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ANALYSIS OF EFFECT OF CUTTING SPEED AND FEED RATE ON CUTTING FORCE DURING THE MACHINING OF 6061 ALUMINUM ALLOYS

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ABSTRACT
This study investigated the effects of the machining parameters, cutting speed, feed rate on main cutting force of 6061 aluminum alloys. The research also examined the effect of cutting parameters, on cutting force by the use of variance analysis (ANOVA). A confidence level of 95% was obtained between all the factors as presented according to the result of variance analysis. The important factor affecting cutting force was cutting speed with 75% significance contribution to the total variation on cutting force. Feed rate with 27.40% significance level has less significant contribution on cutting force. Aluminum Alloy 6061 was machined with tungsten carbide tool using all machining processes with a PATHER 1350 series, lathe machine. The cutting force was measured using cutting tool dynamometer. Two factors were used at three levels (3^2). The factors are cutting speed and feed rate. The experimental design was done using (Design-Expert7 software) full factorial experimental design. The geometry of the cutting tool was 5°, three different cutting speed 80m/min, 90m/min. 100m/min and feed rate 0.10mm/rev, 0.15mm/rev, 0.20mm/rev according to ISO 3685, and constant depth of cut 1.5 mm were selected as the machining parameters. Build – up edge in the cutting tool and work piece were formed most at cutting speed 80m/min and feed rate of0.10mm/rev.The minimum main cutting force value was determined at 16.84 N at feed rate of 0.1 mm/rev and cutting speed of 80(m/min), while maximum cutting force was determined at 33.59 N at cutting speed of 100 m/min and feed rate of 0.2 mm/rev. According to the test results, increasing the feed rate resulted in an increase in cutting forces. It is suggested that the feed rate must be decreased in order to decrease cutting forces.

Keywords: *Cutting speed, Feed rate, Surface roughness, Build – up edge, Wearing, Cutting fluid*.

INTRODUCTION
Aluminum is the second most abundant structural metal in the earth's crust [1]. Aluminum is extracted by the chemical refinement of bauxite using the Bayer process to form aluminum oxide (alumina) from which (99.9% pure) aluminum extracted by hall – heriot method [2]. It is commercially available as rough or cast in the form of ingots, bars, sheet, etc., it is a slivery while metal especially, noted for its density, about a third of steel. It has good electrical and thermal conductivities as well as good ductility and malleability. It can be surface finished within a wide range of values. It has the limitation of lower strength at elevate temperature, limited formability and relatively higher cost compared to steel [3].It is widely used in the food industries, for structural applications, cryogenic applications, and extensively in transportation industry [2]. Aluminums are wildly used in engineering structure and component where light weight or corrosion resistance is required [4].According to [5], 6061 aluminum alloy is an aluminum base alloy often used in the aerospace industries. It is among the strongest available aluminum alloy, as well as having high hardness. He further states that 6061 aluminum alloy is the second most popular of the 2000 series aluminum alloys after 6063 aluminum alloys. It is commonly extruded and forged. Prior to the adoption of the aluminum association alloy designation in 1935, 6061 aluminum alloy was known by the industry conventional designation "61s"[5], [6]. The composition of 6061 aluminum alloy include; Si, Mg, Cu,Mn, Ti, Zn,Fe, Build – up edge on the other hand is a part of chip materials that adheres to the tool rake face when machining 6061 aluminum and other alloys at low to moderate cutting speed [7]. It is extremely strain hardened and can grow up to a noticeable size and replace the cutting tool itself to perform the actual cutting [8]. The process has a profound effect on the cutting force, cutting temperature, tool wear, surface roughness and geometrical dimension of machined product [7]. According to[9], the built-up edge and build up layer formation on the cutting tools is caused by tool-tool chip interface temperature and extreme pressure. The work piece material adheres to the rake face of the cutting tools in two different forms.

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MATERIAL AND METHOD

The materials used for this research work was 6061 aluminum alloy, tungsten carbide and cutting fluid. 6061 aluminum alloy was selected due to the fact that it has a wide range of application in the construction and aerospace industries, etc. it was cut and casted into 80mm diameter and 500mm length according to ASTM A751 standard, the specimen was machined according to the experimental design (3^2) two factors randomized complete block design. The machining process was done with PANTHER 1350 series industrial type lathe machine with tungsten carbide, insert to the tool holder, all cutting force was measured using cutting tool dynamometer. The geometry of the cutting tool was 5^0, the cutting speed were varied from 80 to 100m/min, feed rate was within 0.10, 0.15 and 0.20mm/rev according to ISO 3685, and 1.5mm constant depth of cut used for the entire experiments. The tool was further observed using JEOL – JSM 6060 Scanning Electron Microscope (SEM) for the analysis of build – up edge, each cutting experiment was repeated three times to ensure that the experimental result was repeatable.

