# Tool Life Prediction in Turning of Mild Steel with HSS Cutting Tool Using Statistical Method

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## Abstracts

This study investigated the life of HSS cutting tool while turning mild steel material. It employed statistical experimental design method to develop a predictive tool life model using a centre composite design of experiment (CCD) comprising of fifteen (15) experiments. First order and second order tool life model were developed with 95% confidence level. The results obtained from the statistical model are in good agreement with that obtained from experimental data, with average percentage error of 7% which is reasonably acceptable. Based on ANOVA results, the cutting speed, depth of cut and rake angle were significant factors that influenced tool life.

**Keywords:** Tool life, Response Surface Methodology, Cutting Conditions, Mild Steel

## Introduction

Selection of cutting tool and cutting conditions represent essential elements in process planning for machining. This task is traditionally carried out on the basis of the experience of process planners with the help of data from machining handbooks and tool catalogs. Process planners continue to experience great difficulties due to lack of performance data on the numerous new commercial cutting tools with different materials, coatings, geometry and chip-groove configurations for high wear resistance and effective chip breaking etc (Jawahir & Wang, 2007). However, specific data on relevant machining performance measures such as tool-life, surface roughness, chatter and vibration, chip formation, and cutting forces are hard to find due to lack of predictive models for these measures. Hence, it is well known that obtaining reliable machining data is very costly in terms of time and material (Tsai et al, 2005). Thus, various methodologies and strategies have been adopted by researchers in order to predict tool life in milling and turning. Four major categories were created to classify the methodologies. These are: (i) approaches that are based on machining theory to develop analytical models and/or computer algorithms to represent the machined surface.

(ii) approaches that examine the effects of various factors through the execution of experiments and analysis of the results.

(iii) the artificial intelligence (AI) approaches; (Benardos and Vosniakos, 2003).

DOE is the process of planning the experiments so that the appropriate data should be collected which may be analyzed by statistical methods resulting in valid and objective conclusions, (Montgomery, 1991). DOE therefore provides platform in which the data obtained are uniform and reduce the total number of experiments.

Tool life prediction is important and necessary in metal cutting, since there is considerable time lost and this always leads to cost increase as a result of tool replacement or reset. Therefore, it is important to predict tool life under varying cutting conditions. In this study, a large number of experiments were performed and analyzed in order to establish the knowledge base for tool life. Hence, this led to the development of models of tool life using all the critical parameters that affect cutting process in turning mild steel using HSS cutting tool.

## Materials and Methods

*Materials and equipment*

(a) Workpiece material: Mild steel was chosen as workpiece material primarily because of its wide industrial use; relatively ease of machining and low cost. Metals in this machinability range usually produce a measurable amount of flank wear in the cutting time intervals used in the experiment. The chemical analysis of workpiece material was done in Katsina Steel Rolling Mill, Katsina, Nigeria and is shown on Table 1.

**Table 1:** Chemical composition of workpiece material (mild steel)

| Element | Iron | Carbon | Manganese | Phosphorus | Sulphur | Silicon |
|---|---|---|---|---|---|---|
| Percentage composition (%) | 98.92 | 0.19 | 0.70 | 0.04 | 0.05 | 0.10 |

(b) Cutting tool: The advantages of HSS tool over carbide are its strength to withstand cutting forces and the low cost of the tools. From the tool life point of view, HSS tool performs satisfactory at intermittent cutting applications, but cannot be used for higher cutting speeds like carbide tool. The tool geometry was ground at Defence Industries Corporation (D.I.C), Kaduna for proper geometrical cutting as shown on Table 2. The chemical composition of HSS tool which was analyzed at Katsina Steel Rolling Mill, Katsina, Nigeria is as shown on Table 3:

