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Investigation of optimal parameters in turning of AL-Mn Alloy under soluble oil cutting fluid

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ABSTRACT

This paper investigates the optimal parameters in turning of aluminium manganese alloy under soluble oil as cutting fluid using Taguchi method. The three process parameters considered in this work are spindle speed, feed rate and depth of cut. Orthogonal arrays, the signal-to-noise (S/N) ratio and the analysis of variance (ANOVA) were employed to find the optimal process parameter levels and to analyze the effect of these parameters on surface roughness and tool-tip temperature. Confirmation test with the optimal levels of machining parameters were carried out in order to illustrate the efficiency of the Taguchi optimization method. Taguchi method has shown that the spindle speed has significant role to play in producing best surface quality about 60% followed by feed rate about 33.4% while the depth of cut has least role to play on surface roughness about 20%. For tool-tip temperature, the Taguchi method shown that the spindle speed has significant role in producing lowest tool-tip temperature about 72.2% followed by feed rate about 21.6% while the depth of cut has least role to play on tool-tip temperature.

Keywords: Surface roughness; Tool tip temperature; Soluble oil; Taguchi method

Abbreviation: ANOVA- Analysis of variance; Al-Mn alloy- Aluminium Managenese Alloy

1. INTRODUCTION

Surface roughness is a measure of the finely spaced surface irregularity. In engineering, it is usually called “Surface finish” (Degarmo, et al. 2003). The quality of surface finish in machining operation is an important prerequisite of workpiece and others cutting parameter such as spindle speed, feed rate and depth of cut, etc. in the manufacturing industrials. During machining, tool wear is a normal things that occurred which may tend to tool failure. High cutting temperature is been generated due to the deformation that took place during cutting at the interface between the tool face and workpiece. This reduces the surface quality and tool life of the workpiece material. The application of coolant is to reduce the friction at the tool-workpiece and to produce a good surface quality. Al-Mn 3xxx alloy is one of the most important of aluminium strain hardened alloys. Due to his excellent mechanical properties, they have several applications, such as textiles, cookware, food processing, construction elements, automotive products, panels for refrigerators and heat exchangers (Flores, et al. 2012). The Aluminium manganese 3003 alloy was used for this work because it is one of the most popular alloys in this group, which has good formability, very good resistance to corrosion, and good weldability (Avner, (1974).

Basim, et al. (2011) investigated the effect of cutting speed, feed and depth of cut on surface roughness when machining nickel based hastelloy 276. They found that the good surface finish is obtain with higher cutting speed, minimum feed rate, and lower depth of cut.

Nalbant et al. (2007) conducted experiments to study the application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. TiN coated tool and AISI 1030 steel were used as workpiece. Three parameters insert radius, feed rate and depth of cut are being optimized. The result suggested that the insert radius and feed rate are the main convenient parameters which affect surface roughness more in turning AISI 1030 carbon steel.

Kaladhar, et al. (2011) studied the effects of process parameters on surface finish and material removal rate (MRR) to obtain the optimal setting of these process parameters using AISI Stainless steel workpiece. It have been found that the feed and nose radius is the most significant process parameters on workpiece surface roughness while the depth of cut and feed rate are the significant factors on MRR.

It is found that no work has been reported in the literature on optimization of cutting parameters in turning of Al-Mn 3003 Alloy to reduce surface roughness and tool-tip temperature under soluble oil using Taguchi’s approach.

2. MATERIALS AND METHODS

2.1. Machine and Cutting Tool

Experiments were carried out on a lathe machines XL 400 with spindle speeds ranging from 45 – 2000rpm, feed rate ranging from 0.07-8.400mm/rev and depth of cut ranging from 0.00281-3.421mm. Uncoated carbide inserts tool SNMG 120408-QM H13A were clamped onto a tool holder with a designation of DBSNR 2020K were used for the work.

2.2. Workpiece Material

The material used in this work is Aluminium manganese 3003 alloy with 45mm length and 350mm diameter. The chemical composition of Al-Mn 3003 alloy is shown in Table 1 was carried out at National Geosciences Research Laboratory (NGRL), Kaduna. Nine experiments were carried out accordingly in Taguchi’s L9 orthogonal array. Soluble oil Cutting fluid was used in the work which was kept constant throughout the experiment.