RESULT AND DISCUSSION

Table 1: Selection of factors and levels for cutting speed and feed rate

Factors	Level		
	I	II	III
Cutting Speed (m/min)	80	90	100
Feed rate (mm/rev)	0.1	0.15	0.2

Table 2: Machining conditions for full factorial design of experiments

Number	Runs	Block	Cutting speed (m/min)	feed rate (mm/rev)
1	1	Block 1	80	0.1
2	4	Block 1	90	0.1
3	7	Block 1	100	0.1
4	2	Block 1	80	0.15
5	5	Block 1	90	0.15
6	8	Block 1	100	0.15
7	3	Block 1	80	0.2
8	6	Block 1	90	0.2
9	9	Block 1	100	0.2

Design summary, selection of factors and levels for cutting speed and feed rate are presented in table 1 and 2 respectively. The effects of cutting speed and feed rate on the main cutting force was obtained by applying analysis of multiple variances on the determined data. Significant changes with a confidence level of 95% were determined between all the factors according to the result of the analysis of variance.

Table 3: Results of Cutting Force at Varying Input Parameters

Std	Runs	Block	Factor 1: Cutting speed (m/min)	Factor 2: feed rate (mm/rev)	Response 1 Cutting force (N)
1	1	Block 1	80	0.1	16.84
2	4	Block 1	90	0.1	18.04
3	7	Block 1	100	0.1	27.10
4	2	Block 1	80	0.15	19.28

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5	5	Block 1	90	0.15	23.26
6	8	Block 1	100	0.15	28.12
7	3	Block 1	80	0.2	17.32
8	6	Block 1	90	0.2	22.68
9	9	Block 1	100	0.2	33.59

Table 4: Variance Analysis (ANOVA) Regarding Main Cutting Force (Fc)

Source of Variance	Sum of Square	Degree of Freedom	Variance	F value	P value Prob > F	C (%)
Model	1368.26	8	171.03	2989.89	<0.0001	
Factor A: Cutting Speed	992.25	2	496.12	8672.59	<0.0001	72.46%
Factor B: Feed rate	374.64	2	187.32	3274.61	<0.0001	27.40%
A*B	1.37	4	0.34	6.00	<0.0001	0.10006%
Error	1.03	18	0.057		0.0030	0.07522%
Total	1369.29	26				100%

SS: sum of squares, df: degree of freedom, C: percent contribution
Factor A; Cutting speed (80, 90, 100 m/min)
Factor B; Feed rate (0.1, 0.15, 0.20 mm/rev)

The analysis of variance implemented to determine the effect of cutting speed and feed rate on cutting force is presented in table 4. P – Values presented in table 4 are the realized significance levels, associated with the F – tests for each source of variation. The sources, with a P-value less than 0.10 are considered to have a statistically significant contribution to the performance measures. The last column of table 4 shows that the percentage contribution of each source to the total variation indicating the degree of influence on the result. Table 4 shows that the only significant factor for the cutting force is cutting speed, which has 72.46% of the total variation. It can be concluded from table 4 that feed rate having 27.40% significances level does not have a significant contribution to total variation.

Fit Statistics for cutting force

Std. Dev.	5.60	R^2	0.468
Mean	22.9	**Adjusted R^2**	0.423
C.V. %	24.4	**Predicted R^2**	0.326
		Adeq Precision	6.32

The **Predicted R^2** of 0.3261 is in reasonable agreement with the **Adjusted R^2** of 0.4232; i.e. the difference is less than 0.2.**Adeq Precision** measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 6.322 indicates an adequate signal. This model can be used to navigate the design space.

Table 5: Process Parameters and their Experimental Actual Values and Predicted Values of Cutting Force.