**Table 2:** HSS cutting tool geometric

| Signature | Dimension | Abbreviation |
|---|---|---|
| 0° | Back Rake Angle | BR |
| Varied (10°, 12°, 14°, 16°, 18°) | Side Rake Angle | SR |
| 6° | End Relief Angle | ER |
| 6° | Side Relief Angle | SRF |
| 6° | End Cutting – edge Angle | ECEA |
| 15° | Side Cutting – edge Angle | SCEA |
| 0° | Nose Radius | NR |

**Table 3:** Chemical composition of cutting tool material (HSS tool)

| Element | Cobalt | Carbon | Tungsten | Molybdenum | Chromium | Vanadium |
|---|---|---|---|---|---|---|
| Composition (%) | 8.0 | 1.1 | 1.5 | 9.5 | 4.0 | 1.2 |

(c) Lathe: The lathe used for this experiment was a 1985 model; type SN 281, ARIS-S.A, ARAD – ROMANIA having 7.5 horsepower equipped with a four-jaw universal self-centred chuck and live centre at the tailstock. It is a manual lathe with the following specifications: cutting depth of the range 0.5 mm to 7.5 mm, cutting speed of 45 to 2000 rpm range, 450 mm spindle bore, 35 mm longitudinal feed, feed rate of 0.018 to 2.0 mm/rev range and a thread pitch of 0.5 to 56 mm/rev.

(d) Vernier caliper: Flank wear measurements were done using vernier caliper, a mechanical device used to determine small lengths with reasonable accuracy.

## 2.2 Method

### (a) Design of Experiment

The proposed relationship between the tool life and the machining independent variables speed, depth of cut and rake angle can be represented by the following equation:

$$T = CV^m d^n r^p \varepsilon \qquad (1)$$

where T is the response variable tool life in minutes, V is the cutting speed in metre per minute (m/min), d is the depth of cut in millimetre (mm), r is the rake angle in radian (rad); C, m, n and p are constants or model parameters to be estimated using the experimental results and ϵ is random error having normal distribution with mean zero. In order to facilitate the determination of constants and parameters, the mathematical models were then linearized by using logarithmic transformation.

To develop the first-order model, a design consisting of fifteen experiments was selected. The design of experiments has an effect on the number of experiments required. Therefore, it is essential to have a well-designed experiment so that the number of experiments required can be minimized. A central composite design (CCD) consisting of 15 experiments was used. This central composite design provides five levels for each independent variable and coded values of the variables are shown in Table 4. The central composite, first-order design (with three factors) consisting of 15 experiments was used to develop the first order model as shown in Figure 1. . These 15 tests consist of 4 factorial points, 6 axial design and a centre point repeated five times as shown on Table 5. Since the second-order model is very flexible, easy to estimate the parameters with method of least square error, and work well in solving real response surface problems.

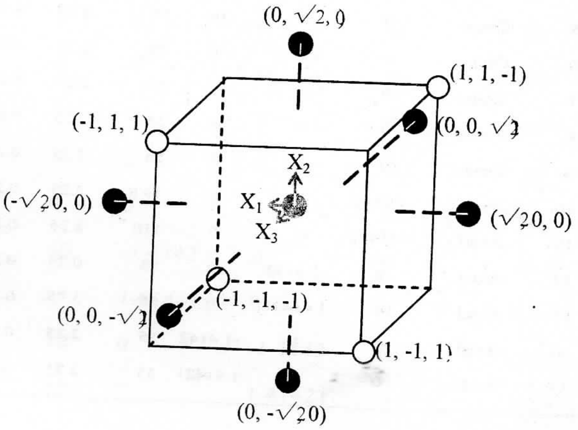

**Figure** 1: Central Composite Design consisting of 15 experiments

Depending on the capacity of the cutting tool, an augmented length of ± √2 was considered for this study. The augment points consist of five levels for each of the independent variables denoted by - √2, -1, 0, +1, + √2.

