Optimization of Tool Wear for Different Metals in Turning Operation Using ANOVA & Regression Analysis

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Abstract: Tool wear investigation is very important for any industry to reduce the cost of production and maintain the quality of manufacturing. Tool life parameters help to understand the behavior of tool wear on different metals under varying conditions. In this project work, high speed steel has been used as the cutting tool and AISI 1040 steel, 6061 aluminium and ASTM A48 Grey cast iron as workpiece materials in turning operation on lathe machine. The experiment has been performed for different depths of cut such as 0.50 mm, 0.75 mm and 1.0 mm with the spindle speeds as 112 rpm, 225 rpm and 280 rpm. Feed rate has varied from 0.115 mm/rev to 0.138 mm/rev randomly. Cutting length of 20 cm has been kept constant under dry cutting condition for the whole machining period. It has been observed that tool wear varies significantly with the variation of cutting parameters. The analysis of variance (ANOVA) has been employed to analyze the influence of cutting parameters on tool wear in turning operation. Finally, the relationship between cutting parameters and the tool wear has been developed by using multiple regression analysis for each workpiece material.

Key words: Tool wear**,** ANOVA, Regression Analysis.

1. Introduction

The increasing customer needs for higher quality enlarge the significance of precision machining. During machining cutting tools are subjected to rubbing process, the friction between cutting tool and workpiece materials results in progressive loss of materials in cutting tool [1]. Tool wear is defined as the change of shape of tool from its original shape resulting from the gradual loss of tool material. Thus tool wear becomes an important parameter in the metal cutting process. Tool wear depends on various parameters such as cutting tool material, workpiece material, tool geometry, lubrication, temperature, spindle speed, depth of cut, feed rate, length of cut etc. It is essential to know how the parameters can be used with a view to increasing the tool life. The consequences of the tool wear are poor surface finish, increase in cutting force, increase vibration of the machine tool, increase in tool-workpiece temperature during machining, decrease in dimensional accuracy, increase in production cost and lower production efficiency and component quality [2]. Aspects such as tool life and wear, surface finish, cutting forces, material removal rate, cutting temperature (on tool and workpiece's surface) decide the productivity, product quality, and overall economy in manufacturing by machining and quality of machining [3]. Many papers have been published in experimental based to study the effect of cutting parameters on surface roughness [4], tool wear [5], machinability [6], cutting forces [7], power consumption [8] and material removal rate [9]. So it is necessary to select the most appropriate machining settings in order to improve cutting efficiency. Hence statistical design of experiments (DOE) and statistical or mathematical model are used quite extensively. Statistical design of experiment refers to the process of planning the experimental so that the appropriate data can be analyzed by statistical methods, resulting in a valid and objective conclusion [5].

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2. Experimental Details

- To investigate tool wear on AISI 1040 Steel, 6061 Aluminium, ASTM A48 Grey Cast ironby varying different cutting parameters
- To determine the percentage contribution of cutting parameters in tool wear by ANOVA method
- To develop the relationship between cutting parameters and the tool wear by using multiple regression analysis

3. Experimental Cutting Conditions

The cutting conditions are:

1. Machine: Universal Lathe Machine (ZMM Machstroy)
2. Workpiece material: AISI 1040 Steel, 6061 Aluminium, ASTM A48 Grey Cast Iron

Table 1: Chemical composition of AISI 1040 Steel

C	S	Mn	Fe	P
0.37-0.44	0.05	0.6-0.9	Balanced	0.04

Table 2: Chemical composition of 6061 aluminium

Mg	Si	Fe	Cu	Zn	Ti	Mn	Cr	Al
0.8-1.2	0.4-0.8	0.7	0.15-0.40	0.25	0.15	0.15	.05-.35	Balanced

Table 3:Chemical composition of ASTM A48 grey cast iron.

C	Si	Mn	Fe
3.40	1.80	0.50	Balanced

3. Cutting tool material: High Speed Steel (HSS)
4. Cutting fluid: No cutting fluid (dry cutting)
5. Cutting conditions:
(a) Spindle speed (V): 112rpm, 225 rpm, 280 rpm
(b) Depth of cut (D): 0.5 mm, 0.75 mm, 1.0 mm
(c) Length of cut: 20 cm
(d) Feed rate (F): 0.115 mm/rev, 0.125 mm/rev, 0.138 mm/rev
6. Measuring tools:
(a) Linear scale
(b) Digital slide calipers

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4. Experimental Analysis

For AISI 1040 Steel:

Table 4: Observation table for AISI 1040 Steel

Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)	Tool wear (mm)
112	0.5	0.115	0.03
112	0.75	0.125	0.04
112	1	0.138	0.07
225	0.5	0.125	0.05
225	0.75	0.138	0.08
225	1	0.115	0.10
280	0.5	0.138	0.07
280	0.75	0.115	0.10
280	1	0.125	0.13

Table 5: Response table of means for tool wear of AISI 1040 Steel

Level	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)
1	0.046667	0.05	0.076667
2	0.076667	0.073333	0.073333
3	0.10	0.10	0.073333

