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OPTIMIZATION ON SURFACE ROUGHNESS OF BORING PROCESS BY VARYING DAMPER POSITION

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ABSTRACT

The paper discusses on investigating surface roughness in the boring (internal turning) process of a workpiece which made of medium carbon steel (AISI 1050). Four parameters were investigated that are damper position, feed rate, depth of cut and insert nose radius. One of investigation of this research is to find a position of the damper to be put in the bar to reduce the vibration during the boring process. The machining process was using Computer Numerical Control (CNC) turning machine Moriseiki NV 2500. Design of experiment (DOE) full factorial with four factors and two levels each, make the total number runs is 16 and three times replications which make the total run of 48 experiments. Random order generator also was applied to select the sequence of experiments. Results of experiment were analyzed using various types of statistical analysis among others are analysis of variance (ANOVA) in MINITAB 16. A regression model was also developed to find the relationship of roughness and parameters under study. The parameters are set that provides the optimum mean of surface roughness achieved is four combinations of damper position (1), feed rate (1), depth of cut (2) and insert radius (1). The highest mean of surface roughness achieved by combination of parameters: damper position (1), feed rate (2), depth of cut (2) and insert radius (2). This research also developed a regression model of surface roughness in boring with parameters involved, verification and validation of the model also was performed. Among the setting of parameters and level, the highest mean of roughness achieved by combination of parameters: damper position (1)* feed rate (2)* depth of cut (2)* insert radius (2). It provides the average roughness of 4.92 µm. The results of this experiment are validating the previous researcher on turning operations that parameters such as damper, feed rate, depth of cut and insert radius effect on the quality of the product which in this case the roughness. The regression model tor predicted model of the research was developed, verification and validation of the model was also being confirmed.

Keywords: boring, damper, factorial, surface roughness, feed rate, depth of cut, insert radius.

INTRODUCTION

The development of accurate and reliable machining process has received considerable attention from both academic researchers and industry practitioners in recent years. This is due to competition among industry requires to manufacture not only low cost product, but also high quality product in short time.

As a basic machining process, turning is one of the most widely used metal removal processes in industry. Turning parts are largely used in aerospace, automotive and machinery design as well as in manufacturing industries. Surface roughness is an important measure of the technological quality of the product and is a factor that greatly influences the manufacturing cost [1].

Turning is the process where a single point cutting tool path is parallel to the surface. Turning is the first most common method for cutting and finishing machined part. High cutting performance can be achieved in turning operations by appropriate selection of the cutting parameters. Cutting parameters are reflected in surface finish, surface texture and dimensional deviations of the product. Surface roughness is an attribute which is used to determine and to evaluate the quality of a turning product [2].

In [3] stated that to determine the cutting parameters, there are few things to be considered. First, understanding of ferrous metal behavior is a must before deciding material to be used. Second, the depth of cut, cutting speed, feed rate and effect of rake angle are the parameters that need to be understood for effective machining process. And third, the selection of cutting tool materials for a particular application is among the most important factors in machining operations.

The parameters influencing the final result in turning operations that have been studied among others are cutting speed, feed rate and depth of cut [4], where other parameter investigated was tool nose radius. Meanwhile, in [5] investigated the effect of vibration on minimum cutting thickness in order to enable greater machining accuracy to be obtained by fine and stable machining.

The selection of cutting parameters can be done properly by several mathematical models based on statistical regression or neural network techniques have been constructed to establish the relationship between the cutting performance and cutting parameter. One of methods to select the correct setting of parameters is using Taguchi method [6]. It provides a simple, efficient and systematic approach to optimize designs for performance and quality.