Table 1 Chemical composition of aluminium-manganese 3003 alloy (workpiece)

Chemical composition	Al	Ca	Ti	Cr	Mn	Fe	Cu	Te	Hf
Wt%	93.4%	0.1%	0.79%	0.94%	2.03%	1.52%	0.06%	0.92%	0.1%

Source: National Geosciences Research Laboratory (NGRL), Kaduna.

Table 2 Cutting Process Variables

Level Number	Spindle Speed (rev/min)	Feed Rate (mm/rev)	Depth of Cut (mm)
-1	250	1.05	0.5
0	355	1.52	1.0
1	500	2.10	1.5

2.3. Experimental procedure

Investigation of optimal parameter in turning of aluminium manganese 3003 alloy using carbide insert as a cutting tool to carried out the turning process. A lathe XL 400 was used for the machining experiments under soluble oil cutting fluid. The work-piece was pre-machined at 1mm thickness prior to the actual turning as to remove any rusted layer in order to minimize the degree of in homogeneity on the experimental results. The experimental work was conducted under three levels of spindle speed, feed rate and depth of cut as shown in Table 2.

The turning of the Al-Mn alloy was performed at three different spindle speeds of 250rpm, 355rpm and 500rpm. The feed rates were 1.05, 1.52 and 2.10mm/rev. The depths of cut used for turning were 0.5, 1.0, and 1.5mm. The surface roughness of the machined workpiece was measured using a surface roughness tester ISR-16. The surface roughness measurements were repeated three times, the average value of surface roughness, Ra to each machining conditions were used. The tool-tip temperature was measured using infrared thermometer (KM 690) for any pass at the tool tip and workpiece interface. The tool-tip temperature measurements were repeated three times, the average value of tool tip temperature. To each machining conditions were taken.

2.4. Taguchi method

Taguchi's method is a unique and powerful statistical experimental design technique, which greatly improves the engineering productivity (Ross, 1996). Taguchi's approach saves the effort in carrying out experiments and realizing significant factor quickly, reducing the cost and saving of experimental time. Taguchi categorizes the objective functions into three as smaller the better type, larger the better type and nominal the best type characteristics, smaller the better characteristic is selected and is given as equation 1.

$$S/N = -10\log_{10} \left(\sum \frac{y^2}{n}\right) \quad (1)$$

Where y is the response of the machining characteristic and n is the number of responses calculated in a row. The S/N ratio is useful for the enhancement of quality through inconsistency reduction and the improvement of measurement.

3. RESULT AND DISCUSSION

3.1. Analysis of Signal-to-Noise (S/N) Ratio on Surface Roughness

Surface roughness is the important parameter in machining of Aluminium manganese alloy 3003. In this work nine experiments were performed at different parameters (spindle speed, feed rate and depth of cut). For this Taguchi L9 orthogonal array was used, which has nine rows corresponding to the number of machining carried out, with three columns at three levels. Taguchi's L9 orthogonal array has eight degree of freedom (DOF), in which 6 were assigned to three factors such as spindle speed, feed rate and depth of cut (each one as 2) and two (2) degree of freedom was assigned to the error. From Table 3, the S/N ratio for each level of the other process parameters can be computed in the similar manner. The greater S/N ratio corresponds to the smaller variance of the output characteristic around the desired value. The mean S/N ratio for each level of the process parameters is summarized which is called the response table for S/N ratios for surface roughness is shown in Table 4. Minitab 16 allocates ranks based on the delta values; rank 1 to the highest delta value, shows that the spindle speed has the strongest effect on surface roughness, second highest (rank 2) which is feed rate and lastly is the depth of cut (rank 3). Based on the analysis of the S/N ratio, the optimal machining performance for the surface roughness was obtained at 355rpm spindle speed (level 2); 1.05mm/rev feed rate (level 1) and 0.5mm depth of cut (level 1).

