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Analysis of Variance for Surface Roughness and Material Removal Rate in Orthogonal Turning of AISI 304L Alloy Steel

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ABSTRACT

The study evaluated the contribution of cutting input parameters on surface roughness and material removal rate (MRR) in orthogonal turning of AISI 304L alloy steel using tungsten carbide insert. The experimental design and analysis were done using Minitab 17 software. The design of experiment employed Taguchi method and the experiments were conducted using CNC lathe. The hierarchy of influence of the cutting parameters was studied using analysis of variance (ANOVA) based on adjusted approach. For surface roughness, the study showed that feed rate had the most significant effect with 36.29% and for MRR , cutting speed has the most significant effect with 49.29%.

Keywords: *ANOVA, cutting speed, feed rate, depth of cut, material removal rate.*

1 INTRODUCTION

The machining of engineering material play a critical role in the provision of various human needs. A vast majority of the shapes used in the engineering world are produced by machining processes. Indeed, it is difficult to think of any product that does not directly or indirectly have some form of metal cutting process; thus, the advancement of our present day technology is intimately connect with the advancement of our knowledge of the machining process (Abu, 2011). The finished products of the machining process are implemented in specialized areas like spaces and air travel, railways, automobile and medical industries. The value of mechanical components manufactured worldwide yearly using machining processes is estimated to be 15% (Lakshmi, and Subbaiah, 2012). The removal of metal from the outer diameter of a rotating cylinder workpiece is known as turning process. This process reduces the diameter of the workpiece to a specified dimension and to produce a good surface finish. Turning process can be defined basically as removal of metal of an external surface of workpiece that is rotating on lathe with a single-point cutting tool, and while the cutting tool feeds parallel to the axis of the workpiece and at a depth that will remove the outer surface of the workpiece. There are many factors that affect the product of turning process such as cutting velocity, feed rate, depth of cut, geometry of cutting tool, and cutting conditions etc (Astakhov, 2006).

Requirements for accurate dimension and surface finish of the machining product are major expectation in present day production in a bid for manufacturers to satisfy the customer's need; ensure machining economy; retain and expand their stake in the market place. Nowadays manufacturing industries are concerned with dimensional accuracy and surface finish. As a result of competition of manufactured products in the market, the quality of products must be guarantee at every stage of manufacturing process. Hence, this has called for an increase in the efficiency of manufacturing processes with the best manufacturing cost and quality. Therefore, the correct selection of cutting tool and cutting parameters are essential to achieve the desired quality of surface finish (Aswathy et al, 2015). In general, material removal rate (MRR) and surface roughness (Ra) mainly depends on cutting variables, tool variables and workpiece variables. Among these, cutting variables are cutting speed, feed rate and depth of cut which can be manually adjusted (Maheswara et al, 2015). Optimisation in machining processes is necessary for continual improvement of quality in product and processes (Komesh, 2014).

Roopa et al (2015) analysed the effect of cutting variables on surface roughness and material removal rate for En19 workpieces material with and without heat treatment. The input parameters are cutting speed, feed rate and depth of cut, which are varied over three levels. The conclusions drawn from the study showed that for En19 steel without heat treatment, cutting speed has the most significant factor on material removal rate with 63.97% followed by feed rate and depth of cut with 16.06% and 3.50% respectively. At 1000 rpm cutting speed, 0.054 mm/rev feed rate and 0.12 mm depth of cut, material removal rate of 249.73 mm^3/min can be obtained. Then, for En19 steel subjected to heat treatment, cutting speed was found to be the most significant factor that affects material removal rate with 69.38% followed by feed rate and depth of cut with 13.76% and 3.94% respectively. While, maximum material removal rate of 200.72 mm^3/min can be obtained at 1000 rpm cutting speed, 0.054 mm/rev feed rate and 0.12 mm depth of cut. For En19 steel without heat treatment depth of cut with 76.0% was the most significant factor that affects the surface roughness followed by feed rate and cutting speed with 8.114% and 2.81% respectively. Surface roughness of 3.003 µm for a given range can be obtained at 1000 rpm cutting speed, 0.04 mm feed rate and depth of cut of 0.04 mm. For En19 steel subjected to heat treatment depth of cut has the most significant factor on the surface roughness with 66.63% followed by cutting speed and feed rate with 10.68% and 9.90% respectively. Surface roughness of 2.1907 µm for a given range can be obtained at 1000 rpm cutting speed, 0.04mm feed rate and depth of cut of 0.04mm.