The methodology is valuable when the design parameters and reduce the sensitivity of the system performance to sources of variation. An objective function with constrains is formulated to solve the optimal cutting parameters using optimization techniques [7] applied the Taguchi method to optimize cutting parameters in turning process for surface roughness. In [8] reported on the use of

Taguchi method based response analysis on multi response optimization of Computer Numerical Control (CNC) turning. In [9] made a comparison of response surface model and neural network in determining the surface roughness values on mold surfaces. While [10] investigated bar diameter as an influencing factor on temperature in turning, which has an effect on tool wear in turning. And recently, in [11] applied Genetic Algorithm (GA) and Artificial Neural Network (ANN) as part of artificial intelligence tools in making prediction the best setting of parameters to produce the finest roughness.

Most literatures in turning operations discuss about the way to find the best setting parameters using some techniques such as Taguchi method to find the optimum setting parameters. Additional techniques were also employed such as NN and GA. Boring is a machining process in which internal surfaces of revolution are generated with single point cutting tool. The term 'boring' is applicable to enlarge an existing drilled or core hole and also includes machining of blind holes, holes with contoured bores and bores with steps, undercuts, etc.

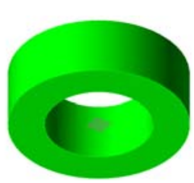
Frequently encountered problem in boring is vibration and chatter. In industry, damper it is very common that are put on a boring bar to reduce vibration. Overhang is a major problem during boring process, especially if the hole is too long. Because of that, the tool deflects causing a detrimental effect on the tool life, surface finish and dimensional accuracy.

This study explores how to damp the vibration produced during internal turning process so that the end product has a better surface roughness. There are two purposes of this research. The first is to demonstrate a systematic procedure of using Design of Experiment (DOE) in the process control of turning machines. The second is to identify the optimum surface roughness performance with a particular combination of cutting parameters in an internal turning operation.

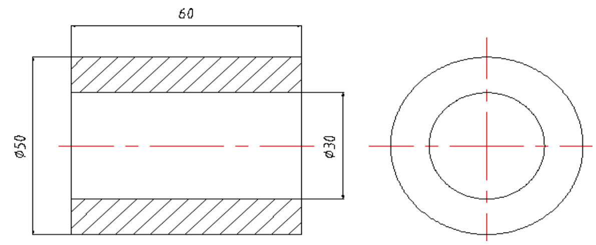
EXPERIMENTAL WORK

Product design

The product for the purposed of this experiment was a hollow cylinder work piece. Hollow cylinder was chosen due to this part is a common part which used and produced by industry. This product needs boring process.
Type of material that used for this experiment is a medium carbon steel (AISI 1050) which has dimension 50 mm for the outside diameter, 30 mm for the inside diameter and the length of the work piece is 60 mm. Figure-1 illustrates the 3D view of the workpiece and the dimension of the workpiece using AUTOCAD.



(a)



(b)

Figure-1. (a) Three dimensional view of workpiece (b) Dimension of the workpiece.

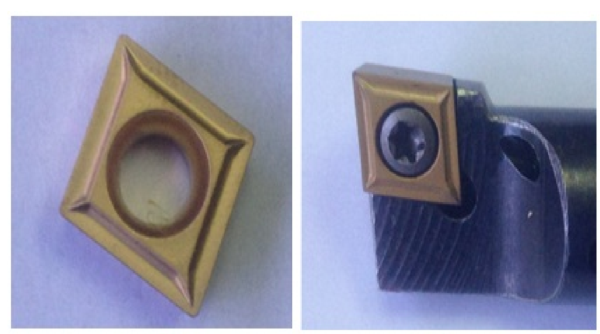
CNC turning

The experiments are carried out using a MORISEIKI CNC machine. Figure-2 shows the typical CNC machine used in this study. The lathe maximum spindle speed is 4000 rev/min, turning over bed 450mm, turning length 500mm, maximum chuck 250mm and 12 station driven turret.

Figure-2.MORISEIKI CNC machine.

Cutting tools

The cutting tool that chosen in this study was coated carbide insert (TiN). The insert grade name as CCMT 09 T3 04LF (0.4mm nose radius) and CCMT 09 T3 02LF (0.2mm nose radius) which produced by Kennametal (Figure-3a). Cutting tool insert is recommended by the manufacturer to carry out the work of medium carbon steel. The cutting tools were clamped on the holder (A16R SCLCL09), as shown in Figure-3b.



