer of aluminium oxide that forms between the cutting chip and tool. The formation of this layer helps to transfer heat away from the tool and into the chip or part.

AISI or known as American Iron and Steel Institute is widely used in manufacturing industry as cold working operation such as molds and dies. The characteristics of AISI D2 are hard and wear resistance. There are some problems on machining hard material such as difficulties in evacuation of chips and dissipation of heat. The dimensional accuracy and surface finish may be affected by the friction occurs between the drill bit, chip and work piece. In some cases, those difficulties mentioned may leads to catastrophic drill failure [13]. AISI D2 Tool Steel still can be machined although it has poor ability to be machining [14]. In addition, AISI D2 is highly preferable among the D series due to its high chromium and high carbon steels properties. It is known to have properties like high compressive strength and wear resistance, good hardening stability, and great through hardening as well as good resistance to tempering back. This die steels have highly alloy steels of Fe-Cr-C base which makes it able to sustain its desirable mechanical properties at high temperature. The benefits of these properties can be an advantage for applications like punches, piercing and blanking dies, spinning tools, shear blades, slitting cutter and especially for higher-end working tools [15,16].

Cutting fluids or lubricants play an important role in material removal process and machining operation such as turning, milling and drilling. It has been used since past machining process because according it achieved 40 per cent increase in cutting speed while machining steel with high speed steel tool and water as a coolant [7]. In this project, the process does not involve of cutting fluid. Drilling is one of the machining processes most used by manufacturing companies which is very complex from the perspective of scientific study. The geometry and the surface are generated in a single operation with many influential parameters. The reduction or elimination of the cutting fluids caused geometric and dimensional controls are more critical because the temperatures in the process may influence the shape and dimensional accuracy of the holes [8]. In manufacturing industry, the effect of cutting fluid has been a consideration because of the negative impacts. The chemical contain in the cutting fluids caused harm for instance dermatitis when in contact with hands or bodies. As for the environment, the use of chlorine in cutting fluid makes it toxic and become harmful such as water pollution and soil contamination if the waste is thrown in the river [7].

Although there are some important operations that are not possible without lubricants, the recent approach using tools with hard coating layers makes it enable for dry drilling and tapping of steels process. The hard coating layers allow the improvement of chip flow with a lowered coefficient of friction and reduced cutting force [3]. Orthogonal arrays of Taguchi, the signal-to-noise (S/N) ratio, the analysis of variance (ANOVA), and regression analyses are employed to find the optimal levels and to analyse the effect of the drilling parameters on hole diameter accuracy values. Taguchi method is desirable in this project due to its practicality in designing high quality systems that provide much-reduced variance for experiments with an optimum setting of process parameters [6].

METHODOLOGY

Experiment Setup

In this study, experiments were carried out using 3 axis CNC milling machine DMC 635 V Ecoline in dry condition using HSS coated with Titanium Nitride (TiN) drill bits, HSS coated with Titanium Carbon Nitride (TiCN) drill bits and HSS coated with Titanium Aluminium Nitride (TiAlN) drill bits spiral types. To achieve the optimum result of hole diameter accuracy, the experiment will conducted with a new drill bit for each hole. three types of coated drill bits used in this study such as HSS coated with Titanium Aluminium Nitride (TiAlN), HSS coated with Titanium Carbon Nitride (TiCN) and HSS coated with Titanium Nitride (TiN). Before the machining process began, the material were firstly goes for grinding process to ensure flatness of material. The speciment used in this experiment is AISI D2 Tool Steel with dimension of 200 mm width × 200 mm length × 13mm thickness. The experiment setup is shown in figure 1.