**Table 4:** Designed experimental factors and their levels

| Levels | Lowest | Low | Centre | High | Highest |
|---|---|---|---|---|---|
| Coding | -√2 | -1 | 0 | +1 | +√2 |
| $X_1$, Cutting Speed (m/min) | 19.8 | 39.6 | 55 | 79.2 | 110 |
| $X_2$, *Depth of cut (mm)* | 0.75 | 1.50 | 2.25 | 3.00 | 3.75 |
| $X_2$, Rake angle (radian) | 0.314 | 0.279 | 0.244 | 0.209 | 0.175 |

**Table 5:** Experimental conditions and coding

| *Trial No.(T)* | *Location in CCD* | *Coding of Levels* | | | *Cutting speed* | *Depth of cut* | *Rake angle* |
|---|---|---|---|---|---|---|---|
| | | $X_1$ | $X_2$ | $X_3$ | | | |
| 1 | Factorial | 1 | 1 | -1 | 79.2 | 3 | 0.279 |
| 2 | Factorial | 1 | -1 | 1 | 79.2 | 1.5 | 0.209 |
| 3 | Factorial | -1 | 1 | 1 | 39.6 | 3 | 0.209 |
| 4 | Factorial | -1 | -1 | -1 | 39.6 | 1.5 | 0.279 |
| 5 | Centre | 0 | 0 | 0 | 55 | 2.25 | 0.244 |
| 6 | Centre | 0 | 0 | 0 | 55 | 2.25 | 0.244 |
| 7 | Centre | 0 | 0 | 0 | 55 | 2.25 | 0.244 |
| 8 | Centre | 0 | 0 | 0 | 55 | 2.25 | 0.244 |
| 9 | Centre | 0 | 0 | 0 | 55 | 2.25 | 0.244 |
| 10 | Axial | -1.4142 | 0 | 0 | 19.8 | 2.25 | 0.244 |
| 11 | Axial | 1.41421 | 0 | 0 | 110 | 2.25 | 0.244 |
| 12 | Axial | 0 | -1.4142 | 0 | 55 | 0.75 | 0.244 |
| 13 | Axial | 0 | 1.41421 | 0 | 55 | 3.75 | 0.244 |
| 14 | Axial | 0 | 0 | -1.4142 | 55 | 2.25 | 0.314 |
| 15 | Axial | 0 | 0 | 1.41421 | 55 | 2.25 | 0.175 |

### *(b) Turning process*

The experiments were performed in the machine shop of Scientific Equipment Development Institute (S.E.D.I), Minna, Niger state. The machining test was carried out by turning mild steel on a lathe (SN 281: Romania) with HSS cutting tool at different cutting speeds (v), depth of cuts (d) and rake angle with constant feed rate (f) of 0.224 mm/rev. The HSS tool was clamped in the tool holder and a cylindrical bar of mild steel of 140 mm diameter by 500 mm length was selected for turning. The steel bar utilized in this experiment was purchased from a local vendor in Kaduna and prepared for this experimental set up. When the proper preparation was made i.e. cleaning the surface and obtaining a smooth cylindrical with smooth honey edge surface; the workpiece material was carefully held in a four-jaw self-centred chuck. To start the experiment, the feed rate was adjusted to constant rate of 0.224 mm/rev. A tool with a rake angle as indicated in the experimental design was selected and the appropriate cutting speed was set. The corresponding depth of cut as indicated in the experimental design was then adjusted. This was accomplished by turning the cross-feed hand wheel mounted on the compound rest until the tool tip barely touched the workpiece surface. A micrometer slip ring on the hand wheel was rotated to show zero depth of cut on the scale and this indicated the reference point to take the required depth of cut.

The tool was then moved longitudinally past the end of the workpiece and the hand wheel rotated to move the tool inward until the desired depth of cut was obtained. The desired feed and spindle speed were selected by levers on the headstock. When these steps were accomplished, the cut was ready to be made. The stop watch was checked for operation, spindle lever engaged, and the feed mechanism engaged. At the instant of contact between the tool and workpiece, the stop watch was started. The experiments were performed with various cutting speeds, depths of cut and rake angle as indicated in Table 5 and the corresponding tool life is taking with the stop watch using vernier caliper. It was decided not to use cutting fluid in the experiment as dry cutting conditions facilitate faster tool wear and eliminate any uncontrollable effect a cutting fluid may have on tool life.

