Effect Of Dry Cutting System On Surface Finish In Turning Operation Of Al-Si Alloy

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***Abstract*—The effects of dry cutting system, on surface roughness of aluminum alloy machined using face turning operation were investigated in this research work. The numbers of runs of experiment was determined using Taguchi's approach to design of experiment. Cutting speed, feed rate and depth of cut were the three significant factors taken as machining parameters at three levels. The experiment was designed and carried out using standard L_{27} Taguchi's orthogonal array, which leads to twenty-seven runs of experiments. The analysis of variance (ANOVA), signal-to-noise (S/N) ratio are employed to find the optimal levels and analyze the effect of cutting parameters. At the end of the experiment, it was found that the optimum setting of the control factors by main effects plots was found to be first level of speed (350 m/min), first level of Feed (0.200mm/rev), and first level of Depth of cut (0.2mm). It was further found that the ideal conditions for least surface roughness (R_a) are speed at level 2 (470 m/min), feed at level 2 (0.225 mm/rev), and depth of cut at level 3 (0.6 mm).**

Keywords—surface roughness, dry cutting, s/n ratio, main effects plot, cutting speed, feed rate, depth of cut.

1.0INTRODUCTION

Aluminium alloys are among the most commonly used lightweight metallic materials which possess attractive mechanical and thermal properties. Machinability of this material possesses relative easiness compared to other metals. Machinability quantifies the machining performance which can be defined by various criteria such as tool life, surface finish, material removal rate and power consumption (V. Songmene et. al. (2011), etc. Pure aluminium possess relatively low mechanical properties, which are improved by alloying the metal with other metals such as copper, manganese, silicon, magnesium, zinc, etc. Aluminium with silicon as major constituent found its application in casting several components.

According to Madic, et al. (2013), the demand for high quality and fully automated production focuses attention on the surface condition of the machined product, especial the roughness of the machined surface because of its effect on product appearance, function, and reliability. For this reasons it is important to maintain consistent tolerances and surface finish. Also, the quality of the machined surface is useful in diagnosing the stability of the machining process, where a deteriorating surface finish may indicate work piece material non-homogeneity, progressive tool wear, and cutting tool chatter Kumar and Packiaraj (2012). Surface roughness is an essential attribute used to determine and evaluate the quality of a turned product. However, the study and optimization of surface roughness is not as easy as determining any other variable. The study of surface Roughness is harder to achieve as it depends on both controllable and uncontrollable factors. The controllable variables include tool rake angle, feed rate, spindle speed, depth of cut etc. while wearing of tool, material friction, tool degradation etc. factors are much harder to control. Surface roughness of a machined product could affect several of the product's features such as surface friction, wearing, light reflection, heat transmission, ability of distributing and holding a lubricant, coating and resisting fatigue Agrawal et al. (2015). Hence, achieving optimal roughness response has become crucial for industries to improve their quality and merit. Identifying the most influential parameter allows proper selection of tool material that prolongs the life of tool and minimizes the surface roughness.

Adedeji et al. (2020) worked on modelling and simulation of orthogonal metal cutting of Aluminium 6061-T6 using ANSYS 19.2 software to investigate the effects of depth of cut, cutting speed and tool rake face angle on cutting variables such as cutting forces, chip morphology, temperature and stress distributions using the Johnson-Cook and Johnson-Cook damage models.

Prajwalkumar et al. (2015), observed and analyzed the effect of cutting parameters on the surface roughness and hardness. Taguchi method was analyzed by the authors in the optimization of cutting parameters. L9 orthogonal array was employed to carry out the analysis. The analysis of means (ANOM) and Analysis of variance (ANOVA) were carried out to determine the optimal parameters level and obtain level of importance of each parameter. From the ANOVA, the feed had maximum significance in case of Ra and Rz. Murat Sarikaya et al. (2014), used Taguchi design and Response Surface Methodology (RSM) Technique under Minimum Quantity Lubrication (MQL) for analyzing CNC turning parameters. The results were analyzed using 3D surface graphs, signal to noise ratios and main effect graphs of means. Also mathematical model output showed that the developed RSM model was statistically significant and suitable for all the cutting conditions because of higher R2 value. In modern manufacturing industries related to turning process, controlling and optimization of surface quality and material removal rate (MMR) are the most important performance and quality measures which are considered as the main response (Moshat et al., 2010). The main objective of this research is to carry out experimental research on the effect of cutting parameters on the surface roughness of Al-Si alloy using dry cutting system using Taguchi Design of Experiment (DOE).