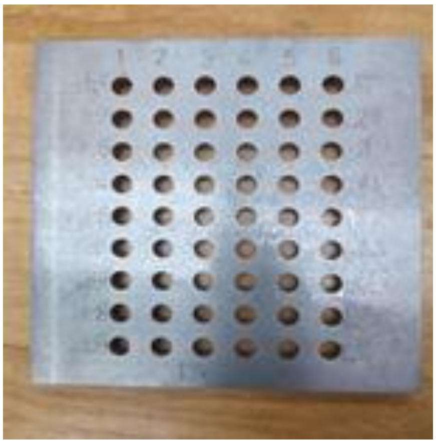

Figure 1: AISI D2 Tool Steel material

The machining program has been done using Catia V5 software on a desktop. After thru hole drilling process, the diameter of every single hole was measured by using Coordinate Measuring Machine (CMM) Contura G2 to get the diameter value of every each hole is shown in figure 2 . In this experiment, the mean value is determined by conducted nine time drilling for each paremeter to guarantee the optimum value is achieved.

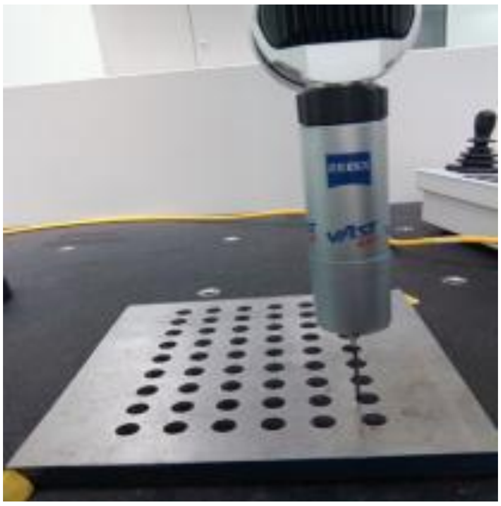

Figure 2: Hole diameter measurement

Design of Experiment

Types of Design of Experiment (DOE) selected in this experiment using Taguchi method. The main factor chosen which are feed rate, cutting speed and types of drill bit will be considered while conducting the experiment. This experiment has 3 level of study which is low, medium and high. The characteristics for cutting parameter have been decided as shown in Table 1.

Table 1: The parameter at three levels and three factors

Factors	Unit	Levels		
		1	2	3
A	Feed rate mm/min	68	103	146
B	Spindle rate RPM	482	550	627
C	Drilling tools 11 mm diameter	HSS+TiN	HSS+ TiCN	HSS+ TiAlN

Data Analysis

Experimental design was developed by Taguchi Method. Minitab 17 software has been utilized to analyze the optimum parameters that control the diameter accuracy. Analysis of variance (ANOVA) used to identify the significant factor contributes to experiment condition. Table 2 shows the S/N ratios and mean using the 'smaller is better' characteristics.

Table 2: An orthogonal array L_9 (3^3) of Taguchi for the surface finish

Exp No.	Designation	SNRA1	MEAN1
1	$A_1B_1C_1$	-20.9152	11.1112
2	$A_1B_2C_2$	-20.8545	11.0338
3	$A_1B_3C_3$	-20.9030	11.0955
4	$A_2B_3C_1$	-20.8995	11.0911
5	$A_2B_1C_2$	-20.8457	11.0225
6	$A_2B_2C_3$	-20.9062	11.0997
7	$A_3B_2C_1$	-20.9445	11.1486
8	$A_3B_3C_2$	-20.8718	11.0559
9	$A_3B_1C_3$	-20.9391	11.1419

Confirmation test

This confirmation test is conducted in order to validate the prediction parameter at the optimal level. The parameter with optimum level suggested by Taguchi method is the combination of $A_2B_3C_2$. Next, the experiment is conducted using the suggested parameter by Taguchi method whereby the AISI D2 tool steel is drilling with two holes. The result shows that the percentage error is 0.42%. Since the percentage error value is lower, the combination parameter suggested by Taguchi is optimal.

RESULTS AND DISCUSSIONS

The reading of diameter for each 54 holes has been taken. The measurement is taken once per parameter each holes since it has been drilled for six times using the same cutting tool. The average of diameter values is calculated. The table below shows the reading of diameter for all nine parameters which conducted by using Coordinate Measuring Machine (CMM) Contura G2 tester.