Aswathy et al (2015) investigated the effect of cutting parameters on surface roughness, material removal rate and roundness error during the wet turning of Ti-6Al-4V alloy. The study focused on the turning process of Ti-6Al-4V using chemical vapour deposition (CVD) coated carbide tools. Cutting speed, feed rate, depth of cut and tool nose radius were the input variables investigated on the responses. Taguchi method was used for the experimental design and the analyses were carried out with Minitab 16 software. The results were validated with mathematical software - PYTHON. This study showed that cutting parameters affected the surface roughness, material removal rate and roundness error in wet turning of Ti-6Al-4V alloy using CVD coated carbide tools as follows:-

i. For maximum surface finish the optimal parametric combination factors are cutting speed = 70 m/min., feed rate = 0.010 mm/rev, depth of cut = 0.02 and nose radius = 0.5.
ii. For maximum material removal rate the optimal parametric combination factors are cutting velocity = 70 m/min., feed = 0.030 mm/rev, depth of cut = 0.05 and nose radius = 0.1mm.
iii. For minimum roundness error the optimal parametric combination factors are cutting speed =70 m/min., feed rate = 0.010 mm/rev, depth of cut = 0.02 mm and nose radius =0.5mm.

Maheswara and Venkatasubbaiah (2016) conducted an experiment to study the optimisation of surface roughness in turning process using Taguchi method. The experiment involved the investigation of the effect of cutting speed, feed rate and depth of cut on AA7075 during turning process to determine the quality of surface roughness using tungsten carbide insert. The experiment was designed as per the Taguchi's L_9 (3^3) orthogonal array. Analysis of variance was performed to determine the significance of the cutting parameters on the surface roughness. The results showed that feed rate and cutting speed were the most important parameters that influenced the surface roughness. Signal – to - noise ratio was used to plot the main effect plot for surface roughness and the optimum values were at cutting speed of 1000 rpm (Level 1), feed of 0.2 mm/rev (Level 1) and depth of cut of 0.5 mm (Level 1). Thereafter, optimal range of surface roughness value was predicted. Finally, the relationship between cutting parameters and response were developed by using the MINITAB-16 software. The predicted value was compared with the experimental value and it was observed that both the values were very close to each other, hence, it can be concluded that the regression models developed was accurate and adequate.

Suha and Mubarak (2016) evaluated the surface roughness and material removal rate in end milling of complex shape. In the study, an analysis of the influence of cutting speed, feed rate and depth of cut on machining output variables (surface roughness and material removal rate) during the CNC end milling process complex shape of copper were undertaken. Three factors of three levels for the input parameters were planned as recommended by Taguchi' orthogonal array. Analysis of variance was employed to study the effect of cutting parameters on the responses. It was observed that the depth of cut has the highest significant effect on surface roughness with 71.06% followed by feed rate with 23.32% and cutting speed with 2.12%. Feed rate has the highest significant effect on the material removal rate with 68.58% followed by depth of cut with 22.13% and cutting speed with 7.52%. The optimum combination of machining parameters which resulted in optimum value of the surface roughness were A3,B1,C2 (cutting speed of 6000 rpm, feed rate of 500 mm/tooth and depth of cut of 0.06 mm). In the same vein, optimum combination of machining parameters which resulted in optimum value of material removal rate were A1,B3,C3, where the values of cutting speed, feed rate and depth of cut are 2000 rpm, 1500 mm/tooth and 0.08 mm respectively.

Krishnamurthy and Venkatesh, (2013) conducted an assessment of surface roughness and material removal rate on machining of TIB2 reinforced aluminum 6063 composites using Taguchi's approach. The study involved the use of orthogonal array for the experimental design, while signal-to-noise ratio and analysis of variance were deployed to determine the performance characteristics in turning operations of 5 and 10 wt. % TiB2 particles reinforced aluminum (Al6063) metal matrix composites. Cutting speed; feed rate and depth of cut were optimized to determine the optimal values for surface roughness and material removal rate. The experimental design was based on L_{27} orthogonal array using carbide tool (K20). The analysis of variance showed that feed rate was the most significant factor that affect the surface roughness followed by cutting speed, while depth of cut was found to be insignificant. For material removal rate, it was observed that cutting speed was the most significant factor followed by feed rate.

2 MATERIALS AND METHODS

The following materials and methods were adopted in this study.

2.1 MATERIALS

The workpiece material used in this study is AISI 304L alloy steel with the chemical composition shown in Table 1. AISI 304L steel alloy is an extra low-carbon variation AISI 304 with a 0.03% maximum carbon content and it display good mechanical characteristics, toughness and corrosion resistance. Due to its high hardness, wear resistance, surface finishing and dimensional precision, it is widely used to manufacture of mechanical components.

TABLE 1: CHEMICAL COMPOSITION OF AISI 304L ALLOY STEEL

Element	Percentage (%)
Carbon	0.030max
Silicon	0.75 max
Manganese	2.00
Phosphorus	0.045max
Sulphur	0.03 max
Chromium	18.00-20.00
Nickel	8.00-10.50
Nitrogen	0.100 max

The cutting tool used in this turning process is tungsten carbide inserts TNMG 160408-DM which a triangular diamond shape.

2.2 METHOD

The experimental method applied in this study is Taguchi method, whose philosophy defines three approaches to minimize variations namely, parameter, tolerance and system design. Taguchi's method has few benefits such as fewer number of trial runs and an acceptable solution is always achieved. It minimizes the variability around the target value with lesser experimental cost. The one factor at –a time approach in which the experiments are conducted by varying one input factor and keeping the other input factors constant is time consuming and expensive. The experimental design consists of three variables at three levels as shown in Table 2, while, the experimental design matrix is shown in Table 3. To determine the effect of each variable on the output, analysis of variance was used. The turning process was carried out at Nigeria Machine Tools (NMT) Osogbo, Nigeria using CNC lathe (Model: SPT- 32). The tool insert used was tungsten carbide (TNMG 160408-DM) and mounted on negative tool holder (ETJNR -2525M16).