1.1Design of Experiment (Taguchi Method)

Due to complexity of classical experimental design methods. This experiments have been carried out using Taguchi's L_{27} Orthogonal Array (OA) experimental design which consists of 27 combinations of spindle speed, longitudinal feed, and depth of cut to solve this problem. This method employs a generic signal-to-noise (S/N) ratio to quantify the present variation. The signal-to-noise (S/N) ratio is a statistical measure of performance which gives the ratio of the quality characteristics or mean (signal) to the signal variation or standard deviation (noise).

This ratios depends on the quality characteristics of the product or process to be optimized. Depending on the particular type of characteristics involved, different S/N ratios may be used, including "smaller is better" (LB), "nominal is best" (NB), and "larger is better" (HB).

2.0MATERIALS AND METHODS

2.1Work piece Material

Al-Si aluminium alloy was selected as the work material. It is one of the most extensively used of the 4000 series aluminum alloys. The presence of silicon as its major element makes it one of the most versatile of the heat-treatable alloys popular for casting. Silicon is good in metallic alloys used for casting. Silicon increases the fluidity of the melt, reduces the melting temperature, decrease the contraction associated with solidification and is very cheap as a raw material. Al-Si aluminum alloy are noted for their unique combination of desirable properties such as excellent castability, low density, good pressure tightness and other mechanical properties Barrie at al. (2016). Applications range from engine block, cylinder heads, components to machinery and equipment applications to recreation products and consumer durables. It is widely used for producing automotive components by turning process.

Table 1: Chemical composition (wt %) of Al-Si specimen

Element	Base Metal	Si	Ca	Mg	Cu	Zn Tn	Fe	Na	Mn
Percentage composition	89.79	8.23	1.24	0.38	<0.001	0.01 0.14	0.18	0.01	0.01

Fig.1 displays the photograph of sample specimens of Al-Si aluminium alloy as taken in the machine shop of Lagos State Polytechnic, Nigeria. It displays the first nine sample.

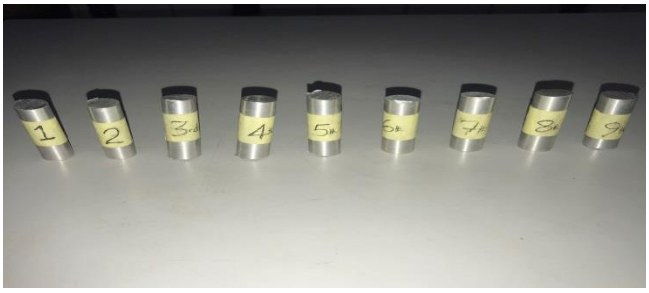

Fig.1 Photograph of sample specimen of Al-Si Aluminium Alloy.

Experimental area

The experiment was conducted in the machine workshop of Mechanical Engineering Department, Lagos State University Epe Campus and Lagos State Polytechnic Ikorodu, South West Region of Nigeria.

Equipment and materials required for the study

The materials used for this research work are Colchester 2000 lathe machine with rated power of 28kVA, High Speed Steel (HSS) cutting tools, hacksaw, Vernier caliper, meter rule, Aluminum-Silicon (Al-Si) alloy, TMR 120 surface roughness tester, The purchase of Al-Si aluminium alloy was done at available market within Nigeria precisely from Owode Onirin market, Lagos.

Description of Cutting Tool Material

HSS cutting tool was used for this experiment. Tool machining is the radical process of friction and wear. Tool wear during cutting not only decreases the service life of cutting tools, but also leads to increased roughness of the cutting surfaces of workpieces (Zhang MZ et al 2001). There are a number of classes of high carbon contents (ranging from 0.8 wt.% to > 3 wt.%), chromium levels of about 4 wt.%. The composition of the HSS used in this research is shown in the table below.

Table 2: Alloy composition of the HSS cutting tool

HSS elemental composition	% composition
Tungsten	18 %
Chromium	4 %
Vanadium	1 %
Carbon	0.7 %
Iron	Remained

Experimental Flow chart

The flow chart shown below is a summary of experimental methods, sequence of operation, equipment and materials required and the results of the experimental research.