**Table 6:** Experimental conditions for turning process

| Factor | Value |
|---|---|
| Tool Shape (side rake angle) | 10°, 12°, 14°, 16°, 18° |
| Cutting fluid | None (dry cut) |
| Cutting speed | 19.8, 39.6, 55.0, 79.2 and 110 m/min |
| Depth of cut | 0.75, 1.50, 2.25, 3.00 and 3.75 mm |
| Feed rate | 0.224 mm/rev |

When the prescribed time period was over, the feed lever was disengaged, the tool backed away from the work, and the spindle lever disengaged ending the cycle. At each cutting condition, the turning process continued until tool failure, which was based on the average flank wear (VB = 0.3 mm). The flank wear was measured at a time interval of 2 minutes until tool failure, and this was done by removing the tool from the experimental setup. Another workpiece was mounted in the lathe, with corresponding variables as designed, and the cycle repeated until all experiments were conducted.

## Results and discussion

Since the experiment was conducted with the objective of determining and predicting the tool life of HSS tool when turning mild steel, the measurement of tool life of the cutting tool was taken at an interval, during the process of turning. The plan of tests was developed with the aim of relating the effects of cutting speed (V), depth of cut (d) and rake angle (r) on the tool life (T) and Table 7 shows measured tool life with the coded variables.

**Table 7:** Experimental coding and result

| *S/No* | *Coding of Levels* | | | *Tool life* |
|---|---|---|---|---|
| | $X_1$ | $X_2$ | $X_3$ | *(min)* |
| 1 | 1 | 1 | -1 | 27.0 |
| 2 | 1 | -1 | 1 | 33.6 |
| 3 | -1 | 1 | 1 | 41.7 |
| 4 | -1 | -1 | -1 | 58.6 |
| 5 | 0 | 0 | 0 | 39 |
| 6 | 0 | 0 | 0 | 39 |
| 7 | 0 | 0 | 0 | 38.5 |
| 8 | 0 | 0 | 0 | 39 |
| 9 | 0 | 0 | 0 | 40 |
| 10 | -1.4142 | 0 | 0 | 90.8 |
| 11 | 1.41421 | 0 | 0 | 23.4 |
| 12 | 0 | -1.4142 | 0 | 60.4 |
| 13 | 0 | 1.41421 | 0 | 32.3 |
| 14 | 0 | 0 | -1.4142 | 41.7 |
| 15 | 0 | 0 | 1.41421 | 39.6 |

The experimental results as obtained in the form of tool life values against all the set experimental conditions as shown on Table 8 were used to obtain the model parameters. It could be seen from the table that the tool life in minutes differed with the different cutting conditions employed. The lowest tool life (23.4 minutes) occurred at the cutting speed of 110 m/min, depth of cut of 2.25 mm and rake angle 0.244 radian (14o). At the cutting speed of 19.2 m/min, depth of cut of 2.25 mm and rake angle of 0.244 radian (14o) the highest tool life of 90.8 minutes was recorded

**Table 8:** Results obtained from the experiment

| *S/n* | *v (m/min)* | *d (mm)* | *r* (radian) | *Tool life (min)* |
|---|---|---|---|---|
| 1 | 79.2 | 3 | 0.279 | 27.0 |
| 2 | 79.2 | 1.5 | 0.209 | 33.6 |
| 3 | 39.6 | 3 | 0.209 | 41.7 |
| 4 | 39.6 | 1.5 | 0.279 | 58.6 |
| 5 | 55 | 2.25 | 0.244 | 39 |
| 6 | 55 | 2.25 | 0.244 | 39 |
| 7 | 55 | 2.25 | 0.244 | 38.5 |
| 8 | 55 | 2.25 | 0.244 | 39 |
| 9 | 55 | 2.25 | 0.244 | 40 |
| 10 | 19.8 | 2.25 | 0.244 | 90.8 |
| 11 | 110 | 2.25 | 0.244 | 23.4 |
| 12 | 55 | 0.75 | 0.244 | 60.4 |
| 13 | 55 | 3.75 | 0.244 | 32.3 |
| 14 | 55 | 2.25 | 0.314 | 41.7 |
| 15 | 55 | 2.25 | 0.175 | 39.6 |