Table 3 Experiment layout, results and S/N ratios for the average surface roughness

S/N	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Average surface roughness R_a (µm)	S/N Ratio (dB)
1	250	1.05	0.5	2.463	-7.82929
2	250	1.52	1.0	2.683	-8.57241
3	250	2.10	1.5	2.773	-8.85900
4	355	1.05	1.0	2.465	-7.83634
5	355	1.52	1.5	2.553	-8.14102
6	355	2.10	0.5	2.612	-8.33946
7	500	1.05	1.5	2.734	-8.73597
8	500	1.52	0.5	2.846	-9.08470
9	500	2.10	1.0	2.857	-9.11820

Table 4 Response Table for S/N Ratios for Surface Roughness Smaller is better

Level	Spindle speed, A (rpm)	Feed rate, B (mm/rev)	Depth of cut, C (mm)
1	-8.420	-8.134*	-8.418*
2	-8.106*	-8.599	-8.509
3	-8.980	-8.772	-8.579
Max-Min	0.874	0.638	0.161
Rank	1	2	3

* Optimum level

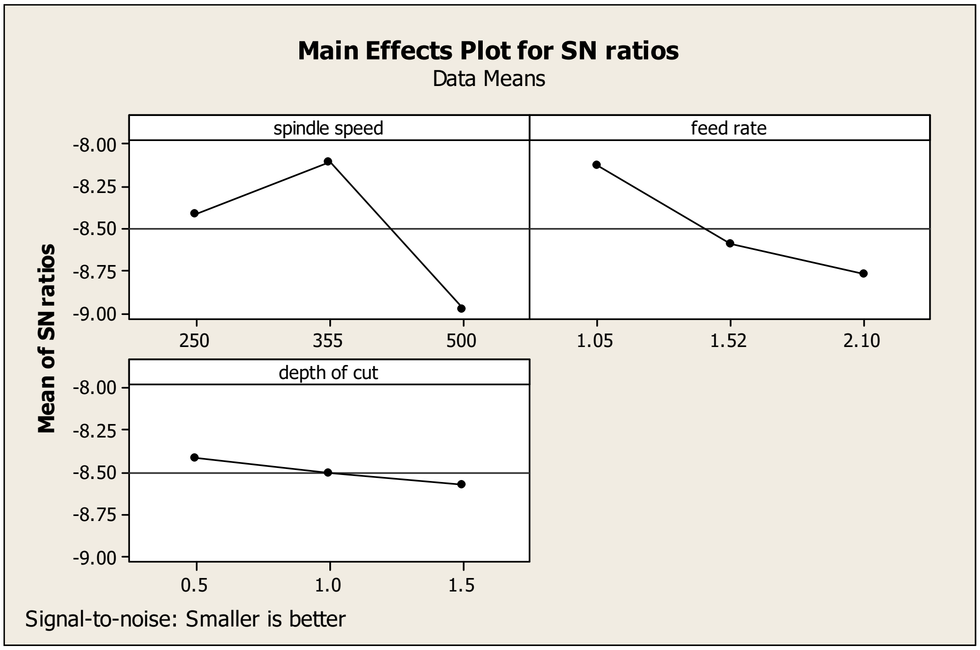

Figure 1 Main effect plots for surface roughness (S/N ratio)

3.2. Mean Effect on the Surface Roughness

Fig. 1 shows the main effect plots for surface roughness of the aluminium manganese alloy 3003 for S/N ratios. The greater is the S/N ratio, the smaller is the variance of the surface roughness around the desired value. It is easy to determine the optimal testing conditions of these control factors from the response graph. The best surface quality value was at the highest S/N value in the response graph. The optimum condition for the machined sample is spindle speed (355rpm), feed rate (1.05mm/rev) and depth of cut (0.5mm).

3.3. Analysis of Variance (ANOVA)

Analysis of variance is a method of portioning variability into identifiable sources of variation and the associated degree of freedom in an experiment. Analysis of variance (ANOVA) was carried out to study the effect of cutting fluid (soluble oil) and cutting parameters on the surface roughness. The frequency test (F-test) is utilized in statistics to analyze the significant effects of the parameters, which form the quality characteristics. Table 5 shows the result of ANOVA analysis of S/N ratio for surface roughness. This analysis was carried out for a level of significance of 0.05 value at 95% confidence level. The last column of the table shows the "percent" contribution (P) of each factor as the total variation, indicating its influence on the result.