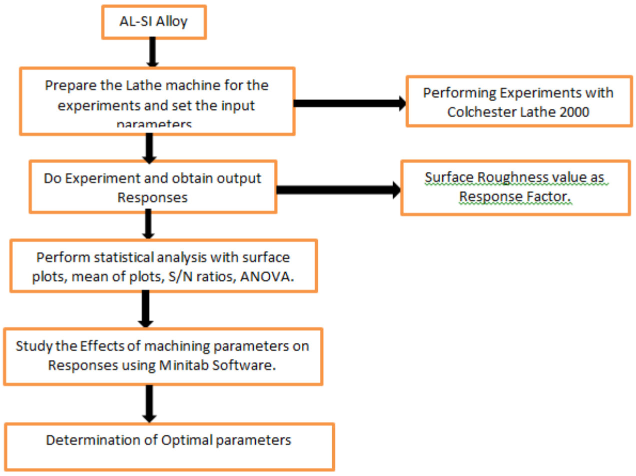

Fig. 2 Flow chart showing optimization methodology for the dry cutting.

Experimental Plan

The experimental work was carried out on Conventional lathe machine, Colchester 2000 as shown in Fig. 2. The surface roughness of the machined work piece has been measured by a Surface Roughness measuring instrument Talysurf TMR 120. TMR 120 is a self contained, portable instrument for the measurement of surface texture and it is suitable for use in both the workshop and laboratory. The parameter used for surface texture evaluation is average roughness (Ra). Ra is the arithmetic average of absolute roughness profile ordinates. The functions and other parameter evaluations of the instrument are microprocessor based Ranganath et al. (2014).

Fig.2 **Colchester lathe 2000**

Experimentation and Analysis

A lathe machine Colchester 2000 with rated power of 28kVA was used for the machining trial and for all the experimental works. The Lathe was checked and prepared ready for performing the machining operations. The Al-Si aluminium rod was cut by hacksaw and initial turning operation was performed on the lathe to get desired dimension of the workpieces (length–50mm; diameter–20mm). Twenty seven numbers of samples of same material and same dimension have been made. The length of each specimen is 50mm and has a diameter of 20mm. Weight of each specimen was measured by the high precision digital balance meter before machining. Straight turning operation was performed on the specimens in various cutting environments involving various combinations of process control parameters like: cutting speed (350, 470 and 625 m/min), feed (0.2, 0.225, and 0.25 mm/rev) and depth of cut (0.2, 0.4, and 0.6 mm). After machining the surface roughness of the work piece at different cutting conditions were measured using TMR 120 surface roughness tester.

Process parameters and their levels

Table 3: Process Parameter Levels

Process Variable	Unit	Level 1	Level 2	Level 3
Cutting Speed	m/min.	350	470	625
Feed rate	mm/rev.	0.2	0.225	0.25
Depth of cut	mm	0.2	0.4	0.6

3.0RESULTS AND DISCUSSIONS

MINITAB 16 software was used to perform the experimental design and explore to analyze the main effects of plots, signal to noise (S/N) ratio, regression, mean and ANOVA in order to achieve the optimization analysis for surface roughness. These experimental results were explored in the determination of direct effect of each of the machining parameters on the response.

Regression analysis

It is used to investigate and model the relationship between a response variable and one or more predictors. Minitab provides least square, partial least square, and logistic regression procedures.

Table 4: Table of Results

Experiment no.	Cutting Speed (m/min)	Feed rate (mm/rev)	Depth of cut (mm)	Ra (µm)
1	350	0.2	0.2	0.50
2	350	0.2	0.2	0.52
3	350	0.2	0.2	0.55
4	350	0.225	0.4	1.85
5	350	0.225	0.4	1.89
6	350	0.225	0.4	1.82
7	350	0.25	0.6	1.31
8	350	0.25	0.6	1.32
9	350	0.25	0.6	1.30
10	470	0.2	0.4	1.43
11	470	0.2	0.4	1.40
12	470	0.2	0.4	1.42
13	470	0.225	0.6	2.65
14	470	0.225	0.6	2.77
15	470	0.225	0.6	2.87
16	470	0.25	0.2	1.90
17	470	0.25	0.2	1.75
18	470	0.25	0.2	1.62
19	625	0.2	0.6	1.60
20	625	0.2	0.6	1.65
21	625	0.2	0.6	1.80
22	625	0.225	0.2	1.69
23	625	0.225	0.2	1.59
24	625	0.225	0.2	1.40
25	625	0.25	0.4	1.70
26	625	0.25	0.4	1.84
27	625	0.25	0.4	1.74