The tool life achieved was between the ranges of 23.4 to 90.8 minutes as shown on Table 8. The shortest tool life occurred at the cutting speed of 110 m/minutes, depth of cut of 2.25 mm and rake angle 14o, while the longest tool life was at cutting speed of 19.8 m/minute, depth of cut of 2.25 mm and rake angle 14o respectively. On the other hand, when the cutting speed and rake angle were held constant at 55 m/minute and rake angle 14o respectively; tool life increased from 39.6 minutes at depth of cut of 3.37 mm to 60.4 minutes at depth of cut of 0.75 mm. Similar trend was observed when rake angle was reduced. At constant cutting speed of 55 m/minute and depth of cut of 2.25 mm; the tool life increased when the rake angle increased. For example, tool life increase from 39.6 minutes to 41.7 minutes when the rake angle increased from 10o to 18o. The reduction of tool life because of increase in cutting speed, depth of cut and decrease in rake angle can be related to the rapid progression of flank wear. Tool life will become shorter when cutting is done at high speed because of less time taken for the tool to achieve a considerable depth of wear. This shows that cutting speed, depth of cut and rake angle were significant factors in the progress of flank wear rate and tool life.

### *Analysis of variance (ANOVA) for first order tool life*

The first order model equation for the tool life is expressed as shown in equation (2) and the analysis of variance for the first- order tool life is shown on Table 9.

| Source | DF | Seq SS | Adj SS | Seq MS | F | P |
|---|---|---|---|---|---|---|
| Regression | 3 | 1.49887 | 1.49887 | 0.49962 | 480.48 | <0.0001 |
| $X_1$ | 1 | 1.20379 | 1.21421 | 1.20379 | 1157.66 | <0.0001 |
| $X_2$ | 1 | 0.29136 | 0.29093 | 0.29136 | 280.20 | <0.0001 |
| $X_3$ | 1 | 0.00373 | 0.00373 | 0.00373 | 3.58 | 0.08 |
| Error | 11 | 0.01144 | 0.01144 | 0.00104 | | |
| Lack-of-Fit | 7 | 0.01066 | 0.01066 | 0.00152 | 7.84 | 0.03 |
| Pure Error | 4 | 0.00078 | 0.00078 | 0.00019 | | |
| Total | 14 | 1.51031 | | | | |

*Significant at 5%*

The model F-value of 480.48% implies that the model is significant. There is only 0.001% chance that a Model F-Value this large could occur due to noise. The ratio of lack of fit to pure error is 7.84. Therefore, the model is adequate. The selected model from sequential model sum of squares of tool life was analyzed using the analysis of variance (ANOVA). The p-value (Prob>F) for the model which is less than 0.0001 is much lower than the significant level (0.05) shows that the tool life model is statistically significant. The ratio of lack of fit to pure error is 7.84. Therefore, the model is adequate. The model terms that were taken into account (X1 and X2) were adequate to represent the model at 95% confidence while the third term (X3) is adequate at 90%. ANOVA table also shows that cutting speed and depth of cut are factors that significantly influence the tool life. The R squared value of 0.99, 0.95 and 0.92 for X1, X2 and X3 respectively are close to one. Hence, the accuracy of the model in the prediction of tool life is justified. The 95% confidence interval of first-order model in Table 4.6 affirms that the rake angle has insignificant effect on tool life, but if the confidence interval is allowed at 90%, it is significant. From this 1st order model equation (2) it is apparent that higher cutting speed will lower the tool life values followed by depth of cut and rake angle. This equation is valid for cutting speed (19.8 ≤ V ≤ 110m/min), depth of cut (0.75 ≤ d ≤ 3.75 mm) and rake angle (10o ≤ r ≤ 18o).