Table 6: ANOVA for the response tool wear of AISI 1040 Steel

Source	Degree of freedom	Sum of squares	Mean of squares	F ratio	% of contribution
Speed	2	0.004289	0.002144	27.56	52.16
Depth of cut	2	0.003756	0.001878	24.14	45.68
Feed rate	2	0.000022	0.000011	0.14	0.27
Error	2	0.000156	0.000078		1.89
Total	8	0.008222			100

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For 6061 Aluminium:

Table 7: Observation table for 6061 aluminium

Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)	Tool wear (mm)
112	0.5	0.115	0.02
112	0.75	0.125	0.03
112	1	0.138	0.04
225	0.5	0.125	0.03
225	0.75	0.138	0.05
225	1	0.115	0.07
280	0.5	0.138	0.05
280	0.75	0.115	0.06
280	1	0.125	0.09

Table 8: Response table of means for tool wear of 6061 aluminium

Level	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)
1	0.03	0.033333	0.05
2	0.05	0.046667	0.05
3	0.066667	0.066667	0.046667

Table 9: ANOVA for the response tool wear of 6061 aluminium

Source	Degree of freedom	Sum of squares	Mean of squares	F ratio	% of contribution
Speed	2	0.002022	0.001011	13.01	52.00
Depth of cut	2	0.001689	0.000845	10.86	43.43
Feed rate	2	0.000022	0.000011	0.14	0.57
Error	2	0.000155	0.000078		4.00
Total	8	0.003889			100

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For ASTM A48 Grey Cast Iron:

Table 10: Observation table for ASTM A48 Grey Cast Iron

Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)	Tool wear (mm)
112	0.5	0.115	0.04
112	0.75	0.125	0.07
112	1	0.138	0.10
225	0.5	0.125	0.08
225	0.75	0.138	0.12
225	1	0.115	0.16
280	0.5	0.138	0.11
280	0.75	0.115	0.15
280	1	0.125	0.20

Table 11: Response table of means for tool wear of ASTM A48 Grey Cast Iron

Level	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)
1	0.07	0.076667	0.116667
2	0.12	0.113333	0.116667
3	0.153333	0.153333	0.11

Table 12: ANOVA for the response tool wear of ASTM A48 Grey Cast Iron

Source	Degree of freedom	Sum of squares	Mean of squares	F ratio	% of contribution
Speed	2	0.010555	0.005278	67.65	53.79
Depth of cut	2	0.008822	0.004411	56.54	44.96
Feed rate	2	0.000089	0.000045	0.57	0.45
Error	2	0.000156	0.000078		0.80
Total	8	0.019622			100

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Main effects plot:

Main effects plot is used to determine whether pattern is statistically significant or not. In the plots, the X-axis indicates the value of cutting parameters and Y-axis indicates tool wear. Main effect plots determine the optimal design conditions. Figure 1, 2 and 3 show the main effects plot for tool wear on AISI 1040 steel, 6061 aluminium and ASTM A48 grey cast iron respectively. Figures show that with the increase in spindle speed, there is a continuous increase in tool wear. And similarly with the increase in depth of cut, there is also continuous increase in tool wear. Spindle speed of 112 rpm (level-1), Depth of cut 0.5 mm (level-1) and feed of 0.138 mm/rev (level-3) produce the lower tool wear.