Main Effect Plots for Means

The main effect plot for means is shown in fig.4 below. They show the variation of response with the parameters considered i.e. speed, feed rate and depth of cut. The plots x-axis represents the value of each process parameter and y-axis is the response value. Horizontal line indicates the mean of the response. The main effect plots are used to determine the optimal design conditions to obtain the minimum or optimal surface finish. It is evident from Fig.4 that R_a is minimum at the first level of speed (350 m/min), first level of Feed (0.200mm/rev), and first level of Depth of cut (0.2mm). Summarily, we can depict from the graph below that main effect exists between the three machining variables (cutting speed, feed rate and depth of cut) and the surface roughness. Both cutting speed, feed rate and depth of cut exhibited similar main effect characteristics on surface roughness.

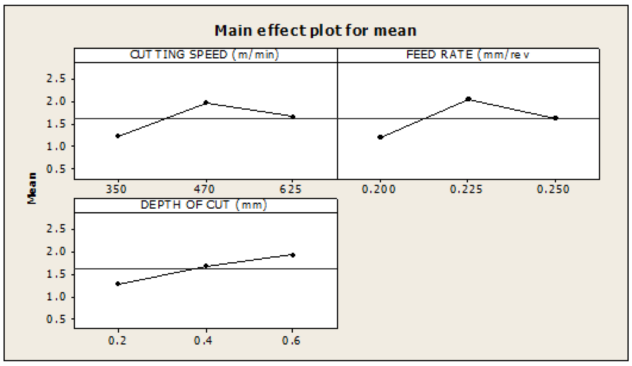

Fig.4 Main Effects Plot for means

Main Effect Plots for S/N ratio

The main effect plot for signal-to-Noise (S/N) ratio is shown in figure 5 below. The main objective of using the S/N ratio as a measure of performance is simply to develop products and the processes insensitive to variance factors known as noise Devesh and Singh (2015). Every experiment is aimed at determining the highest S/N ratio possible for the experimental results. Process parameters setting with the highest S/N ratio always yield the optimum quality with minimum variance. Minitab creates the main effects plot by plotting the means for each variable parameters. A line connects the points for each variable, the x-axis indicates the factor while the y-axis indicates the response. In the plots, the X-axis indicates the value of each process parameter, and the Y-axis indicates the response value. Horizontal lines indicate the mean value of the response. The main effect plots are used to determine optimal design conditions, to obtain optimum material removal rate. Consequently, we can say that the level with larger S/N is the optimum level of each factor. From Fig.5 level two for speed (470 m/min) has maximum S/N ratio value, which defines that the machining performance at such level gives minimum variation of the surface roughness. Hence, as indicated by main effect plots for S/N ratio, the ideal conditions for least surface roughness (R_a) are speed at level 2 (470 m/min), feed at level 2 (0.225 mm/rev), and depth of cut at level 3 (0.6 mm).

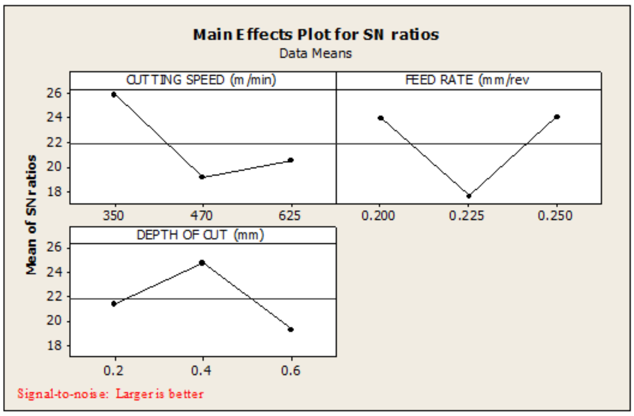

Fig. 5: Main effects plots for signal-to-noise (S/N) ratio

Main effect plot analysis for signal-to-noise (S/N) ratio and Surface roughness

Process parameters	Level	Response Value
Cutting speed	1	350 m/min)
Feed rate	1	(0.200 mm/rev)
Depth of cut	1	(0.2 mm)