Figure 2 shows the plot of residual versus predicted response for first order tool life data. All points are randomly dispersed around the horizontal axis and within the band of ± 0.050 except one of data that is an outlier. Hence, the random pattern of these points indicates that the model is appropriate for the data obtained.

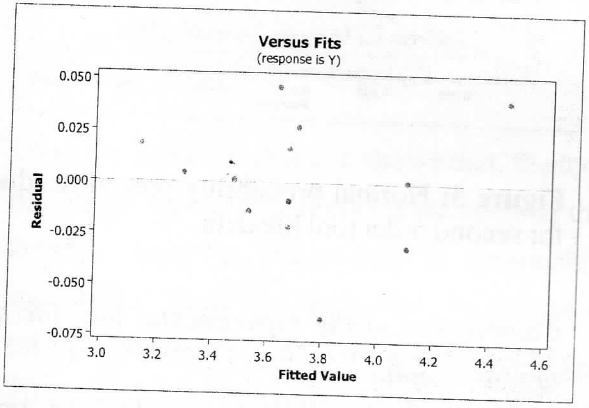

**Figure 2:** Plot of residual versus predicted response for first order tool life data

Figure 3: plot of the normal distribution of the residual point. The plot shows scatter points evenly distributed over and below a central line of fit. The statistical implication is that all the points had constant variance of experimental errors less than 0.01.shows the

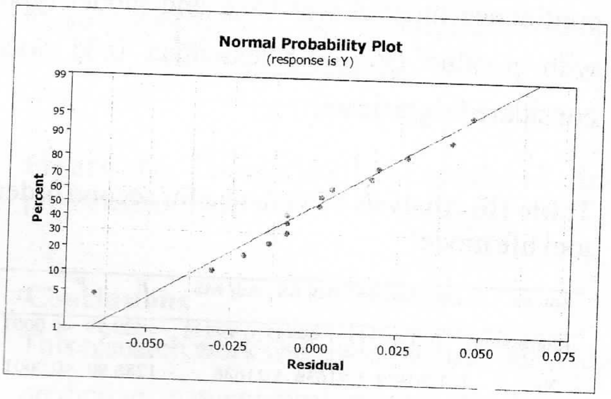

**Figure 3:** Normal probability plot of residuals for first order tool life data

*Analysis of variance for second order tool life*

Using the experimental data in Table 7, the second order model is derived from equation (3) for the second order tool life model and experiments were carried out to substantiate the validity of the model.

$$y_2 = 3.69 - 0.48X_1 - 0.22X_2 - 0.018X_3 + 0.037X_1^2 + 0.016X_2^2 - 0.026X_3^2 + 0.012X_1X_2 - 0.082X_1X_3 - 0.23X_2X_3 \quad (3)$$

Equation (3) was later reduced to equation 4 as the model parameters, b3, b4, b5, b6, b7, and b8 are statistically insignificant, as the t – value is less than 2.57.

$$y_2 = 3.71 - 0.48X_1 - 0.18X_2 - 0.23X_2X_3 \quad (4)$$

The selected model from sequential model sum of squares of tool life was analyzed using the analysis of variance (ANOVA). The analysis of variance as shown in Table 10 proved the adequacy of the model as the regression effect is dominant in relation to linear and interaction effects. However, the insignificance of the quadratic model parameter, those that did not justify the development of higher order model. There were linear and interaction effect rather, on the quadratic model. In this study 95% confidence interval was used and model type with p-value (Prob>F) less than 0.05 was considered significant.