(a) (b)

Figure-3. (a) Carbide (TiN) cutting tool insert (b) Tool holder.

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Digital surface roughness

The most common instrument used to measure finish is the surface indicator. The tracer head houses a diamond stylus that having a point radius of 0.0005 in. (0.013mm), which bear against the surface of the work. Figure-4 shows the digital surface roughness equipment.

Figure-4. Digital surface roughness.

RESULTS AND DISCUSSION

Design of experiment

The selection of parameters that contribute significantly influence surface roughness, i.e. the work piece surface for machining internal turning process has been identified. A full factorial DOE of four parameters with two levels in each was identified to be verified their contribution to surface roughness in internal turning. These factors were defined as feed rate, depth of cut, insert radius and damper position. A design of 2x2x2x2 (2^4) or 16 experiments minimum was identified. Three replications were also performed in each set of experiment, so there were 48 workpieces produced. DoE for different combination parameters is shown as Table-1.It shows the level description of each parameter.

Table-1.DOE matrix of two level full factorials.

Variable Level	Damper Position (A)	Feed Rate(B)/mm /rev	Depth of Cut (C)/mm	Insert Radius (D)/mm
Level1(-1)	# 1	0.1	0.25	0.2
Level2 (1)	# 2	0.15	0.5	0.4

Parameters screening

The first step of the factorial design analysis is assuming all factors and interactions have contributed to the roughness. Figure-5 shows a Pareto chart which indicating the contribution of each parameter with alpha is set to 0.10that refers as the red line, which is set at 90% of confidence level. Alpha indicates the risk of incorrectly, which concluding that a factor has a significant effect.

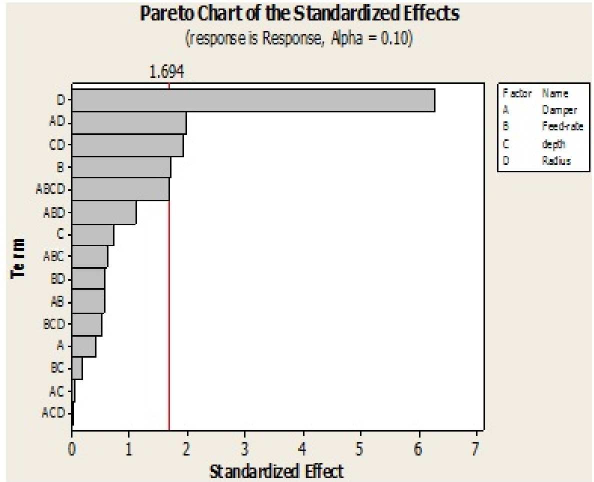

Figure-5. Pareto chart of first screening of factors.

Any effect that extends past this reference line is potentially important namely factor D which is insert radius and feed-rate (B), two ways interaction AD and CD, and four interaction ABCD. These factors and combination determined as the important effect of quality of surface finish by using the CNC turning machine. While parameters A and C are still both needed, since it has contributed to the significance of the combination of factors AC and CD.

Figure-6 shows the normal probability plot of standardized effects for surface roughness measurement. The normal probability plot is a graphical technique for assessing whether or not the data is approximately normally distributed. It clearly shows factors which significantly affect the roughness are factors D (insert radius), B (feed-rate), interaction CD (depth of cut and insert radius) and interaction AD (damper and insert radius).

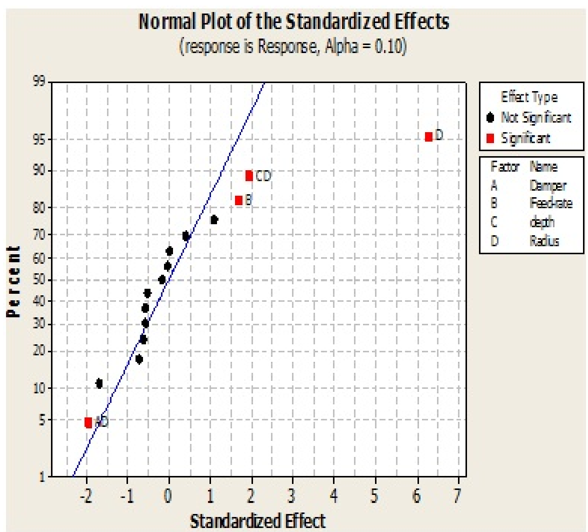

Figure-6. Normal plot of first screening factors.