From the analysis of Table 5, the ANOVA result shows that the F-values of spindle speed and feed rate were greater than $F_{0.05,2.26} = 3.146$ except F-values of depth of cut means is not significant.

Spindle speed emerges as the most significant (with a p value 0.071) with percentage contribution of 60% to the surface quality followed by feed rate of percentage contribution of 33.4% (p value 0.121) while depth of cut has the least percentage contribution of 2.0% (p value 0.697).

Table 5 ANOVA Table of surface roughness for SN ratios

Source	Degrees of freedom	Sum of squares	Mean squares	F	P	Contribution %
Spindle speed (rpm)	2	1.17582	0.58791	13.09	0.071	60.0
Feed rate (mm/rev)	2	0.65407	0.32704	7.28	0.121	33.4
Depth of cut (mm)	2	0.03904	0.01952	0.43	0.697	2.0
Error	2	0.08984	0.04492			4.6
Total	8	1.95877				100

S = 0.211941   R-Sq = 95.41%   R-Sq(adj) = 81.65%

Table 6 Confirmation result

1	2	3	Average surface roughness, Ra (µm)	S/N ratio (dB)
2.387	2.446	2.459	2.431	-7.716

Table 7 comparison of S/N ratios

$\eta_{predicted}$ (dB)	-7.654
$H_{confirmation}$ (dB)	-7.716

3.4. Estimating Optimal Surface Roughness

Optimal surface roughness is predicted at the already selected optimal levels of process parameters from Table 4 such as A_2, B_1, C_1. Additive model was used to predict the S/N ratio of the optimum condition as shown in equation 2:

Predicted S/N ratio = $\bar{\bar{Y}} + (A_2 - \bar{\bar{Y}}) + (B_1 - \bar{\bar{Y}}) + (C_1 - \bar{\bar{Y}})$ (2)

$= A_2 + B_1 + C_1 - 2\bar{\bar{Y}}$

$= -8.106 + -8.134 + -8.418 - (2 \times -8.502)$

= -7.654dB

Where $\bar{\bar{Y}}$ is overall mean of the surface roughness (S/N ratio) = -8.502dB; A_2, B_1, C_1 are the average values of the surface roughness (S/N ratio) with parameters at optimal level from Table 4: $A_2 = -8.106\text{dB}$, $B_1 = -8.134\text{dB}$, $C_1 = -8.418\text{dB}$

3.5. Verification

Confirmation test can be used to verify the predicted response. This involves using the same experimental setup and the optimal combination of controlled parameters (spindle speed (355rpm), feed rate (1.05rev/mm), depth of cut (0.5mm)) to create a sample for measurement and compare it to the predicted response as shown in Table 6 and 7. It is discovered that S/N ratio value of the confirmation test is within the range of the acceptable limit of the predicted.

A confidence interval (CI) for the prediction of the confirmation run can be calculated using the equation 3

CI = $\sqrt{\frac{F_{\propto(1,f_e)} \cdot V_e}{\eta_e}}$ (3)

Where F_α (1, fe) = F ratio required for α; α= risk, using the value f_e= error DOF = 2; Ve is the error variance = 0.04492 from table 5, from F distribution table, $F_{0.05}$ (1, 2) = 18.51

$\eta_e = \frac{N}{1+V}$; where η_e is the effective number of replications, N is the total number of the experiments = 9, V is the total degree of freedom associated in the estimate of mean = 3

$\eta_e = \frac{9}{1+3} = 2.25$

CI = $\sqrt{\frac{18.51 \times 0.04492}{2.25}}$

CI = ±0.608dB

The predicted optimal of Ra at 95% confidence level is: $(-7.654 - 0.608) \leq \bar{\bar{Y}}_{\min} \leq (-7.654 + 0.608)$

$-8.262 \leq \bar{\bar{Y}}_{\min} \leq -7.046$

Since the prediction error was within confidence interval (95%) value of the predicted optimal surface roughness has been validated.