Table 3: Result of Holes Diameter

No. Of Experiment	Feed Rate (mm/min)	Spindle Speed (RPM)	Drilling Tools	Diameter (mm)	Avg. Diameter (mm)
1	68	482	TiN	11.0959 11.1073 11.0970 11.1039 11.1199 11.0802	11.1007
2	68	550	TiCN	11.0517 11.0404 11.0328 11.0373 11.0415 11.0464	11.0417
3	68	627	TiAlN	11.0934 11.0945 11.0976 11.1141 11.0950 11.0938	11.0981
4	103	627	TiN	11.1037 11.1046 11.1041 11.0900 11.0958 11.0961	11.0990
5	103	482	TiCN	11.0408 11.0250 11.0158 11.0358 11.0261 11.0070	11.0251
6	103	550	TiAlN	11.0946 11.0854 11.1020 11.0854 11.0856 11.0821	11.0892

Diameter Accuracy Analysis using Taguchi Method

Upon obtaining the results from CMM and calculating the average for each parameter, Minitab 17 is used to analyse the data collected. The values of Signal to Noise Ratio (S/N Ratio) and means were observed. The graphs of main effects for signal to noise ratios and means are plotted by using 'smaller is better' as its type of characteristic. The optimum parameter and most contribution factor in this experiment obtained through the graphs.

Terms in Taguchi method such as 'signal' is representing the desirable value of mean for the output characteristic while 'noise' represent the undesirable value of standard deviation for output characteristic. Thus, the S/N Ratio shows the ratio of mean to the standard deviation. The S/N ratio used to measure the deviation of quality characteristic from desired value. There are several types of S/N Ratio according to the characteristic; *lower is better* (LB), *nominal is better* (NB) or *higher is better* (HB) [6].

For *lower is better* (SB) Equation (1).

$$\frac{S}{N} = -10 \log \frac{1}{n} \left(\sum_{y} 2 \right) \qquad (1)$$

Where; n is the is the observed data. The characteristic chosen in this experiment is *lower is better* which means lower diameter error is desirable.

In order to reduce the time and cost, the number of experiments carried out is nine which then used in the optimization method and orthogonal array of L_9 is created. There are nine rows corresponding to the number of tests with three columns at three levels. The output chosen to be study is diameter accuracy. The observation for the influence of cutting conditions which are feed rate, spindle speed and types of drill bit coating is made by consideration of three factors whereby each at three levels as shown in Table 1.

Results of Signal to Noise Ratio and Mean

Minitab 17 is used to analyse the data from diameter reading by calculating the values of signal to noise ratio and mean. Both graphs are plotted according to its values and observation is made by using '*lower is better'*.

Table 4: The values of S/N Ratio and Diameter Error

	C1	C2	C3-T	C4	C5	C6
	Feed rate	Spindle speed	Drill bit types	diameter	S/N RA	MEAN
1	68	482	TiN	11.1007	-20.9152	11.1112
2	68	550	TiCN	11.0417	-20.8545	11.0338
3	68	627	TiAlN	11.0891	-20.9030	11.0955
4	103	627	TiN	11.0990	-20.8995	11.0911
5	103	482	TiCN	11.0251	-20.8457	11.0225
6	103	550	TiAlN	11.0892	-20.9062	11.0997
7	146	550	TiN	11.1512	-20.9445	11.1486
8	146	627	TiCN	11.0454	-20.8718	11.0559
9	146	482	TiAlN	11.1498	-20.9391	11.1419