**Table 10:** Analysis of Variance for second order tool life model

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Regression | 3 | 1.49993 | 1.49993 | 0.49998 | 529.79 | <0.0001 |
| $X_1$ | 1 | 1.20379 | 1.21636 | 1.21636 | 1288.90 | <0.0001 |
| $X_2$ | 1 | 0.29136 | 0.00191 | 0.00191 | 2.02 | 0.183068 |
| $X_2X_3$ | 1 | 0.00478 | 0.00478 | 0.00478 | 5.07 | 0.045796 |
| Error | 11 | 0.01038 | 0.01038 | 0.00094 | | |
| Lack-of-Fit | 7 | 0.00960 | 0.00960 | 0.00137 | 7.07 | 0.038813 |
| Pure Error | 4 | 0.00078 | 0.00078 | 0.00019 | | |
| Total | 14 | 1.51031 | | | | |

Significant at 5%The analysis of variance for second-order tool life model is shown in Table 10. The model F-value of 529.79 implies that the model is significant. There is only 0.001% chance that a Model F-Value this large could occur due to noise. The ratio of lack of fit to pure error is 7.07. Therefore, the model is adequate. It can be concluded that cutting speed is the most significant effect on tool life.

Figure 4 shows the plot of residual versus predicted response for second order tool life data. All points are randomly dispersed around the horizontal axis and within the band of ± 0.050 except one of data that is an outlier. Hence, the random pattern of these points indicates that the model is appropriate for the data obtained.

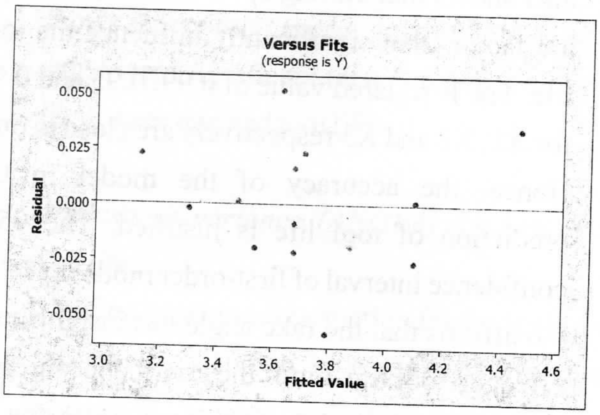

**Figure 4:** Plot of residual versus predicted response for second order tool life data

Figure 5 shows the plot of the normal distribution of the residual point. The plot shows scatter points evenly distributed over and below a central line of fit. The statistical implication is that all the points had constant variance of experimental errors less than 0.01.

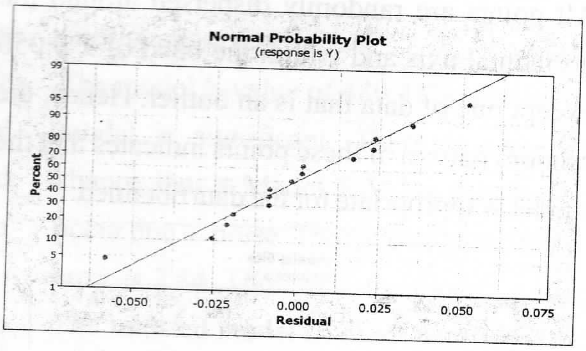

**Figure 5:** Normal probability plot of residuals for second order tool life data

*Comparison of the experimental tool life and predicted data*

The predicted values were obtained using equation (5) and the computed and experimental values are shown on Table 11.