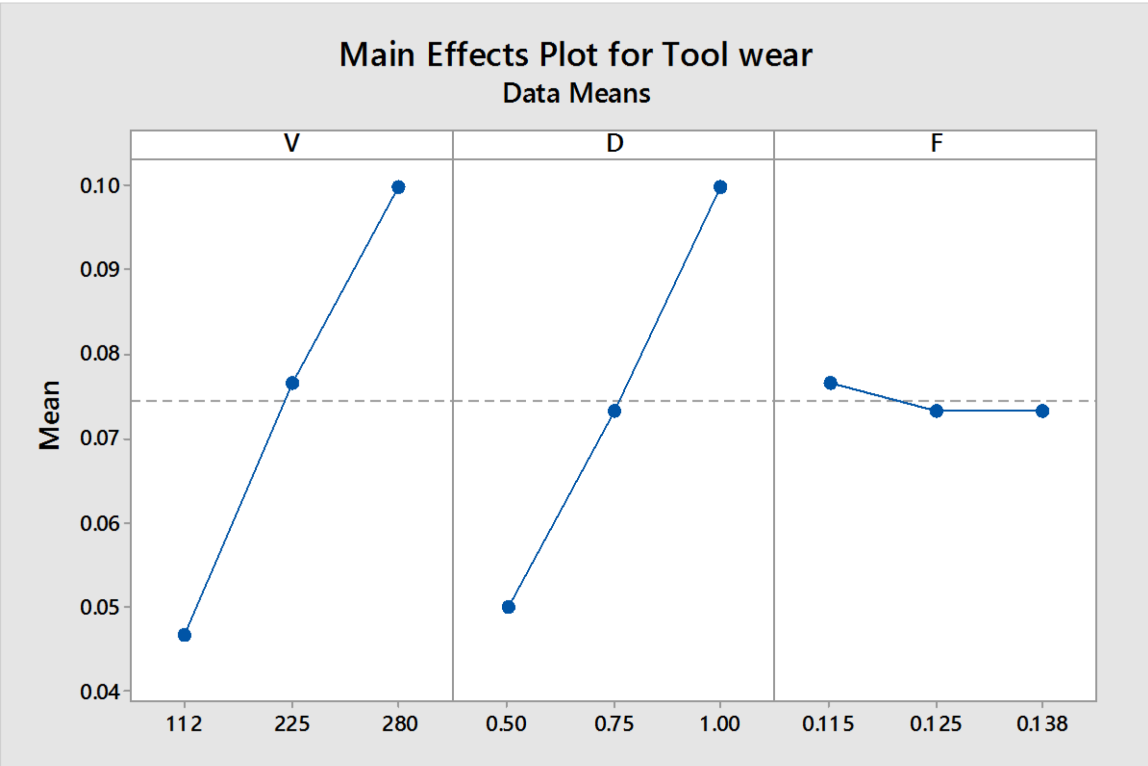

Fig. 1: Tool wear rate for AISI 1040 steel

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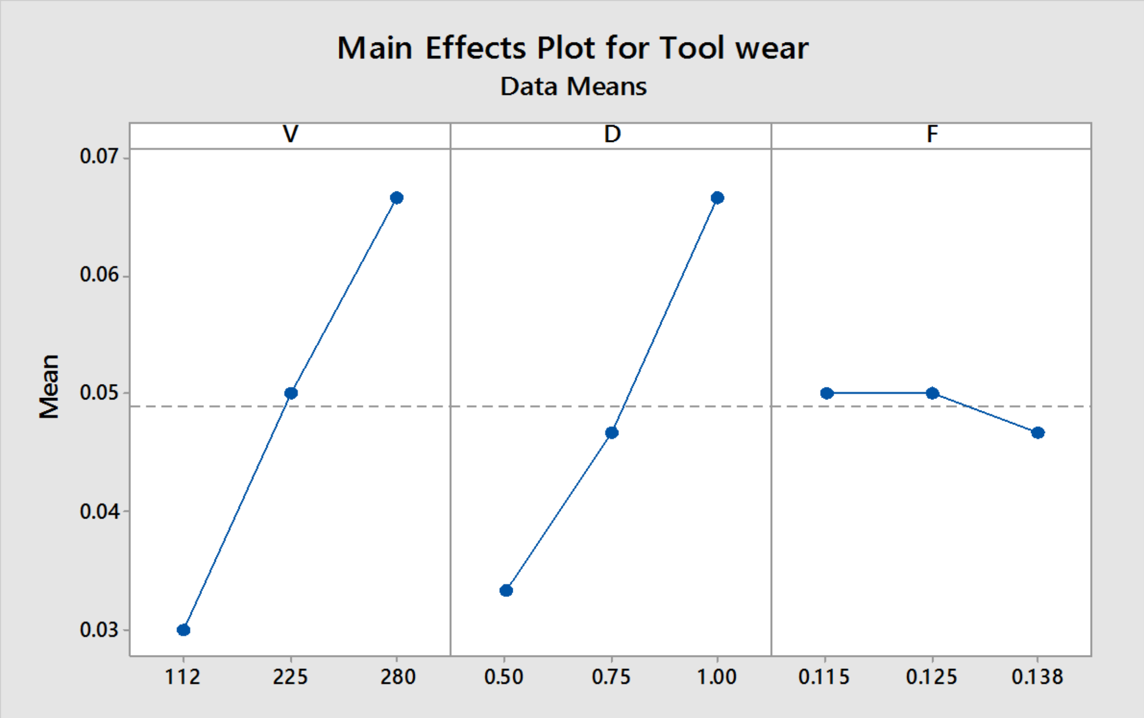