Table 5: The Values of S/N Ratio and Diameter Error

No Of Exp	Feed Rate (mm/min)	Spindle Speed (RPM)	Drilling Tools	Avg of Diameter (mm)	S/N Ratio (dB)	Diameter Error (µm)
1	68	482	TiN	11.1007	-20.9152	11.1112
2	68	550	TiCN	11.0417	-20.8545	11.0338
3	68	627	TiAlN	11.0981	-20.9030	11.0955
4	103	627	TiN	11.0990	-20.8995	11.0911
5	103	482	TiCN	11.0251	-20.8457	11.0225
6	103	550	TiAlN	11.0892	-20.9062	11.0997
7	146	550	TiN	11.1512	-20.9445	11.1486
8	146	627	TiCN	11.0454	-20.8718	11.0559
9	146	482	TiAlN	11.1498	-20.9391	11.1419

Main Effects Plots for S/N Ratio and Mean

The graph of Signal to Noise Ratio and Mean Diameter Error has been plotted. The analysis of graphs is made by referring to Figure 1 and 2. The optimum parameter is observed by the highest level plotted in SN ratio graph. This is because the higher values of SN ratio identify control factor settings that minimize the effect of the noise factors. In other words, the highest value of SN ratio shows that it lower the effect of noise factor [5].

Meanwhile, the analysis on means graph is observed by the lowest level plotted. It is because graph of means shows the average of variation. In other words, the lowest value of means shows that the variation is smallest.

Main Effect represents a value that shows the extent of influence of a factor on the response. Main Effect Plot represents the variation in the response variable with the variation in control factors and is used to examine differences between level means for factors. If the line plotted in a Main Effect Plot is horizontal, means that the factor is non-significant since there is no change in responses with the factor. If the line has higher slope then it shows that the factor is significantly affecting the response [5].

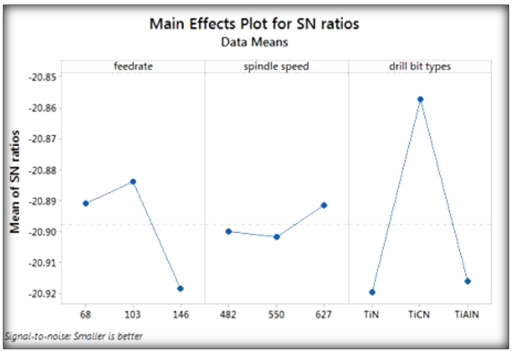

Figure 1: Main Effect Plots for SN Ratios

By referring to the Figure 1, the highest value plotted for feed rate is level 2 (103 mm/min). The highest value plotted for spindle speed is from level 3 (627 RPM) while for drill bit types is contributed by level 2 (HSS coating with TiCN). There is no horizontal line plotted. Hence, it shows that the combination of higher level of feed rate, spindle s peed and drill bit coating can give the minimum S/N Ratio among the all possible combinations.

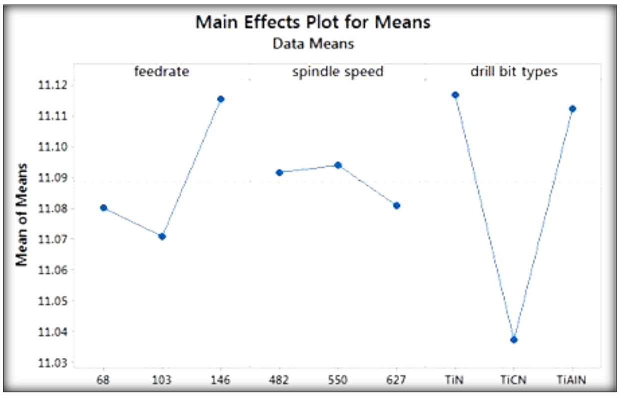

Figure 2: Main Effect Plots for Means

The variability in the model should be minimized in order to meet the aim which is to minimize the means. By referring to the Figure 2, the lowest value plotted for feed rate is from level 2 (103 mm/min). The lowest value plotted for spindle speed is from level 3 (627 RPM) while for drill bit types is contributed by level 2 (HSS coating with TiCN). Therefore, the optimum parameter suggested by Taguchi is the combination of A2B3C2 (103 mm/min, 627 RPM, HSS coating with TiCN) which give the most accurate diameter.