3.6. Mathematical Models and Confirmation Test for Surface Roughness

The experimental results are used to obtain the mathematical relationship between process parameters (spindle speed (A), feed rate (B) and depth of cut (C)) and surface roughness. The coefficients of mathematical models were obtained by multiple linear regressions. The statistical software package MINITAB 16 was used for the regression analysis.

The regression equation is

Ra = -6.50333- 0.00247006*A - 0.596044*B - 0.160845*C (4)

The high correlation coefficients (R^2) indicate the suitability of the function (model) and the correctness of the calculated constants.

3.7. Analysis of Signal-to-Noise (S/N) Ratio for Tool-tip Temperature

Table 8 shows the experiment layout, results and S/N ratios for the average tool-tip temperature. The greater S/N ratio corresponds to the smaller variance of the output characteristic around the desired value. The mean S/N ratio for each level of the process parameters is summarized which called the response table for S/N Ratios for tool-tip temperature is shown in Table 9. Minitab 16 allocates ranks based on the delta values; rank 1 to the highest delta value, shows that the spindle speed has the strongest effect on tool-tip temperature, second highest (rank 2) which is feed rate and lastly is the depth of cut (rank 3). Based on the analysis of the S/N ratio, the optimal machining performance for the tool-tip temperature was obtained at 250rpm spindle speed (level 1); 1.05mm/rev feed rate (level 1) and 1.0mm depth of cut (level 2).

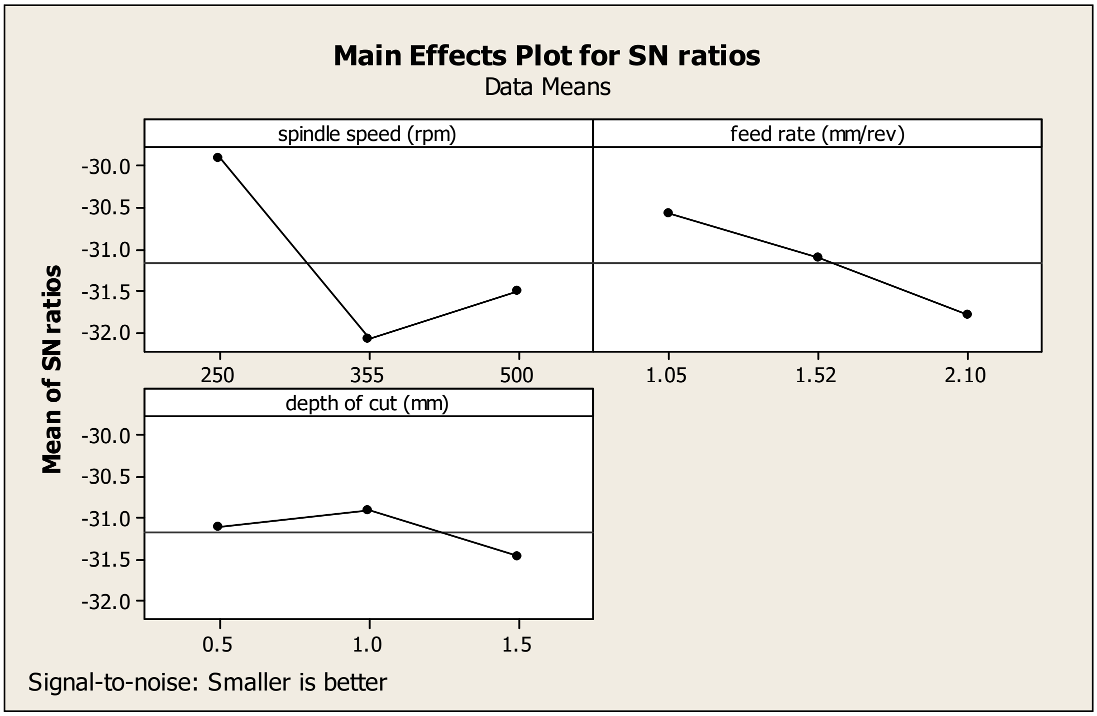

Figure 2 Main effect plots for tool-tip temperature (S/N ratio)