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Table-2 shows not only the P-value of each factor and interactions among the factors, but also showing the effect of each factor. Those factors with P-value larger than 0.10 are not significant. Screening the parameters by eliminating some insignificant interactions to determine the true effects to the whole output in this case the roughness. Factors C and D are not significant by since the P-value are larger than 0.10, however the interaction of the CD and AD are significant. Thus, factors A(damper position) and C(depth of cut) are maintained in the model representing the effect to roughness.

Table-2. Estimated effects and coefficients for response (coded units).

Term	Effect	SE Coef	T	P
Constant		0.823715	4.90	0.000
A	-0.6209	0.228458	-1.36	0.184
B	-0.4679	0.228458	-1.02	0.313
C	-0.4910	0.228458	-1.07	0.291
D	0.0832	0.228458	0.18	0.857
A*B	-0.1417	0.063363	-1.12	0.272
A*C	-0.1839	0.063363	-1.45	0.157
A*D	-0.1589	0.063363	-1.25	0.219
B*C	-0.2205	0.063363	-1.74	0.091
B*D	-0.1364	0.063363	-1.08	0.290
C*D	-0.1015	0.063363	-0.80	0.429
A*B*C	-0.0614	0.017574	-1.75	0.090
A*B*D	-0.0280	0.017574	-0.80	0.431
A*C*D	-0.0490	0.017574	-1.39	0.173
B*C*D	-0.0594	0.017574	-1.69	0.101
A*B*C*D	-0.0165	0.004874	-1.69	0.101

After parameter screening, analysis of variance (ANOVA) as shown in Table-3 shows that the main effects and interaction are significant with P-value < 0.10. This confirms that main effect feed rate (B) and insert radius (D) are highly significant. This is also validating that there are significant interaction between parameters depth of cut (C)-insert radius (D) and A (damper position)-D (insert radius).

Table-3.ANOVA table after screening parameters.

Source	DF	Seq SS	Adj MS	F	P
Main effects	4	12.6097	3.1524	12.52	0.000
A	1	0.0488	0.0488	0.19	0.662
B	1	0.8560	0.8560	3.40	0.073
C	1	0.1508	0.1508	0.60	0.444
D	1	11.5542	11.5542	45.87	0.000
2-way interactions	2	2.2023	1.1011	4.37	0.019
A*B	1	1.1133	1.1133	4.42	0.042
C*D	1	1.0890	1.0890	4.32	0.044
4-way interactions	1	0.8348	0.8348	3.31	0.076
A*B*C*D	1	0.8348	0.8348	3.31	0.076
Residual error	40	10.0746	0.2519		
Lack of fit	8	0.7332	0.0916	0.31	0.955
Pure error	32	9.3414	0.2919		
Total	47	25.7213			

Main effects plot for roughness

Main effects plot for roughness (Ra) purpose is to map the dependent variables for different level. The graphs show the individual effect of parameter to roughness. The bigger the slope indicates the higher the effect in this process. Figure-7 shows the factors that affected the roughness.