Response Table for S/N Ratio and Mean

Table 6 and 8 shows the response table for Signal to Noise Ratio and Means. The values of Delta indicate overall change in the value of control factor. In mathematically terms, Delta is the difference between maximum and minimum average of SN ratio for the factor. Meanwhile, the highest rank has the highest value of delta. The highest rank shows it is the most significant or affected factor contributed in this experiment.

Based on the Table 6, types of drill bit coating is the first rank (0.06), followed by feed rate (0.03) and spindle speed (0.01). By referring to Table 4.4, first rank is the types of drill bit coating (0.08), followed by feed rate (0.04) and spindle speed (0.01) which are the same as Table 4.3. Throughout the observation, it demonstrate that the delta of all factors which are drill bit types, feed rate and spindle speed is almost nearest to each other which are below 0.1. It can be inferred that all parameter tested in this experiment are almost equivalent significant.

Table 6: The Response Table for Signal to Noise Ratios (smaller is better)

Level	Feed Rate(mm/min)	Spindle Speed (RPM)	Drill Bit Types
1	-20.89	-20.90	-20.92
2	-20.88	-20.90	-20.86
3	-20.92	-20.89	-20.92
Delta	0.03	0.01	0.06
Rank	2	3	1

Table 7: The Response Table for Means of Diameter Error

Level	Feed Rate (mm/min)	Spindle Speed (RPM)	Drill Bit Types
1	11.08	11.09	11.12
2	11.07	11.09	11.04
3	11.12	11.08	11.11
Delta	0.04	0.01	0.08
Rank	2	3	1

Based on Table 6 and 7, the coating types are the first rank which mean it is the most significant factor. It might be due to the material itself. By using high speed steel (HSS) cutting tool with multi abrasive coating, it contributes to very high performance in terms of higher diameter accuracy. It might be due to the best coating material selection that produced good diameter accuracy. The using of very high abrasive coating material results in high resistance to the wear performance by increasing the abrasive resistance during material sliding.

Besides that, multi abrasive coating material will increase lubricant while reducing the friction as well as temperature generation. The coating causes reducing of friction during machining since it has the lubricant properties. As cutting tool shear the material with lower temperature, the stability of cutting tool can be retain for longer period of time. Therefore, cutting tool can shear the metal or work piece clearly resulting more accurate of material removal process that produce better accuracy of holes diameter [9].

The performances of each coating material are vary depends on its abrasive characteristic. In this case, the using of high speed steel (HSS) with TiCN coating contribute most accuracy. Titanium Carbon Nitride (TiCN) is an abrasion resistant ceramic coating that formed by addition of small amount of carbon to the Titanium Nitride (TiN) during the deposition process. This coating is harder than TiN which provides the cutting edge with good protection from wear. TiCN coatings with increasing carbon content makes it have higher hardness and wear resistance [12]. At the same time, the addition of carbon not only increased the hardness but resulting in lower friction coefficient. Besides that, this coating provides lubricating effect which helps in machining of metal under dry condition [10].

The second significant factor is feed rate. The feed rate affected the diameter accuracy based on the thrust force during drilling process that moves into work piece during shearing action. During low feed rate which is 68 mm/min, the thrust force incapable to create enough energy to shear the material. It might be due to inappropriate yielding. During moderate feed rate which is 103 mm/min, the result shows better accuracy near to 11 mm of holes diameter. It indicates the higher feed rate causes the thrust force able to penetrate into work piece and can shear material effectively. Thus, it resulting straight movement of cutting tool during drilling process to create hole accurately.

