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The Effect of Turning Parameters on the Surface Roughness of Aluminium Alloy Components

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ABSTRACT

The greatest advantage of using hard turning is the reduced machining time and complexity required to manufacture metal parts. This detailed experimental study has been conducted using Taguchi design in the Design of Experiments (DoE) on Computer Numerical Controlled (CNC) lathe machine process. The machining process is studied under operating conditions with factors at three levels. The machining process on CNC lathe is programmed by speed, feed and depth of cut. In order to obtain a good surface finish on the aluminium alloy component, low cutting speed, lower feed rate and high depth of cut where all carried out on the CNC lathe machine under dry conditions. The prediction model developed by the multilinear regression technique is adequate with a statistical adjusted R^2 value of 98.59%. The results of optimization from the Genetic algorithm shows that the cutting speed, feed rate and depth of cut are 45m/min, 0.3mm/rev and 3.0mm respectively. The result yielded surface roughness fitness value of 0.98µm.

Keywords: *Taguchi design, Design of Experiment, Genetic Algorithm and Optimization*

INTRODUCTION

Surface roughness is a component of texture which is quantified by the deviations in the direction of the normal vector of a real surface from its ideal form. A large deviation connotes rough surface while a small deviation show smooth surface (Xavior and Adithan, 2009). Surface roughness has become one of the most significant technical requirements and it is an index of product quality (Ravindra, 2008). In order to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product, a reasonably

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good surface finish is desired (Patel, 2014). Nowadays, manufacturing industries specially concerned to dimensional accuracy and surface finish (Praveen and Arun, 2015). In order to obtain optimal cutting parameters, manufacturing industries have depended on the use of handbook based information which leads to decrease in productivity due to sub-optimal use of machining capability this causes high manufacturing cost and low product quality (Upadhye and Keswani, 2012). Hence, there is need for a systematic methodological approach by using experimental methods and statistical/ mathematical models. The design of experiments (DoE) is an efficient procedure for the purpose of planning experiments (Oji, Sunday and Adetunji, 2013). The data can further be analyzed to obtain valid and objective conclusions.

Several experimental investigations have been carried out over the years in order to study the effect of cutting parameters, tool geometries on the work pieces surface integrity using several work pieces. Tool geometry plays an important role in machining (Praveen and Arun, 2015). Taguchi's approach to design of experiments is easy to adopt and apply for users with limited knowledge of statistics; hence it has gained a wide popularity in the engineering and scientific community. In the Taguchi design method the design parameters (factors which can be controlled) and noise factors (factors which can't be controlled), which influence product quality are considered (Mohiuddin et al, 2015). The main trust of the Taguchi technique is the use of parameter design, which is an engineering method for product or process design that focuses on determining the process parameter settings producing the best levels of quality characteristic with minimum variation (Mohiuddin, Krishnaiah and Hussainy, 2015). Taguchi design provides a powerful and efficient method for designing processes that operate consistently and optimally over a variety of conditions. Experimental design methods were developed in the early 20th century and have been extensively studied by the statistician since then, but they were not easy to use by practitioners (Kumar and Grewal, 2013).

Thus, the application of empirical modelling and the optimization of the operating parameters for turning aluminum alloy using genetic algorithm is a recommended approach. The use of genetic algorithms will improve on the existing method for turning aluminium alloy components and also system performance, technological adaptation and reduction in production cost (Azhagan, Mohan and Rajadurai, 2014). This study will help us to know or uncover critical areas in empirical modelling and the optimization using genetic algorithm that many researchers were not able to explore. Thus, a new theory on turning metallic components may be arrived at in predicting surface roughness in machining process and to know their optimal cutting speed, feed rate and depth of cut. The findings of this study will bring about benefit in industries and manufacturing companies considering that manufacturing components to specific dimensions involve the removal of excess materials by turning. Turning process is one of the methods to remove material from cylindrical and non-cylindrical parts (Praveen and Arun, 2015). The greater demand for optimal settings and operating parameters for turning aluminium alloy components justifies that the need for more effective and life-changing and technical approach to the subject at hand (Manohar, Joseph, Selvaraj and Sivakumar, 2013).

Little work has been reported on the determination of optimum machining parameters when machining aluminum alloy components. Also very few researchers have worked on optimization of aluminium engine compnents using advanced optimization techniques so we selected this area to carry out analysis and optimization of hard turning parameters for aluminium alloy components. The study aims at determining the effect of turning parameters on the surface of roughness of aluminium alloy using genetic algorithm. Specifically, the objectives are:

i. Creation of Taguchi L9 orthogonal array Design for the conduction of experiments
ii. Application of cutting speed, depth of cut, and feed rate during turning process of aluminium alloy
iii. Determination of surface roughness of the aluminium alloy
iv. Development of a multiple linear regression model that can predict surface roughness
v. Determination of the optimal levels of the cutting parameters using Genetic algorithm

MATERIALS AND METHOD

The materials used in this study are aluminium alloy, vernier calipher, micrometer screw gauge, stop watch, surface gauge profilometer and CNC turning machine (Xavior and Adithan, 2009). The Design of experiment Taguchi orthogonal array was used to develop experimental layout for the conditions applied in performing the turning operation.. The experimental matrix contains 9 experimental runs at 3 levels each (Oji, Sunday and Adetunji, 2013).