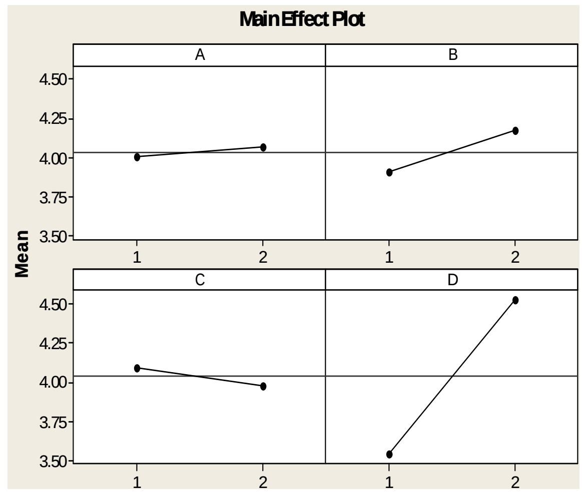
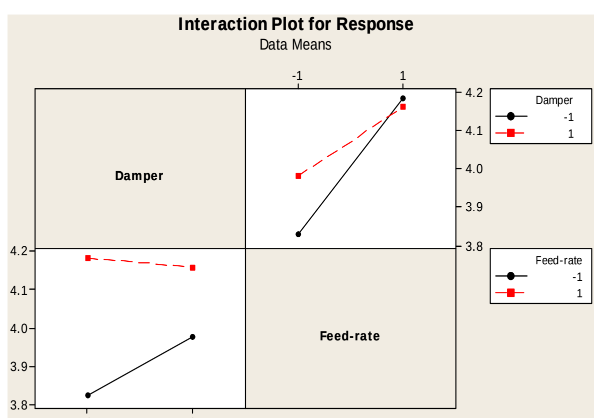


Figure-7. Main effect plots for roughness.

It shows that the slope of insert radius (D) was the biggest. It indicates the insert radius is the main effect of roughness. The second highest slope is feed rate (B), then the depth of cut (C) and lastly damper position (A). However, the last two parameters are not showing the significant steep slope which means the setting of each level do not significantly differ in influencing the variance.

Interaction plot for roughness

An interaction plot as shown in Figure-8, the relationship between the factors which are represented by the lines of the graph. Significant interactions are shown by the different slopes of the lines. If the lines are almost or closely parallel, the interaction between this factor are insignificant.



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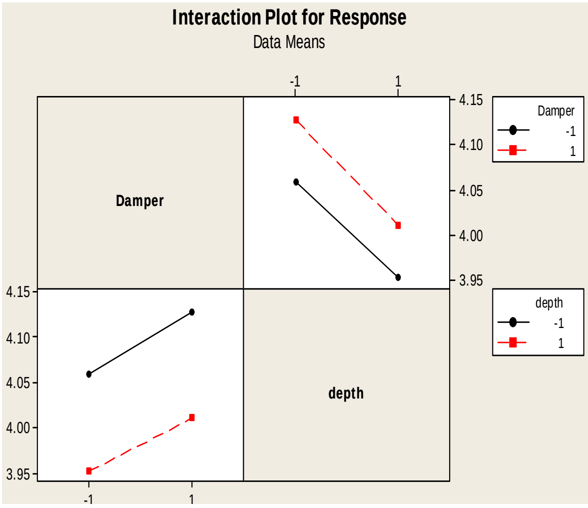

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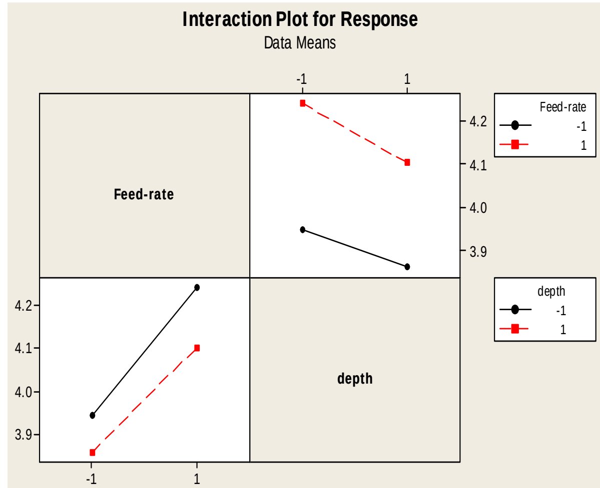