TABLE 2: CUTTING PARAMETERS AND THEIR LEVELS

Parameters	Levels		
	L_1	L_2	L_3
Cutting speed (rpm)	500	1000	1500
Feed rate (mm/rev)	0.20	0.30	0.40
Depth of cut (mm)	0.4	0.6	0.8

TABLE 3: EXPERIMENTAL DESIGN MATRIX

Runs	Cutting speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)
1	500	0.2	0.4
2	500	0.3	0.6
3	500	0.4	0.8
4	1000	0.2	0.6
5	1000	0.3	0.8
6	1000	0.4	0.4
7	1500	0.2	0.8
8	1500	0.3	0.4
9	1500	0.4	0.6

The turning process of AISI 304L was done under wet condition using cutting fluid (*Lactuca LT 3000*) made by Total which is a soluble oil. It was mixed at a ratio of 3% cutting fluid to 97% distilled water and the method of application was flood method. The length of workpiece material for each experimental runs was 750mm. The measuring device used in measuring the surface roughness (Ra) is Portable Surface Roughness Tester, SRT-6200 and material removal rate (MRR) was determined by measuring the diameter of the workpiece before and after each run. The relationship shown in equation 1 was used to compute for MRR

$$MRR = \frac{\pi}{4}\left(D_i^{\,2} - D_f^{\,2}\right) fN \qquad (1)$$

Where, D_i = initial diameter, mm, D_f = final diameter, mm, f= feed rate, mm/rev, N=spindle speed, rpm (Dhabale and Vijaykumar, 2015)

3 RESULTS AND DISCUSSION

Based on the measurement obtained using the surface roughness tester and analysis of various experimental parameters with initial and final workpiece measurement, the result of the experiments for surface roughness and MRR are shown in Table 4.

TABLE 4: SURFACE ROUGHNESS AND MRR RESULTS

Runs	Surface roughness, Ra (μm)	D1 (mm)	D2 (mm)	MRR (mm^3/min)
1	1.130	50	49.2	6232.92
2	1.970	49.2	48.0	13741.33
3	2.440	48.0	46.4	23725.31
4	1.120	46.4	45.2	17266.19
5	1.420	45.2	43.6	33476.81
6	0.975	43.6	42.8	21714.69
7	0.860	42.8	41.2	31667.25
8	0.900	41.2	40.4	23071.85
9	2.220	40.4	39.2	45012.74

3.1 ANALYSIS OF VARIANCE

The influence of the three cutting parameters, that is, the cutting speed, feed rate and depth of cut are evaluated using ANOVA and with the help of MINITAB 17 statistical software. ANOVA was used in the study to identify the significance factors as it affects the surface roughness and material removal rate. The cutting process parameters and their levels of significance are presented in Table 5. It can be seen that feed rate with 36.29% has the most significant effect on the surface roughness and closely followed by the depth of cut with 32.60% . While cutting speed has the least significant effect with 25.58%..

TABLE 5: ANOVA FOR SURFACE ROUGHNESS

Factor	DOF	SS	MS	F	P
Cutting speed (rpm)	2	0.75	0.375	4.66	25.58
Feed rate (mm/rev)	2	1.064	0.532	6.57	36.29
Depth of cut (mm)	2	0.9558	0.4779	5.9	32.60
Error	2	0.162	0.081		5.526
Total	8	2.9318	0.366475		100

For the MRR, Table 6 shows the ANOVA result, it is observed that cutting speed with 49.29% has the most significant effect on the MRR and followed by depth of cut with 23.24% and the least significant effect is feed rate, which has a 19.66%.

TABLE 6: ANOVA FOR MRR

Factor	DOF	SS	MS	F	P
Cutting speed (rpm)	2	523762084	2.62E+08	6.32	49.29
Feed rate (mm/rev)	2	208932143	1.04E+08	2.52	19.66
Depth of cut (mm)	2	246972813	1.23E+08	2.97	23.24
Error	2	82877132	41438566		7.79
Total	8	1062544172	1.33E+08		100

The analysis of variance for both surface roughness and MRR shows that the percentage errors are within acceptable level.

4 CONCLUSION

The analysis of variance shows the amount of percentage that each cutting parameters contribute to both surface roughness and MRR. The following conclusions can be drawn from the results for surface roughness and MRR.

1. Analysis of variance shows that feed rate has the most significant effect on surface roughness with 36.29%, followed closely by depth of cut with 32.60% and while cutting speed has the least effect with 25.58%.
2. Analysis of variance for MRR showed that cutting speed with 49.29% has the most significant effect, while the contributions of depth of cut and feed rate were 23.24% and 19.66% respectively.

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