Fig. 2: Tool wear rate for 6061 aluminium

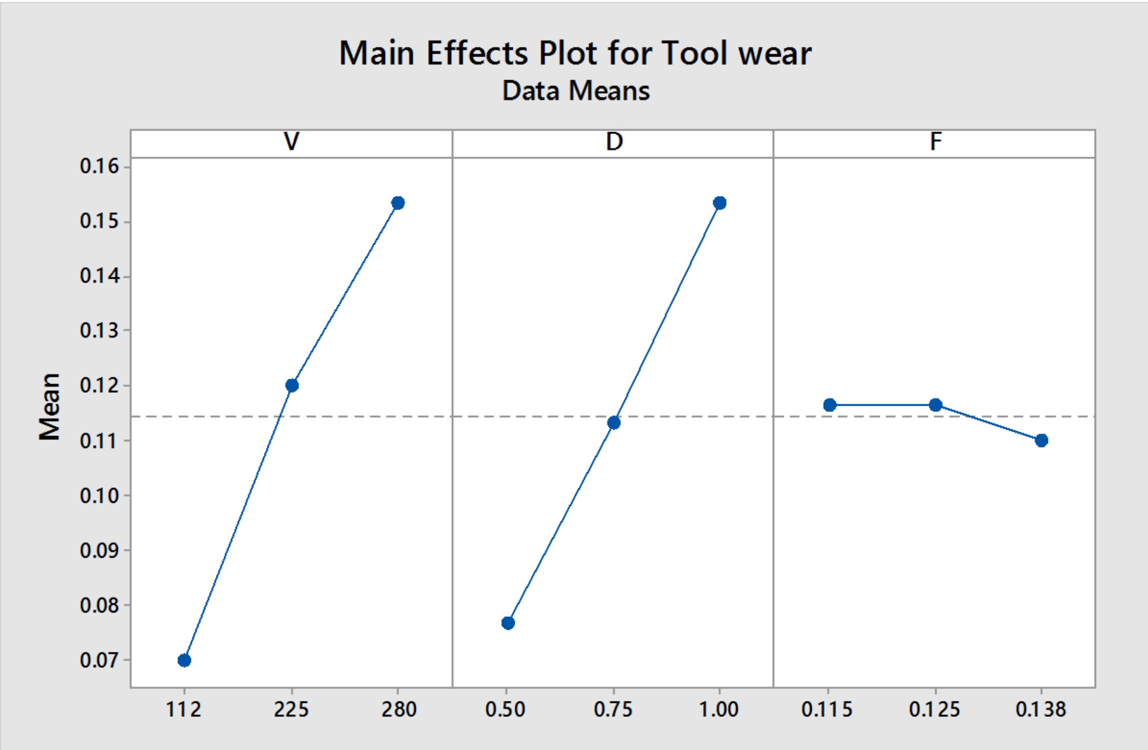

Fig. 3: Tool wear rate for ASTM A48 Grey cast iron

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Interaction plot:

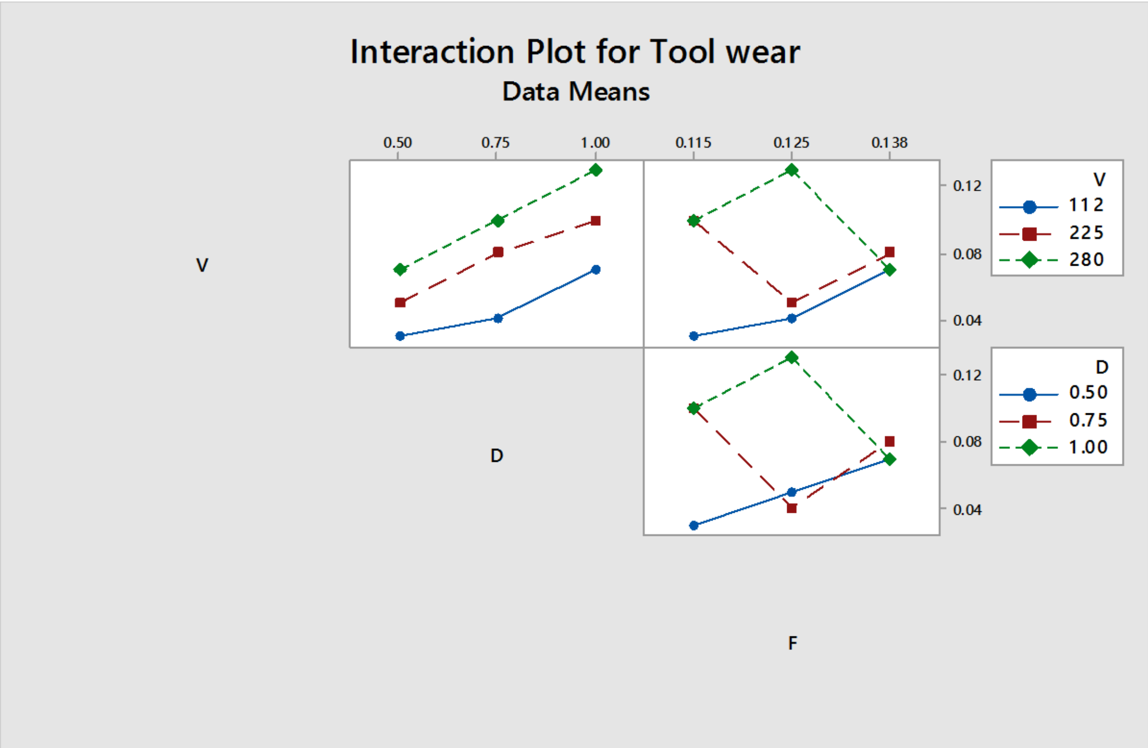

Fig. 4: Interaction plot for AISI 1040 steel

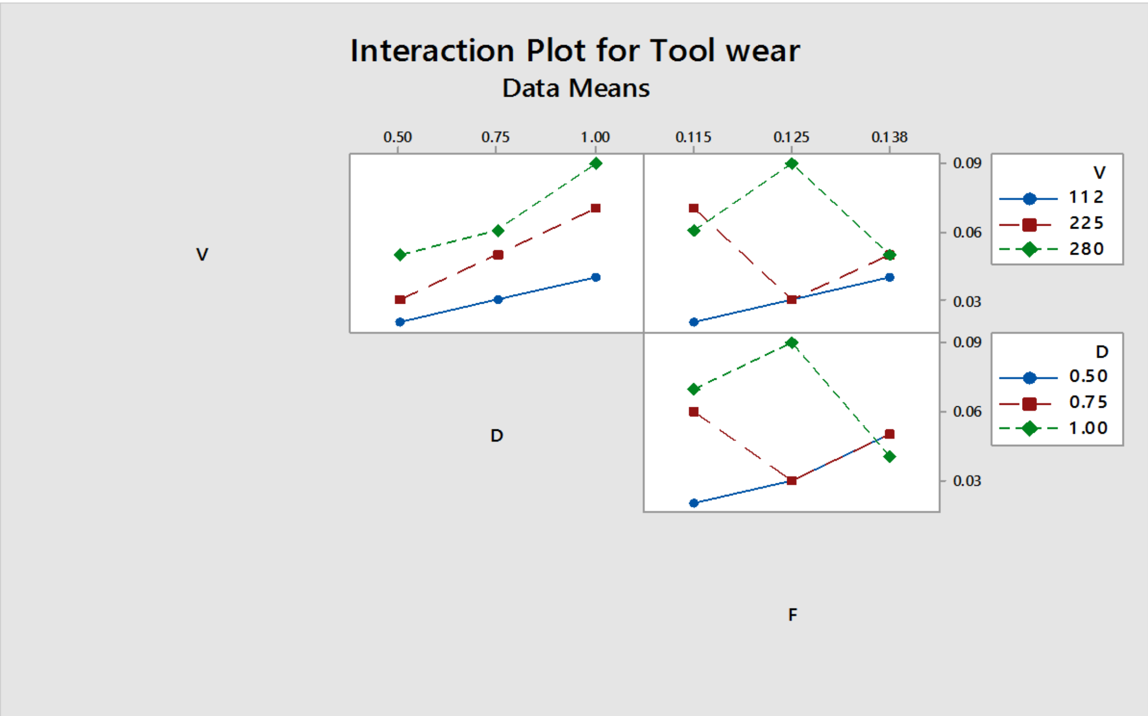

Fig. 5: Interaction plot for 6061 aluminium

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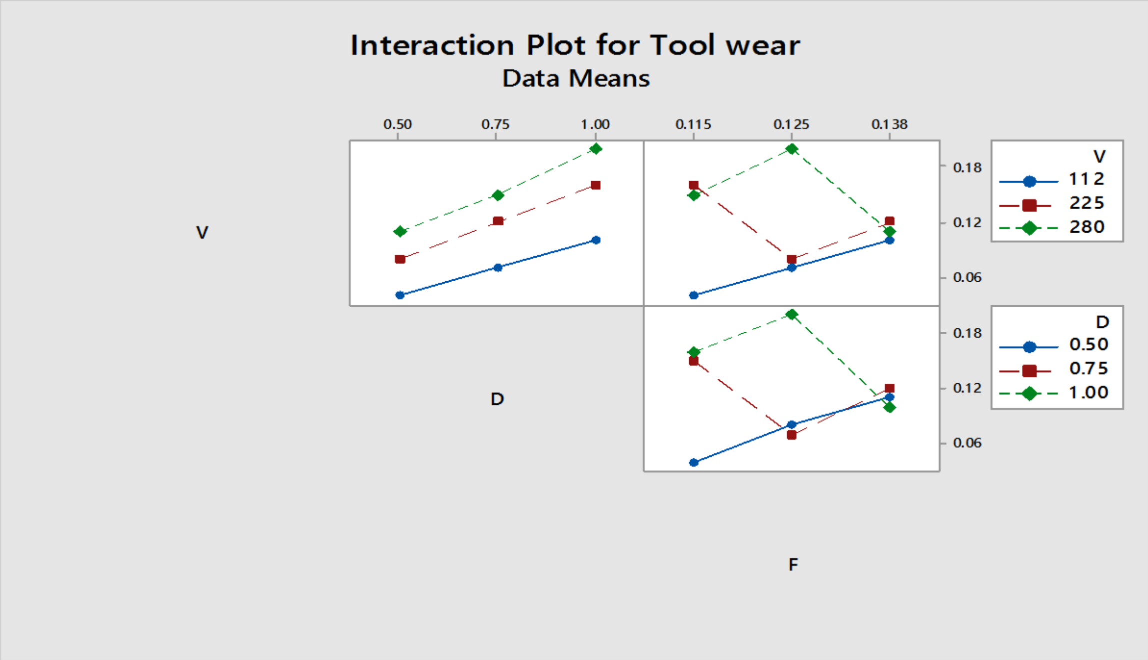

Fig. 6: Interaction plot for ASTM A48 Grey cast iron

Regression equation for tool wear on workpiece materials:

The relationships between the cutting parameters and the tool wear for different workpiece materials have been modeled by multiple linear regression (using Minitab 17) which are in following equations forms

Tool wear = - 0.0469 + 0.000310 Spindle speed + 0.100 Depth of cut- 0.138 Feed rate (R=0.98) [For AISI 1040 Steel]

Tool wear = - 0.0258 + 0.000212 Spindle speed + 0.0667 Depth of cut- 0.150 Feed rate (R=0.97)
[For 6061 Aluminium]

Tool wear = - 0.0630 + 0.000488 Spindle speed + 0.153 Depth of cut- 0.301 Feed rate (R=0.99)
[For ASTM A48 Grey Cast Iron]

In normal probability plot the residuals have been distributed normally for tool wear. Fig. 7, 8 and 9 show a scatter plot of residuals on the Y-axis and fitted values in the X-axis. The plot is used for detecting non-linearity and unequal error variance. The distance from the line at 0.00 shows how bad or good the prediction is for that value. Positive values for the residual (on the Y-axis) mean prediction is too low and negative values mean the prediction is too high.

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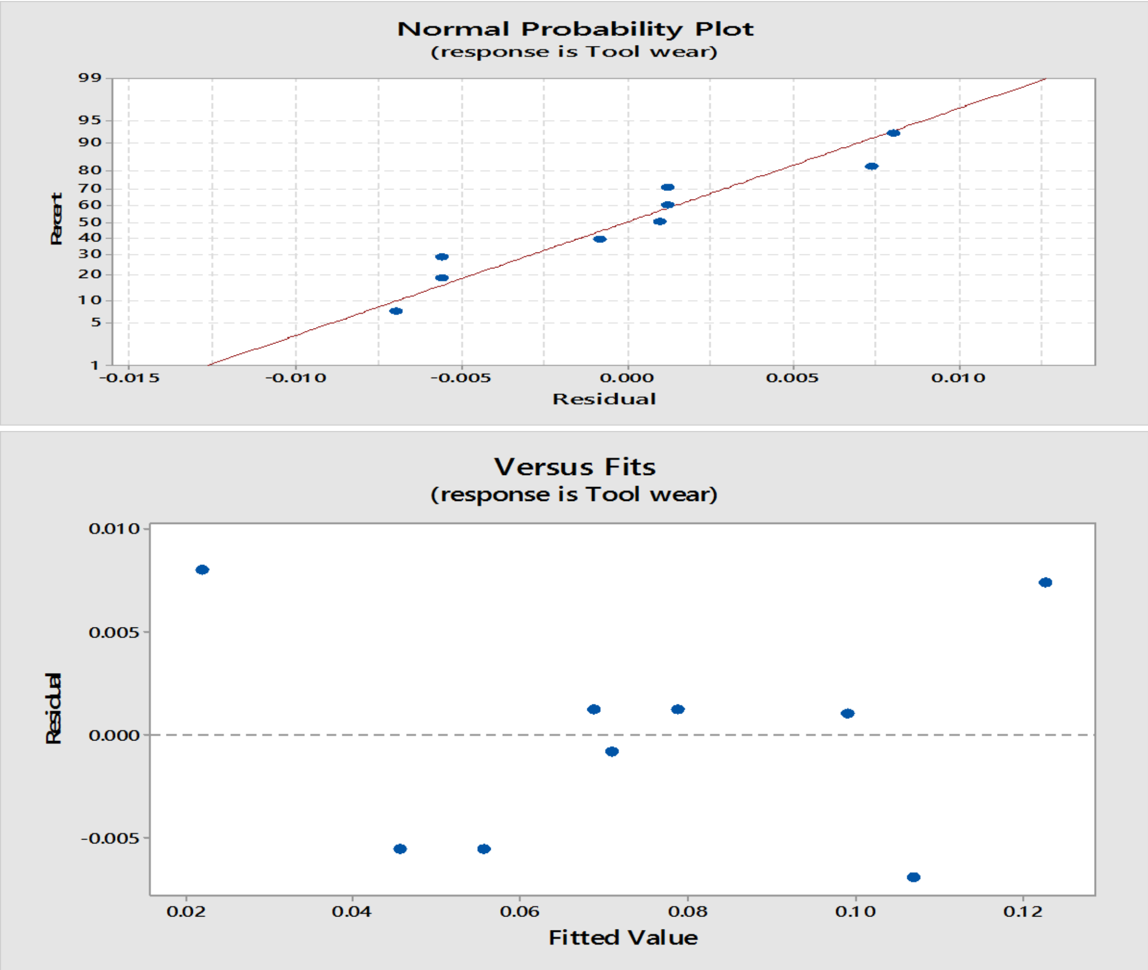
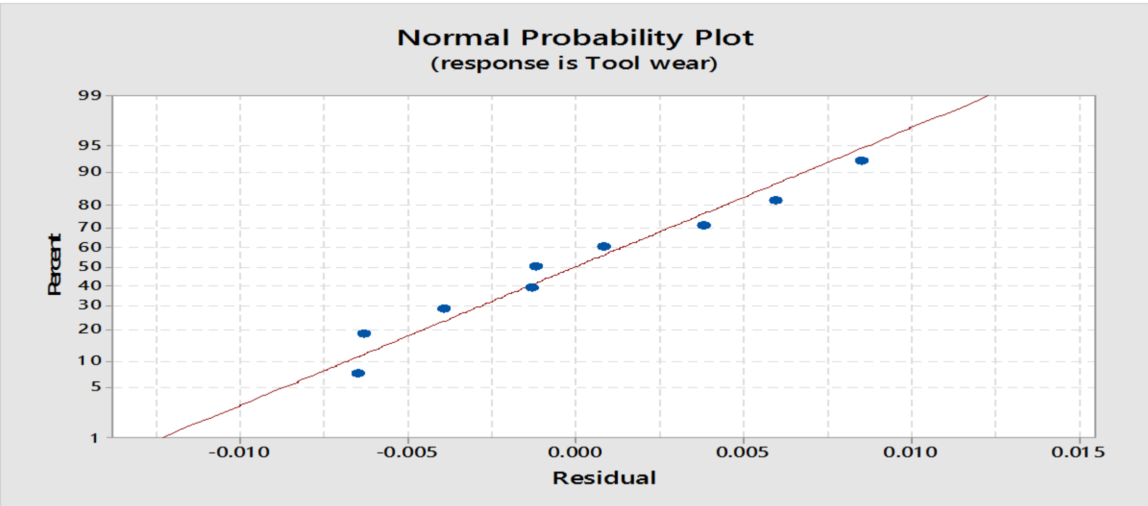