Basically, tool wear happened due to time and nature of the cutting tool and work piece contact. According to Monaghan and O'reilly [11], higher feed rate caused lower tool wear due to lower cutting time [11]. Thus, it can be said that when the feed rate increase, the contact time also lowered due to lower cutting time which results in better accuracy. Conversely, when feed rate is further increase to 146 mm/min, the very high thrust force could deform waste material due to very fast engagement between cutting tool and work piece. At this time, it is expected that work piece material deform first before shearing action takes place. It could initiates to slightly inaccuracy of the diameter.

The least affecting factor is spindle speed. The spindle speed influence diameter accuracy by rotating into the sheared metal remove the material and form a hole according to cutting tool diameter. Spindle speed is directly proportional to the cutting temperature by meaning that an increasing in spindle speed resulting increasing in cutting temperature. The result obtained indicates that lowest spindle speed which is 482 RPM produce inaccurate diameter. This happened might be due to improper shearing process or cutting force is not sufficient enough to shear the work piece metal properly. Besides that, work piece material might probably deform first before sheared by cutting tool so that producing slightly inaccurate diameter. Thus, lowest spindle speed causing not smooth of cutting process which then affecting the diameter accuracy.

Though the spindle speed increase to 550 RPM, it still unable to produce good diameter accuracy. This is because of inadequate force provided causing the shearing action is not smooth. On the other hand, when the spindle speed is further increase to 627 RPM it results in better diameter accuracy. It is because of the higher rotating of cutting tool and sufficient of cutting force causes the work piece can be shear effectively. The increasing of spindle speed will also increase the movement of sliding action thus causing the work piece can be shear cleanly and create a hole accurately according to the cutting tool diameter. Besides that, an increasing in cutting speed results in lower cutting force and torque [11].

The example calculation of Mean of Signal to Noise (S/N) Ratio for each factor and level is shown below.

Example calculation of Mean of S/N Ratio for Factor A (feed rate) at Level 1:

S/N_{A1} = (-20.9152) + (-20.8545) + (-20.9030)/3

= - 20.89

For Rank determination, the values of Delta were taken for consideration. The highest Rank shows the highest value of Delta. The example calculation of Delta for each factor is as shown below.

Example calculation of Delta for Factor A (feed rate):

Delta =Max –Min

= (-20.89) - (-20.92)

= 0.03

Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) is performed to test the significance of the factors for the response which in this study is diameter accuracy [17,18. There are several terms used as shown in Table 8. The term 'DF' indicates the degree of freedom which refers to the number of terms that will contribute to the error in prediction. The term 'Adj SS' indicates the adjusted sum of squares which refers to the sum of squares obtained after removing insignificant terms from the model. Meanwhile, the adjusted mean square or 'Adj MS' indicates the mean square obtained after removing the insignificant terms from the response equation. The F-value is used to test the hypothesis and it is calculated as the ratio of adjusted mean square value to residual error. The analysis is made by referring to the P-value and the percentage contribution calculation. The result was interpreted by using 95% of confidence level for all analysis of data [18-21].

ANOVA used to test the significance of all main factors and their interactions by comparing the Mean Square (MS) against an estimate of the experimental errors at specific confidence levels. It is done by separating the total variability of the S/N Ratios, which is measured by the sum of the squared deviations from the total mean S/N Ratio, into contributions by each of design parameters and the error [17-21].

Through the Table 8, the P-value of coating types is 0.043 which is less than 0.05 corresponding to 95% confidence level. It indicates that this factor have significant contribution on the diameter accuracy. This factor also possesses the highest percentage contribution which is 74.32%. On the other hand, both factors feed rate and spindle speed are found to be non-significant as their P-value is more than 0.05. These factors are said to be non-significant since the percentage of contribution are small. In other words, the types of coating is the most critical factor that must be taken into consideration while the rest factors does not affected too much in terms of diameter accuracy.