Table 5: Response Table for Signal to Noise Ratios (Larger is better)

Dynamic Response

Level	Cutting Speed (m/min.)	Feed rate (mm/rev.)	Depth of cut (mm)
1	25.85	23.95	21.42
2	19.21	17.61	24.83
3	20.52	24.03	19.33
Delta	6.64	6.42	5.49
Rank	1	2	3

Regression Analysis (Ra) versus cutting speed, feed rate and depth of cut.

Ra = - 1.50 + 0.00142 Speed + 8.02 Feed rate + 1.60 Depth of cut.

Table 6.

Predictor	Coef SE	Coef	T	P
Constant	-1.505	1.101	-1.37	0.185
Cutting speed	0.0014246	0.0008074	1.76	0.091
Feed rate	8.022	4.453	1.80	0.085
Depth of cut	1.5972	0.5566	2.87	0.009

Table 6.S = 0.472298 R-Sq = 38.8% R-Sq(adj) = 30.8%

Analysis of Variance

Source	df	ss	Ms	F	P
Regression	3	9587.60	3195.87	116.323	0.0000000
Residual error	23	386.73	386.73	14.076	0.0010398
Total	26	4637.85	4637.85	168.808	_

Table 7

Sequential sum of squares

Source	Df	Seq ss
Speed	1	386.7
Feed	1	4637.9
DOC	1	4563.0

Table 8

3.6.1Unusual Observation

Observation	Speed	Ra	Fit	SE fit	Residual	St resid
15	470	2.87	1.9280	0.1440	0.9420	2.09R

Table 9.R denotes observation with large standardized residual

Residual plot for surface roughness

The diagnostic checking has been performed through residual analysis for the developed model. The Residual plots for surface roughness are shown in Fig.6. These fall on a straight line implying that errors are distributed normally. From Fig.6 it can be further concluded that all the values are within the control range, indicating that there is no obvious pattern and unusual structure and also the residual analysis does not indicate any model inadequacy.

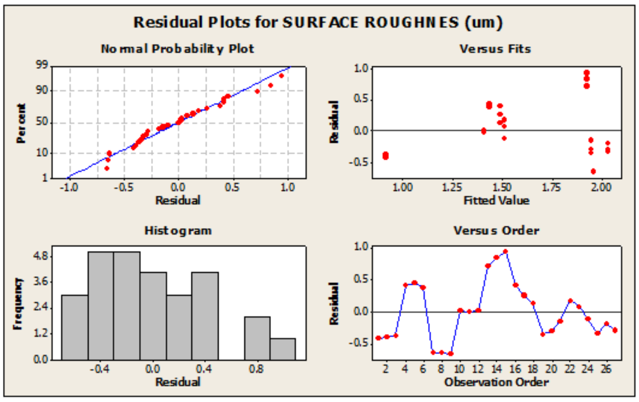

Fig. 6: Residual plots for surface roughness

4.0CONCLUSION

The regression model is;

Ra = - 1.50 + 0.00142 Speed + 8.02 Feed rate + 1.60 Depth of cut.

This implies that the depth of cut showed a very weak regression coefficient for surface roughness while both cutting speed and feed rate showed a very strong regression against surface roughness.

In this research we present a way to Optimize cutting and cutting tool parameters as well as cutting tool parameters during turning operation of Al-Si alloy. The optimum setting of the control factors by main effects plots was found to be first level of speed (350 m/min), first level of Feed (0.200mm/rev), and first level of Depth of cut (0.2mm). This result is ideal when the prime requirement is to minimize surface roughness while machining Aluminum-Silicon alloy. As indicated by main effect plots for S/N ratio, the ideal conditions for least surface roughness (R_a) are speed at level 2 (470 m/min), feed at level 2 (0.225 mm/rev), and depth of cut at level 3 (0.6 mm). Taguchi Design of Experiment ensures a systematic, efficient and quality method for evaluating optimum operating conditions of an experiment. The research can be extended to more number of responses for further increment in operational efficiency.

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