Fig. 7: Residuals Vs the predicted plot for AISI 1040 steel



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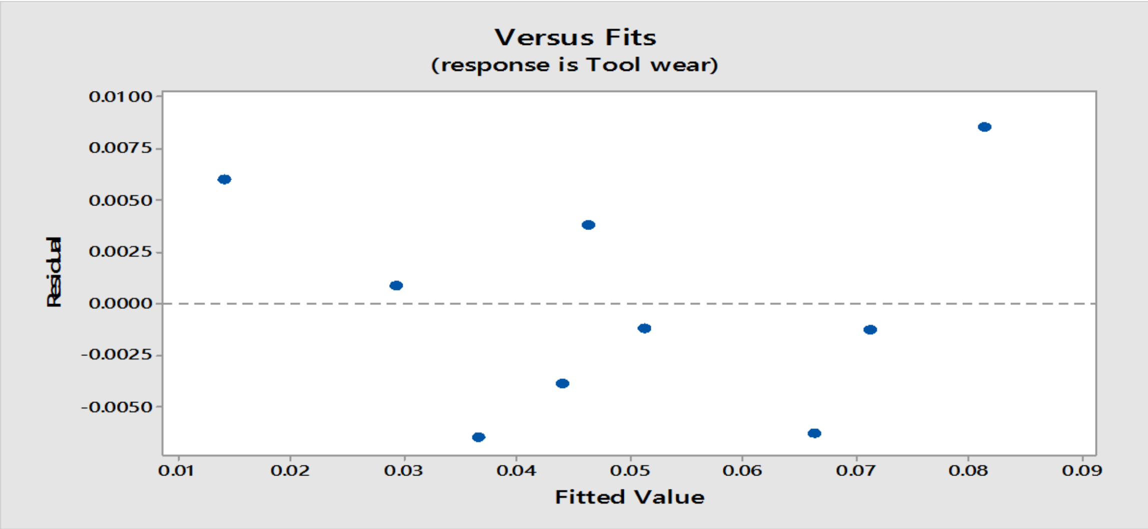