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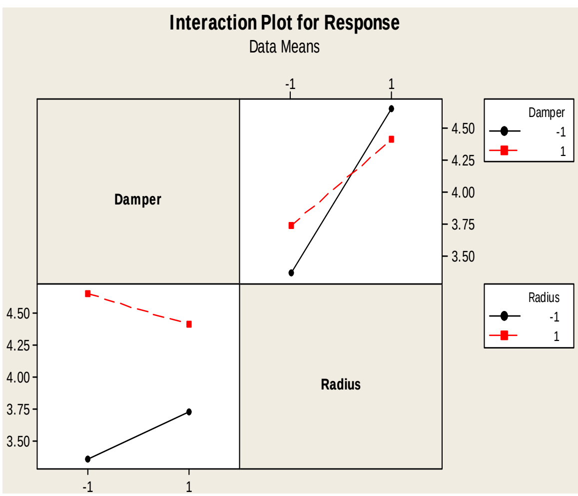
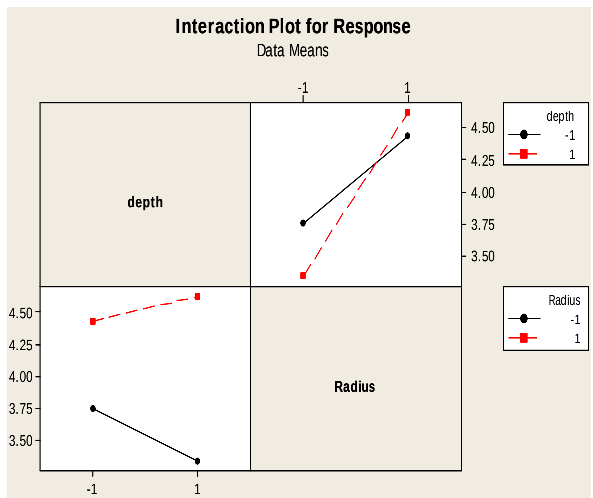
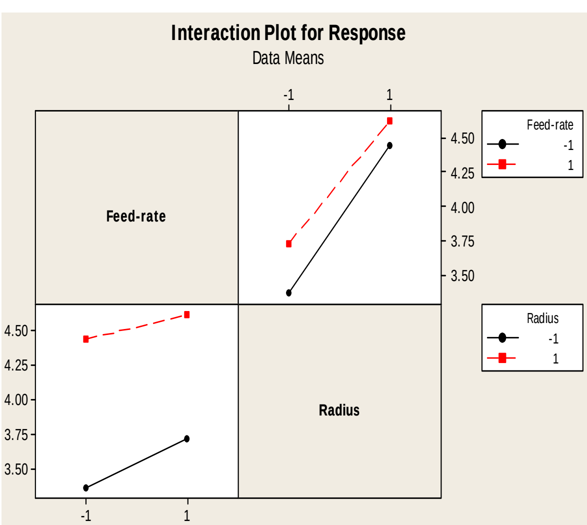


(c)



(f)



(d)

Figure-8. Interaction plot for two parameters (a) Feed rate (B) and depth of cut (C) (b)Damper position (A) and depth of cut (C) (c) Damper position (A) and inner radius (D) (d) Feed rate (B) and inner radius (D) (e) Feed rate (B) and depth of cut (C) (f) Depth of cut (C) and inner radius (D).

Significant interaction is found when the lines are crossed with each other, whereas the parallel lines show insignificant interactions. Therefore, it can be concluded that, there is interaction between feed rate (black line) and damper position (red line) in Figure-8a. The two factors interact influencing the roughness. The graph explains that for two different damper position the roughness is increasing for the damper position (-1) to damper position (1) given the feed rate was on the level (-1), whereas this is not true when the feed rate at a level (1), the roughness is reducing. This can be stated that the two parameters are strongly interacting in influencing the roughness.