Run	Cutting speed rpm	feed rate (mm/rev)	Predicted values Cutting force (N)	Actual values Cutting force (N)
1	80	0.1	16.68	16.84
4	90	0.1	18.02	18.04
7	100	0.1	26.93	27.10

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2	80	0.15	19.30	19.28
5	90	0.15	23.33	23.26
8	100	0.15	28.05	28.12
3	80	0.2	17.35	17.32
6	90	0.2	22.70	22.68
9	100	0.2	33.59	33.59

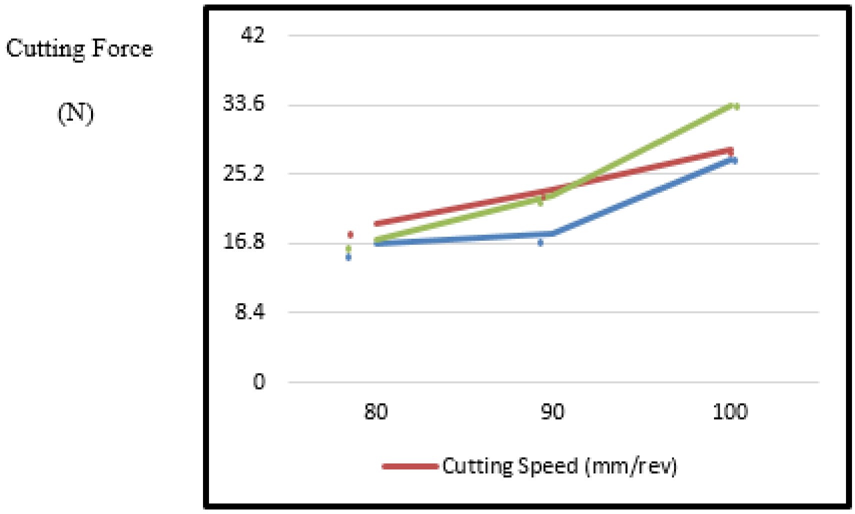

Fig 1: Cutting force vs Cutting speed

Key: Blue – cutting speed at 80 m/min, Cutting speed at 90 m/min and Green – cutting speed at 100 m/min

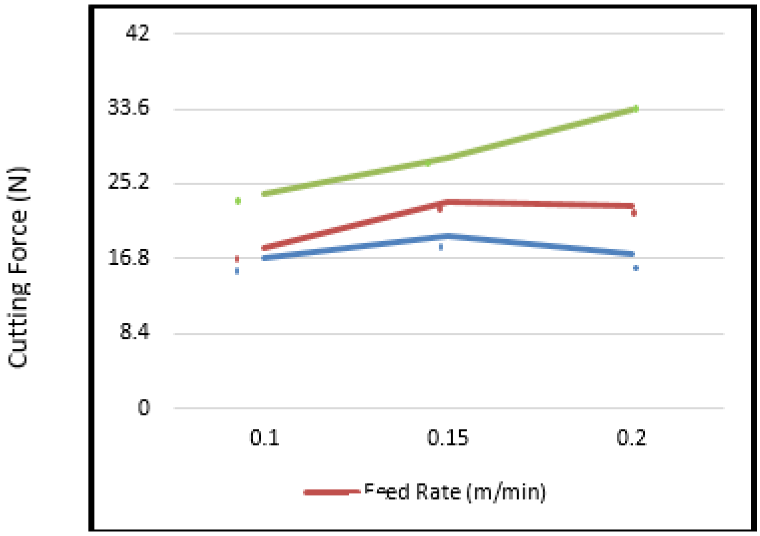

Fig 2: Cutting force vs Feed rate

Key: Blue – feed rate at 80 m/min, Red - feed rate at 90 m/min and Green – feed rate at 100 m/min

According to test result on fig. 1, lower cutting speed of 80m/min give lower cutting forces of 16.84, while fig. 2, indicate that increase in feed rate from 0.1 – 0.2 (mm/rev) also increase the cutting force. It is considered that high temperature at the flow zone and decreasing surface area are the reason for this case. Reduction amount in cutting forces depends on work piece material, working condition and cutting speed ranges. In fig. 1 and 2, minimum cutting force of 16.84N was obtained at feed rate of 0.10m/min and cutting speed of 80mm/rev, while maximum cutting force of 33.59N, was determined at feed rate of 0.2mm/rev and cutting speed of 100 m/min. according to the test result increasing the feed rate resulted in an increase in cutting forces. Table 5 shows the process parameters and their experimental actual values and predicted values of cutting force.

CONCLUSION
The effect of machining parameters namely, cutting speed and feed rate on main cutting force was both experimentally and statistically investigated. It was observed from the test result that the most important parameter affecting main cutting force is cutting speed, significance level of these effects was 72.48% for main cutting force. It was found that build – up edge formation on tool surface at the cutting speed of 80m/min was larger than those of 90 and 100 m/min. hence cutting speed must be selected above 80 – 90m/min in order to prevent build – up edge formation. Maximum cutting force value (33.59N) was determined at 100m/min cutting speed and 0.20mm/rev feed rate when machining 6061 aluminum alloy, while minimum cutting force was determined at 80m/min and 0.10mm/rev.

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