Fig. 8: Residuals Vs the predicted plot for 6061 aluminium

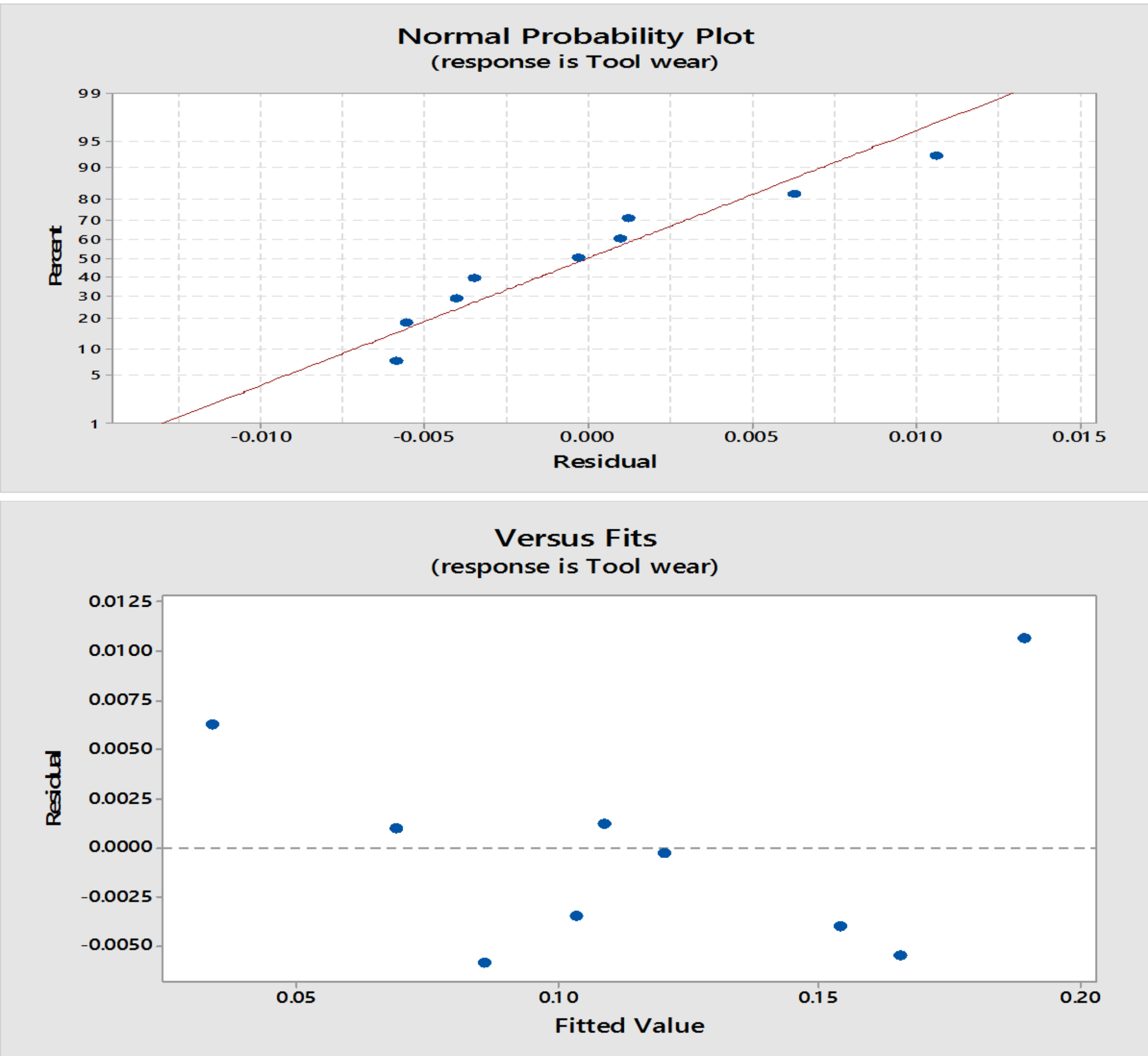

Fig. 9: Residuals Vs the predicted plot for ASTM A48 Grey cast iron

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5. Conclusion

In this research work, the wear of high speed steel cutting tool has been analyzed for turning operation under various parameters for AISI 1040 steel, 6061 aluminium and ASTM A48 grey cast iron as workpiece materials.

From the results obtained, the following conclusions can be drawn:

i. Tool wear increases with the increase of spindle speed, depth of cut and feed rate.
ii. ASTM A48 grey cast iron shows greater tool wear than AISI 1040 steel, as mild steel shows greater tool wear than 6061 aluminium. That means, cutting harder materials causes tool wear rapidly.
iii. For AISI 1040 steel, 6061 aluminium and ASTM A48 grey cast iron at spindle speed 112 rpm, depth of cut 0.5 mm and feed rate 0.138 mm/rev minimum tool wear is found
iv. From ANOVA it is seen that for AISI 1040 steel the percent contribution of spindle speed (52.16%), depth of cut (45.68%) and feed rate (0.27%). For 6061 aluminium the percent contribution of spindle speed (52%), depth of cut (43.43%) and feed rate (0.57%) and for ASTM A48 grey cast iron the percent contribution of spindle speed (53.79%), depth of cut (44.96%) and feed rate (0.45%). Hence, it can be said that the effect of spindle speed and depth of cut is more as compared to feed rate in tool wear on materials.
v. The relationship between the cutting parameters and the tool wear, modeled by multiple linear regression are in following equations forms:

Tool wear = - 0.0469 + 0.000310 Spindle speed + 0.100 Depth of cut- 0.138 Feed rate
(R=0.98) (For AISI 1040 Steel)

Tool wear = - 0.0258 + 0.000212 Spindle speed + 0.0667 Depth of cut- 0.150 Feed rate
(R=0.97) (For 6061 Aluminium)

Tool wear = - 0.0630 + 0.000488 Spindle speed + 0.153 Depth of cut- 0.301 Feed rate
(R=0.99) (For ASTM A48 Grey Cast Iron)

The optimum equations for different materials can be used to estimate the expressed values of the performance level for any parameter levels and for continuous quality improvement of the product.

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Biography of Authors

Md. Moin Uddin achieved B.Sc. in Mechanical Engineering (ME) degree from Khulna University of Engineering and Technology with 1st div. He was the member of the ME association in KUET. . He also got technical scholarship throughout all semesters.
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