Similarly, in Figure-8c shows (damper position) and D (insert radius) where the two lines show strong interaction between the two. This indicated by crossing the line between the two parameters, which can be stated that the two parameters are interacting in producing the roughness. For the same insert radius level (-1), the roughness increase when the damper position changes from position 1 (-1) to position 2 (1). However, the results are the other way when the insert radius set to (1), the roughness decrease when the damper change from position 1 (-1) to position 2 (1).

The observation was also found in Figure-8f. It shows the depth of cut (C) and insert radius (D) interaction. The figure shows that the two lines crossing each other, where there is interaction between parameters depth of cut (C) and insert radius (D).For the same level of insert radius (1), the roughness shows a decreasing order from the depth of cut (-1) to level (1).However, this result is the other way when the insert radius was set (1) where the reading of roughness showing an increasing order. In other words, the two parameters in different setting are interacted to influence the end results of roughness measured.

Discussion of results

As identified in the previous section that all single parameters namely damper position (A) and feed rate (B), depth of cut (C) and insert radius (D) are significant in contributing to roughness in boring process. It not only single factor but also some combination of parameters that do interact in affecting the roughness which are two ways interaction AD and CD, and four interaction ABCD.

These results verified previous study by [2, 4, 6] in their research on turning using DOE Taguchi method. They found that surface roughness is strongly correlated with cutting parameters such as insert radius, feed rate and depth of cut.

Further research by [12] also found that the impact of particle damping in boring operation on roughness. It stated that the innovative shatter suppression method based on particle damping technique is reducing chatter in boring tool, and thereby improve the surface finish.

Furthermore, in [13] also has done some works on the effect on dampers to roughness in boring operation. He found that the improvement of the damping capability of boring tools and suppression of chatters is obtained with four different types of damping materials. The materials having high density produce more inertial mass which is used to suppress the chatter in boring operations. At the end, this will give better quality of the end product.

These findings validate the results of the experiments that the four parameters such as damper position (A) and feed rate (B), depth of cut (C) and insert radius (D) do effect on the quality of the product, i.e. surface roughness. The uniqueness of this research is that the damper position indeed influence the roughness. This two position of the damper potentially reduced the vibration on the tool holder. It was verified by the experiment that position insert radius level (-1), where the roughness increase when the damper position changes from position 1 (-1) to position 2 (1). Position (-1) is when the damper is put on the top of the holder or in may state as parallel to y-axis, and position (1) when the damper is parallel to z-axis or 90 degrees of y-axis. However, the results are the other way when the insert radius set to (1). The roughness decrease when the damper change from position 1 (-1) to position 2 (1). So, the choice of insert radius and combination of damper position is important to be notified when the experimenter wants to find the reduction on the roughness.

Regression modeling

Based on previous discussion, it was found that the significant factors are D, B, AD, CD and ABCD. Table-4 contains information on regression modeling generated by MINITAB 16. This model explains the relation or contribution for the factors mentioned above to internal surface roughness by turning (boring) operation.

In order to create the regression modeling, the value of code units was used to check if the formula that have been created was correct or not with the experiment desired value. The data from coefficient was taken to create a formula for internal turning operation of cylinder for mild steel.

Table-4. Coefficient of parameters after screening for 90% confidence level.

Term	Coeff	SE Coef	T	P
Const	4.0373	55.73		0.000
A	0.0637	0.0319	0.44	0.662
B	0.2671	0.1335	1.84	0.073
C	-0.1121	-0.0560	-0.77	0.444
D	0.9813	0.4906	6.77	0.000
A*D	-0.3046	-0.1523	-2.10	0.042
C*D	0.3012	0.1506	2.08	0.044
A*B*C*D	-0.2638	-0.1319	-1.82	0.076
S = 0.501861		PRESS = 14.5074		
R-Sq = 60.83%		R-Sq(pred) = 43.60%	R-Sq(adj) = 53.98%	

So, the regression model that describes the relationship of dependent variable, i.e. surface roughness and the independent variables, i.e. damper position, feed rate, depth of cut and insert radius can be explained in the model as:

$$X=4.0373+0.0637(A)+0.2671(B)-0.1121(C)+0.9813(D)-0.3046(AD)+0.3012(CD)-0.2638(ABCD) \quad (1)$$

Regression modelling validation

The predicted model is validated by some data generated based on the experimental value. The new experiments were conducted based on the screening parameters. Table-5 shows the results of confirmatory experimental and predicted value based on the model for three runs.