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The general form for the multiple linear regression equation for representing a 3-parameter response (Y) is given as (Montgomery and Runger, 2003)

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C \quad (1)$$

Where A,B and C are the process parameters. While $\hat{A}_0$, $\hat{a}_1$, $\hat{a}_2$, and $\hat{a}_3$ are the regression coefficients.
The surface roughness determined using a profilometer applied equation 2

$$R_a = \frac{1}{n}\sum_{i=1}^{n} \|Y_i\| \quad (2)$$

Where R_a =Average roughness
n = space points along the trace
Y_i = vertical distance from the mean line to the *ith* data
The process parameters and levels used in this study where arrived at after deep review of related literature of Manohar, Joseph, Selvaraj and Sivakumar (2013) and Praveen and Arun (2015). The turning parameters and their levels are shown in table 1.

Table 1: Turning parameters and their levels

Levels	**Cutting speed (m/min)**	**Feed rate (mm/rev)**	**Depth of cut (mm)**
Level 1	45	0.30	2.0
Level 2	60	0.40	2.5
Level 3	75	0.50	3.0

Source: Experimentation, 2017

Figure 1: CNC Lathe machine

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The experiment was carried out in accordance with the parametric conditions prescribed by the Taguchi Design. The Aluminium alloy specimen was machined on the CNC lathe machine shown in figure 1 while the cutting speed, feed rate and depth of cut were adequately measured using tachometer, micrometer screw gauge and vernier calipher. The surface roughness of the aluminium alloy component was adequately measured with a surface gauge profilometer at every experimental run and the outcome used as the response in the Taguchi Design.

Developed Prediction Model

The developed mathematical model for predicting surface roughness of aluminium alloy is given as:

Surface roughness (μm)=-1.001+0.03678A+1.70B-0.060C (3)

Where A=cutting speed (m/min)
B= feed rate (rev/min)
C=depth of cut (mm)

The Analysis of Variance (ANOVA) test was carried out to validate the developed mathematical model and determine the significance of the individual turning parameters. Table 3 shows the ANOVA test result

RESULTS AND DISCUSSION

The Taguchi L9 orthogonal array for conducting the turning experiment is shown in Table 2.

Table 2: Taguchi L9 Orthogonal Array for the Turning Experiment

Run order	Cutting speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Surface roughness (μm)
1	45	0.3	2.0	1.05
2	45	0.4	2.5	1.20
3	45	0.5	3.0	1.36
4	60	0.3	2.5	1.49
5	60	0.4	3.0	1.70
6	60	0.5	2.0	1.90
7	75	0.3	3.0	2.11
8	75	0.4	2.0	2.40
9	75	0.5	2.5	2.41

Source: Experimentation, 2017

Table 3: ANOVA Test result

Source	DF	Adj SS	Adj MS	F-value	P value
Regression	3	2.005	0.668	183.50	0.000
A	1	1.826	1.826	501.50	0.000
B	1	0.173	0.173	47.62	0.001
C	1	0.005	0.005	1.48	0.278
Error	5	0.018	0.004		
Total	8	2.023			

Source: Experimentation, 2017

The result shows that the developed mathematical model is adequate with a p-value of 0.000, $R^2 = 99.10\%$ and $R^2(adj) = 98.56\%$. Also, the ANOVA table indicates that the cutting speed and feed rate are significant with p-values of 0.000 and 0.001 respectively using a statistical significant value of 0.05. Furthermore, a normality probability plot shown in figure 2 was developed so as to ascertain the distribution of the residual points along the normal distribution diagonal line. The result shows that the residual points of the process parameters satisfy the normality conditions