Table 8 Experiment layout, results and S/N ratios for the average tool-tip temperature

S/N	Spindle speed (rpm)	Feed rate (mm/rev)	Depth of cut (mm)	Average measured tool-tip temperature	S/N Ratio (dB)
1	250	1.05	0.5	29.67	-29.4464
2	250	1.52	1.0	30.20	-29.6001
3	250	2.10	1.5	34.20	-30.6805
4	355	1.05	1.0	35.80	-31.0777
5	355	1.52	1.5	42.30	-32.5268
6	355	2.10	0.5	43.07	-32.6835
7	500	1.05	1.5	36.37	-31.2149
8	500	1.52	0.5	36.47	-31.2387
9	500	2.10	1.0	40.17	-32.0780

Table 9 Response Table for S/N Ratios for Tool-tip Temperature Smaller is better

Level	Spindle speed, A(rpm)	Feed rate, B(mm/rev)	Depth of cut, C (mm)
1	-29.91*	-30.58*	-31.12
2	-32.10	-31.12	-30.92*
3	-31.51	-31.81	-31.47
Max-Min	2.19	1.23	0.56
Rank	1	2	3

3.9. Mean Effect on the Tool-tip Temperature

Fig. 2 shows the main effect plots for tool-tip temperature during machining of aluminium manganese alloy 3003 using carbide tool under cutting fluid (soluble oil) for S/N ratios. The greater is the S/N ratio, the smaller is the variance of the tool-tip temperature around the desired value. It is easy to determine the optimal testing conditions of these control factors from the response graph. The best surface quality value was at the higher S/N value in the response graph. The optimum condition for the machined sample is spindle speed (250rpm), feed rate (1.05mm/rev) and depth of cut (1.0mm).

3.10. Analysis of Variance (ANOVA)

Analysis of variance is a method of portioning variability into identifiable sources of variation and the associated degree of freedom in an experiment. Analysis of variance (ANOVA) was carried out to study the effect of cutting fluid (soluble oil) and cutting parameters on the tool-tip temperature. The frequency test (F-test) is utilized in statistics to analyze the significant effects of the parameters, which form the quality characteristics. Table 10 shows the result of ANOVA analysis of S/N ratio for tool-tip temperature. This analysis was carried out for a level of significance of 0.05 value at 95% confidence level. The last column of the table shows the "percent" contribution (P) of each factor as the total variation, indicating its influence on the result.

From the analysis of Table 10, the ANOVA result shows that the F-values of spindle speed and feed rate were greater than $F_{0.05,2.26}$ = 3.146 except F-values of depth of cut means is not significant.

Spindle speed emerges as the most significant (with a p value 0.024) with percentage contribution of 72.2% to the surface quality followed by feed rate of percentage contribution of 21.6% (p value 0.075) while depth of cut has the least percentage contribution of 4.5% (p value 0.281).

Table 10 ANOVA Table of tool-tip temperature for SN ratios

Source	Degrees of freedom	Sum of squares	Mean squares	F	P	Contribution %
Spindle speed (rpm)	2	7.6906	3.8453	41.48	0.024	72.2
Feed rate (mm/rev)	2	2.2968	1.1484	12.39	0.075	21.6
Depth of cut (mm)	2	0.4736	0.2368	2.55	0.281	4.5
Error	2	0.1854	0.0927			1.7
Total	8	10.6464				100

S = 0.304468   R-Sq = 98.26%   R-Sq(adj) = 93.03%

3.11. Estimating Optimal Tool-tip Temperature

Optimal tool-tip temperature is predicted at the already selected optimal levels of process parameters at Table 9 such as A_1, B_1, C_2. Additive model was used to predict the S/N ratio of the optimum condition as shown in equation 5:

$$\text{Predicted S/N ratio} = \bar{\bar{Y}} + \left(A_1 - \bar{\bar{Y}}\right) + \left(B_1 - \bar{\bar{Y}}\right) + \left(C_2 - \bar{\bar{Y}}\right) \qquad (5)$$

$$= A_1 + B_1 + C_2 - 2\overline{\overline{Y}}$$

$$= -29.91 + -30.58 + -30.92 - (2 \times -31.172)$$

= -29.066dB

Where $\overline{\overline{Y}}$ is overall mean of the tool-tip temperature (S/N ratio) = -29.066dB; A_1, B_1, C_2 are the average values of the tool-tip temperature (S/N ratio) with parameter at optimal level from Table 4: $A_1 = -29.91\text{dB}$, $B_1 = -30.58\text{dB}$, $C_2 = -30.92\text{dB}$