Table 8: Results of Analysis of variance (ANOVA)

Source	DF	Adj SS	Adj MS	F-value	P-value	% of Contribution
Feed rate	2	0.0032	0.0016	6.14	0.140	20.46
Spindle speed	2	0.0003	0.0001	0.56	0.641	1.86
Drill Bit Types	2	0.0119	0.0059	22.28	0.043	74.32
Residual error	2	0.0005	0.0002			3.11
Total	8	0.0161				100

Equation 2 is a formula of Percentage of Contribution:

$$P = \frac{SS_d}{SS_T} \quad (2)$$

Where, SS_d is the sum of square deviation and SS_T is the sum of square deviation total.

Calculation for percentage of contribution:

Feed rate % = 0.0032 / 0.0161
= 20.46%
Spindle speed % = 0.0003 / 0.0161
= 1.86%
Drill bit types % = 0.0119 / 0.0161
= 74.32%

Taguchi Analysis Predictions

The prediction of signal to noise ratio and mean of hole diameter is made by using the combination obtained for optimize parameter. Using the Minitab 17 software, select the 'Predict Taguchi Design' features and choose the factor such as for feed rate is 103 mm/min, spindle speed is 627 RPM and drill bit type is TiCN. Figure 4.3 shows the predicted value of signal to noise ratio and mean diameter error for the combination of optimum parameter.

Predicted value:
S/N Ratio= -20.8371
Mean= 11.0115

Factor levels for predictions:
feed rate: 103
spindle speed: 627
drill bit type: TiCN

Figure 3: Predicted Values of Suggested Parameter

The prediction value can be calculated by using equation below:

Prediction S/N Ratio for holes diameter error in equation 3;

$\eta_{A2}+\eta_{A3}+\eta_{A2}$ -2(η)

-20.88 + -20.89 + -20.86 -2(-20.9)

-20.84 dB

Prediction Means of Diameter error equation 4;

A2+B3+C2 -2(Y)

11.07+ 11.08 + 11.04 -2 (11.09)

11.01µm

Where η is the average value of the holes diameter error in S/N Ratio and η_{A2} is the minimum S/N Ratio at Factor A.

Confirmation Test

This confirmation test is conducted in order to validate the prediction parameter at the optimal level. It is a crucial step which is highly recommended by Taguchi to verify the result obtained [6]. The parameter with optimum level suggested by Taguchi method is the combination of A2B3C2. The value of holes diameter predicted for this combination parameter is obtained earlier. Next, the experiment is conducted using the suggested parameter by Taguchi whereby the AISI D2 tool steel is drilling with two holes. The diameter value is obtained by using CMM tester for both holes. Then, calculate the percentage error between the predicted value and actual value. Therefore, the percentage error is 0.42%. Since the percentage error value is lower, the combination parameter suggested by Taguchi is optimal. Table 4.6 shows the result of confirmation test while table 10 shows the calculation of percentage error.

Table 10: The Result of Confirmation Test

Hole 1	Hole 2	Average	
Diameter value	11.0543	11.0604	11.0573

The values of diameter for both holes were obtained by using Coordinate Measuring Machine (CMM) and the average of holes is calculated.

Percentage error

= (actual value-predicted value)/(predicted value)×100

= (11.0573-11.0115)/11.0115×100

= 0.42%

Since the percentage error between prediction and actual value is smaller which 0.42%, thus the validation test is successful.

CONCLUSIONS

This paper has presented the effect of drilling tools coating and parameters during dry drilling of AISI D2. Taguchi method used to determine the optimum machining parameter for this machining condition. Meanwhile, ANOVA was established to analyze the significant factor affect the performance of drilling hole in D2 steel. Based on the result, some conclusions can be made:

- The drill bit coating type has mainly affects the diameter accuracy based on the highest percentage distribution, followed by the feed rate and spindle speed.
- The optimum parameter is observed by using HSS coated with TiCN while the feed rate at 103 mm/min and spindle speed at 627 RPM. Coated drill bit gave best performance result on highest significant percentage change.
- Feed rate and spindle speed control the efficiently of drilling by affecting the temperature generation on work piece which resulting thermal softening and reduction of thrust force

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