Table-5. Validation test.

Surface Roughness	Predicted/µm	Experimental/µm
Run#1	3.15	2.97
Run#2	5.01	5.24
Run#3	4.05	3.99

In terms of accuracy of the predicted results, Run #1 shows the difference of 0.18 µm which about 6%. Whereas, Run#2 has the difference of 0.23µm(4.5%) and Run#3 has a difference of 0.06µm (1.5 %).

Based on three confirmation samples, it was found that the average of biased of predicted value and experimental value was less than 5%. This indicates that the model of roughness quite represent the relation of the dependent variable and its independent variables.

Optimization of surface roughness

The optimal condition of surface roughness was set to the lowest roughness. The analysis shows the most optimum surface roughness is determined by the lowest value of Ra achieved during internal turning process experiments.

Using response optimizer function available in MINITAB, the optimum response provides either minimum or maximum setting of parameters. This function needs some input such as significant variables that have been identified before, where the result is shown in Figure-9.

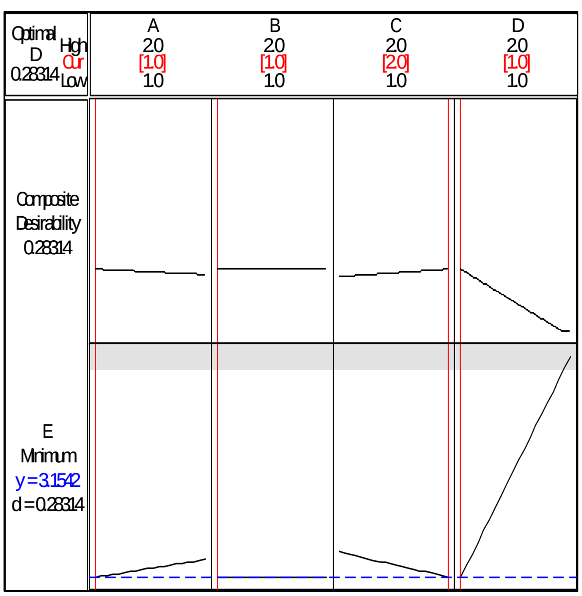


Figure-9. Response optimizer for surface roughness.

In response optimizer, it is shown that the lowest roughness (Ra) given as 3.15417 where the setting given as A = 1, B = 1, C = 2 and D = 1. Figure-9confirmed that the variable D (insert radius) is the most significant factor.

CONCLUSIONS

The study investigated four parameters affecting the surface roughness of boring process namely damper position, feed rate, depth of cut and insert radius. All the single factors investigated, i.e. damper position, feed rate, depth of cut and insert radius have significant contribution to surface roughness at significance level 0.1. The most significant factor that contributes to roughness is insert radius. The second most significant factor is the feed rate, the third is the depth of cut and lastly damper position. Significant two-ways interaction factors are damper position * insert radius and depth of cut and insert radius. For interaction of four parameters, i.e. damper position*feed rate* depth of cut* insert radius has significant contribution to the roughness. The regression model for predicting model of the research was developed, verified and validated. Between the setting of parameters and level, the optimum condition for low mean of roughness is the damper position (1)* feed rate (1)* depth of cut (2)* insert radius (1). This setting reaches in average roughness which is 2.91 µm. Among the setting of parameters and level, the highest mean of roughness achieved by combination of parameters: damper position (1)* feed rate (2)* depth of cut (2)* insert radius (2). It provides the average roughness of 4.92 µm. The results of this experiment are validating the previous studies on turning operations that parameters such as damper, feed rate, depth of cut and insert radius effect on the quality of the product which in this case the roughness.

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