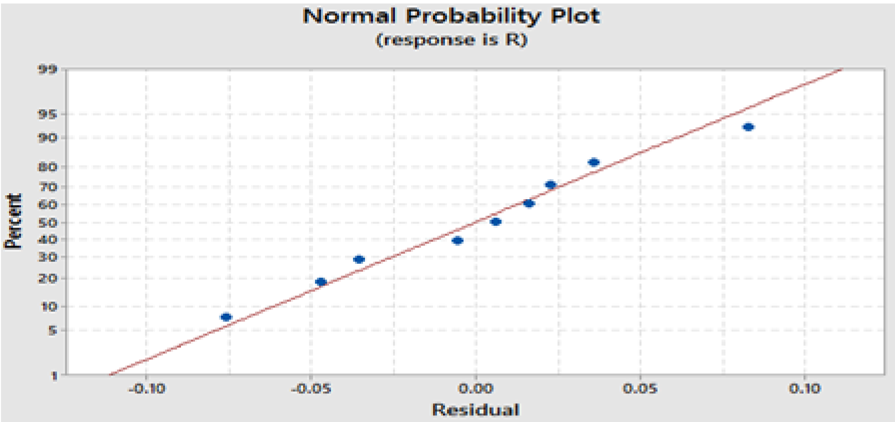

Figure 2: Nomality Plot for surface roughness

Optimization Analysis

The Genetic algorithm technique was applied in developing optimal levels for the turning parameters. The regression model obtained through multiple linear regression technique was used as the objective function in the MATLAB genetic algorithm tool box. The population size used was 50, number of variable used is 3, crossover and mutation probability rate applied are 85% and 0.01 respectively. A number of 100 generations and 50 seconds time limit were used for the optimization (Azhagan, Mohan and Rajadurai, 2014).

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The Lower bound of the turning parameters = {45, 0.30, 2.0}
The Upper bound of turning parameters = {75, 0.50, 3.0}
The table 4 shows the tested levels and best optimal levels for the turning parameters used in the surface roughness model from the genetic algorithm tool.

Table 4: Optimal levels of turning parameters

Factor	Process Parameter	Level range	Optimal level
A	Cutting speed(m/min)	45-75	45
B	Feed rate(mm/rev)	0.30-0.50	0.3
C	Depth of cut (mm)	2.0-3.0	3.0

Source: Experimentation, 2017

The optimal value of the surface roughness is 0.98mm. The surface roughness optimization plot from the evolutionary algorithm depicting the fitness value and number of generations is shown in Figure 3.

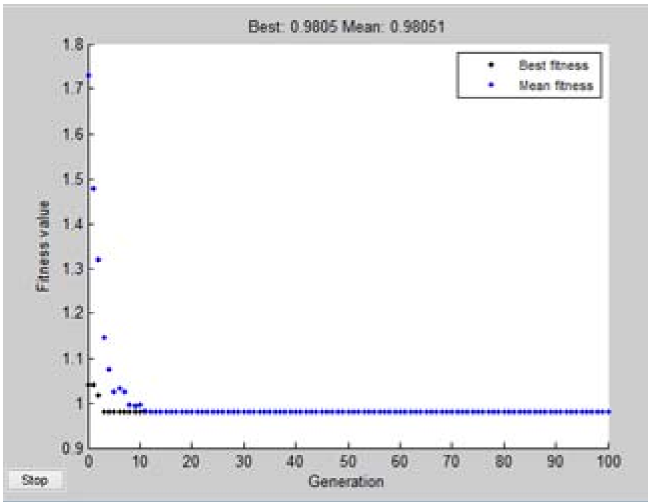

Figure 3: Surface roughness optimization plot

Confirmation test

The optimal levels developed from the evolutionary algorithm were validated by carrying out actual experiment at the machine shop. A cutting speed of 45m/min, feed rate of 0.3mm/rev and depth of cut of 3.0mm were applied in turning an aluminium alloy specimen. The surface roughness of the machined aluminium alloy was measured using the surface gauge profilometer. The surface roughness from the machined aluminium alloy was determined to be 0.978µm which was a good match to that predicted by the developed model 0.98µm.

The developed mathematical model showed that 98.56% of the variation in surface roughness response is explained by the predictor variables. This indicates that the developed regression model is adequate. Also, the difference between the R^2 and adjusted R^2 values indicates that over fitting scarcely exist in the developed model. In addition, the probability plot shown in figure 2 reveals that normality conditions were satisfied. The results of optimization from the Genetic algorithm showed that the cutting speed, feed rate and depth of cut which are 45m/min, 0.3mm/rev and 3.0mm respectively yielded surface roughness fitness value of 0.98µm which was very close to the confirmatory test value obtained from the surface gauge profilometer .

CONCLUSION

This experiment was carried out to examine the effect of turning parameters on the surface roughness of aluminium alloy components. We used Taguchi Design to develop experimental layout for the conditions used in the machining operation and multilinear regression technique for generating a predictive model for the surface roughness in terms of machining parameters. The developed model was used as objective function in the Genetic algorithm (GA) tool box to optimize the machining parameters that resulted in minimum surface roughness. The machining parameters obtained from this study showed similarity with the results achieved in Manohar et al (2013) and Praveen et al (2015).

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