$$T = 492.01v^{-0.53} d^{-0.35} r^{0.07} \tag{5}$$

**Table 11.** Experimental tool life Data and Predicted Data

| S/N | Cutting Speed (m/min) | Depth of cut (mm) | Rake angle (radian) | Measured tool life (min) | Predicted tool life (min) | Percentage Deviation (%) |
|---|---|---|---|---|---|---|
| 1 | 79.2 | 3 | 0.279 | 27.0 | 30.6 | 13.390 |
| 2 | 79.2 | 1.5 | 0.209 | 33.6 | 38.3 | 14.161 |
| 3 | 39.6 | 3 | 0.209 | 41.7 | 43.2 | 3.477 |
| 4 | 39.6 | 1.5 | 0.279 | 58.6 | 56.3 | 3.908 |
| 5 | 55 | 2.25 | 0.244 | 39 | 40.6 | 4.313 |
| 6 | 55 | 2.25 | 0.244 | 39 | 40.6 | 4.313 |
| 7 | 55 | 2.25 | 0.244 | 38.5 | 40.6 | 5.667 |
| 8 | 55 | 2.25 | 0.244 | 39 | 40.6 | 4.313 |
| 9 | 55 | 2.25 | 0.244 | 40 | 40.6 | 1.705 |
| 10 | 19.8 | 2.25 | 0.244 | 90.8 | 69.6 | 23.386 |
| 11 | 110 | 2.25 | 0.244 | 23.4 | 28.3 | 21.022 |
| 12 | 55 | 0.75 | 0.244 | 60.4 | 59.9 | 0.756 |
| 13 | 55 | 3.75 | 0.244 | 32.3 | 33.9 | 5.205 |
| 14 | 55 | 2.25 | 0.314 | 41.7 | 41.4 | 0.568 |
| 15 | 55 | 2.25 | 0.175 | 39.6 | 39.7 | 0.306 |

Table 11 presents the predicted results obtained from the models and actual results obtained from the experiments. It also shows the percentage deviation of the predicted value from the model values. The average percentage deviation of the experimental value from the predicted value is calculated the following formulae;

$$Avg_{ei} = \frac{\sum_{i=1}^{15} |Sum\ of\ error\ of\ linear\ (e_i)}{Total\ number\ of\ trial\ (T)} \quad (6)$$

From the Table 11 above, it shows that, the tool life model predicts the model quite fairly as the average error is 7% which is reasonably acceptable. Therefore, the model can be used to estimate the performances reasonably correctly. The correlation between the values obtained from measurement and proposed model for tool life have been depicted in Figure 6.

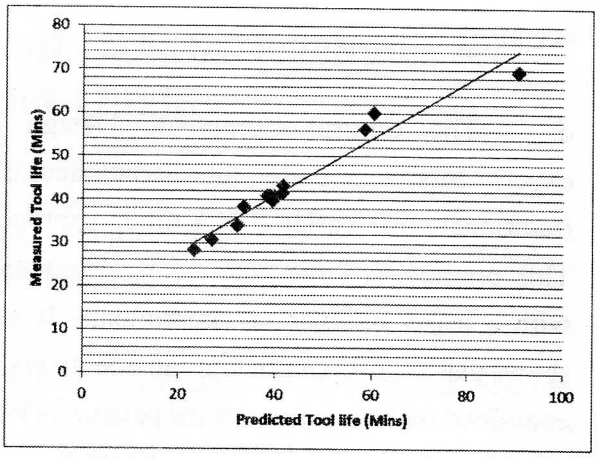

**Figure 6:** Comparison of measured and predicted tool life

## Conclusions

This research work was undertaken to develop a predictive mathematical relationship between the tool life in turning of mild steel with HSS tool and the machining variables by using the experimental results obtained through the use of the concept of DOE. Based on the results and analysis carried out in this study, several conclusions can be made.

a. Tool life reduces with increase in cutting speed, depth of cut and decrease in rake angle. Increase in the cutting speed, depth of cut and decreasing the rake angle will increase the wear rate and cause the tool life to be shortened.

b. Based on ANOVA results, the cutting speed, depth of cut and rake angle were significant factors that influence tool life.

c. The percentage average error between the predicted and measured tool life of the models is 7% at best which can be considered to be reasonable and the model can be considered accurate.

d. The Central Composite Design of experiments is a better alternative than the traditional one-variabie-at-a-time approach. This provides a large amount of information with a lesser number of experiments. It also shows that cutting parameters can effectively be combined with tool geometrical parameter such as rake angle to carry out an investigation.

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