3.12. Verification

Confirmation test can be used to verify the predicted response of the tool-tip temperature. This involves using the same experimental setup and the optimal combination of controlled parameters (spindle speed (250rpm), feed rate (1.05rev/mm), and depth of cut (1.0mm)) to create a sample for measurement and compare it to the predicted response as shown in Table 11 and 12. It is discovered that S/N ratio value of the confirmation test is within the range of the acceptable limit of the predicted.

A confidence interval (CI) for the prediction of the confirmation run can be calculated using the equation 6

$$\text{CI} = \sqrt{\frac{F_{\propto(1,f_e)} \cdot V_e}{\eta_e}} \qquad (6)$$

Where $F_\alpha(1, fe)$ = F ratio required for α; α= risk, using the value f_e= error DOF = 2; Ve is the error variance = 0.0927 from table 5, from F distribution table, $F_{0.05}(1, 2) = 18.51$

$\eta_e = \frac{N}{1+V}$; where η_e is the effective number of replications, N is the total number of the experiments = 9, V is the Total degree of freedom associated in the estimate of mean = 3

$$\eta_e = \frac{9}{1+3} = 2.25$$

$$\text{CI} = \sqrt{\frac{18.51 \times 0.0927}{2.25}}$$

CI = ±0.873dB

The predicted optimal of Ra at 95% confidence level is: $(-29.07 - 0.873) \leq \overline{\overline{Y}}_{\min} \leq (-29.07 + 0.873)$

$$-29.943 \leq \overline{\overline{Y}}_{\min} \leq -28.197$$

Since the prediction error was within confidence interval (95%) value of the predicted optimal tool-tip temperature has been validated.

Table 11 Confirmation result

1	2	3	Average surface roughness, Ra (µm)	S/N ratio (dB)
26.61	25.79	25.36	25.92	-28.27

Table 12 comparison of S/N ratios

$\eta_{predicted}$ (dB)	-29.07
$H_{confirmation}$ (dB)	-28.27

3.13. Mathematical Models and Confirmation Test for Tool-tip Temperature

The experimental results are used to obtain the mathematical relationship between process parameters (spindle speed (A), feed rate (B) and depth of cut (C)) and tool-tip temperature. The coefficients of mathematical models were obtained by multiple linear regressions. The statistical software package MINITAB 16 was used for the regression analysis.

The regression equation is

Tool-tip temperature (^{O}C) = -26.8659 - 0.00576549*A - 1.17629 *B - 0.351211 *C (7)

The high correlation coefficients (R^2) indicate the suitability of the function (model) and the correctness of the calculated constants.

4. CONCLUSION

The following conclusions are drawn based from the results obtained when turning of aluminium manganese 3003 alloy using carbide tool under soluble oil as cutting fluid.

1. The overall results indicate that spindle speed and feed rate have significant effect on the surface quality of turning of AL-Mn alloy.
2. ANOVA indicated that spindle speed has the most effective control factor on the surface roughness value on the machined surface, followed by feed rate while the depth of cut has the least effect at 95% of confidential level. The percentage contribution of spindle speed is 60%, feed rate is 33.4% and depth of cut is 20% on surface roughness.
3. Spindle speed has the greatest effect on too-tip temperature, followed by feed rate and lastly depth of cut.
4. ANOVA indicated that the spindle speed has the most significant effect on tool-tip temperature, followed by feed rate while depth of cut is the least at 95% of confidential level. The percentage contribution of spindle speed is 72.2%, feed rate iis 21.6% while depth of cut is 4.5%.

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