Finite Element Analysis of An Aluminium Shaping Tool and Titanium Workpiece

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Abstract- The Finite Element Analysis (FEA) of an Aluminium shaping tool on Titanium workpiece is presented. A detailed analysis of aluminium tool and titanium workpiece was conducted using Full factorial method and FEA technique. The finite element analysis was carried out using Explicit dynamic tool of the ANSYS workbench software. In the recent past finite element has been applied often in machining operation as a result of its speed in computational analysis. In predicting cutting force of the aluminum tool a mathematical model was developed using Full factorial method and multiple linear regression technique.The developed mathematical model was adequate with R2 and adj R2 values of 98.0% and 89.0% respectively. The predicted R2 value was 0.89.The maximum and minimum stress values of the cutting tool are 495.42Mpa and 7.71Mpa respectively. Also, a maximum deformation of 79.49mm and strain of 3.95mm were obtained for the workpiece.

Keywords Finite element analysis, full factorial method, shaping tool and multiple linear regression.

1. Introduction

Machining of metallic components is highly important in production of finished products in emerging global technology [1]. It provides a viable means of automobile parts getting appropriately fixed into various engine compartments. Machining of components provides parts the ability to maintain mechanical shapes excellent finishings, better surface roughness, less time for finishing, maintenance or adherence to engine specification and quality inclination[2]. Machining has to be carefully done so as to attain utmost specification and tolerance required for material installation .

Various metallic materials are needed to be machined to ensure proper finishing of automobile components in the manufacturing world. Scientific investigation shows that these materials such as steel, iron, aluminum, alloys, titanium and manganese offer great mechanical properties which make them highly applicable in different fields of engineering [3]. Metal cutting entails permanently detaching materials from the outermost part of a metallic material in order to attain excellent surface quality and required dimensions [4]. Apparently the magnitude of shaping parameters applied on material workpiece depends on the material resistance and the force applied on the shaping tool [5]. A study on the response of cutting force on cutting parameters such as cutting speed, feed rate and depth of cut was examined by [6] during machining of steel. Also, distribution of stress on a steel work piece was conducted by [7]. In a machine shaping operation involving 1020 steel the shaping parameters were noticed to have influenced the rate at which orthogonal cutting was done [8]. Finite element analysis has been widely used in determination of mechanical properties such as thermal stresses, strain and rate of deformation inherent in machined engine components . This computational technique ensures accurate prediction of shaping tool and work piece geometrical properties. Computational numerical techniques has great advantage of predicting numerical values of mechanical properties of components before they are manufactured so as to present a clear view of how the machined component will perform after production[8]. The aim of this research is to carry out the finite element analysis on an aluminium shaping tool on a titanium workpiece. The objectives pursued in this study are;

I. To use the Design of experiment to carry out the experimental condition for the shaping process.

II. To determine the cutting force of the shaping tool.

III. To optimize the shaping parameters.

IV. To determine equivalent stresses, strain and deformation on the work piece.

2. Materials and methods

Design of Experiment was employed in creating a layout for the experiment. The full factorial method of the design of experiment was used in the experimentation. A two level and a total of 8 runs of experiment was employed as prescribed by the Design expert software. The shaping parameters employed in this study are cutting speed, depth of cut and feed rate. The cutting force which was determined using a dynamometer was used as the response parameter of the experiment. [9]. The experimental matrix was inputted with the shaping parameters and the cutting force response measured accordingly. Finite element analysis was carried out using explicit dynamic tool of the ANSYS software.

The aluminium tool and titanium workpiece were modeled using the Solidwork software before been imported into the ANSYS Design Modeller environment for accurate simulation and analysis. The Design of experiment used in this study is shown in Table 1. It shows experimental conditions for each run and the resultant cutting force.

Table 1. Design of experiment result for cutting force

Std	Run	Cutting speed (m/s) [A]	Feed rate (mm/s) [B]	Depth of cut (mm)[C]	Cutting force(N) [C_f]
7	1	200	1	0.5	6000
4	2	400	1	0	5500
2	3	400	1	0	5000
6	4	400	0.5	0.5	6045
1	5	200	0.5	0	5890
5	6	200	0.5	0.5	5600
3	7	200	0.5	0	6200
8	8	400	1	0.5	6800

3. Results and Discussion

3.1. Statistical Determination of The Mathematical Model

The obtained values of the cutting force were subjected to multiple linear regression analysis. The developed mathematical model is as given in equation 1.

$$C_f = 6845.62 - 6.02A - 7.50B - 3842.50C + 2.72AB + 14.18A - 690.00BC \quad (1)$$

Where A= Cutting speed (m/s), B= Feed rate (mm/s), C= Depth cut (mm), Cf = Cutting force (N). The developed mathematical model is significant with an R^2 and adjusted R^2 of 0.98 and 0.97 respectively. The predicted R^2 value was determined to be 0.89. The ANOVA result shown in Table 2 depicts the p-values which show the rate of significance of the parameters. The ANOVA table shows that the developed mathematical model and cutting parameters were significant with p-values less than 0.05 significance level. The interaction between the main parameters was found to be significant as shown by the interaction plot depicted by Fig. 1. and the p-value shown in the ANOVA Table 2

Table 2. ANOVA results

Source	Sum of squares	DF	Mean Square	F-value	P-value
Model	1.98E+06	6	3.31E+05	97.18	0.027
A-A	14878.13	1	14878.13	4.37	0.028
B-B	4.82E+05	1	4.83E+05	141.83	0.050
C-C	4.30E+05	1	4.30E+05	126.39	0.045
AB	37128.13	1	37128.13	10.91	0.187
AC	1.005E+06	1	1.005E+06	295.21	0.037
BC	14878.13	1	14878.13	4.37	0.264
Residual	3403.12	1	3403.12		
Total	1.988E+06	7			

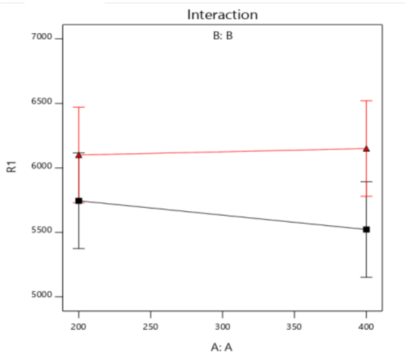

Fig. 1. Interaction plot.

3.2. Finite Element Analysis

The Explicit dynamic tool of the ANSYS workbench software was applied in this study. The aluminium tool and titanium workpiece were imported into the ANSYS environment as shown in Fig. 2.

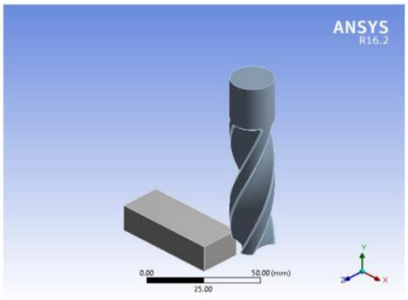

Fig. 2. The assembly of the tool and work piece.

The workpiece and tool were meshed into tiny elements as shown in Fig. 3 for easy computation of the requisite mechanical properties. The nodes and elements were 21971 and 41327 respectively. A friction coefficient and dynamic coefficient of 0.4 and 0.2 respectively were applied in the analysis.

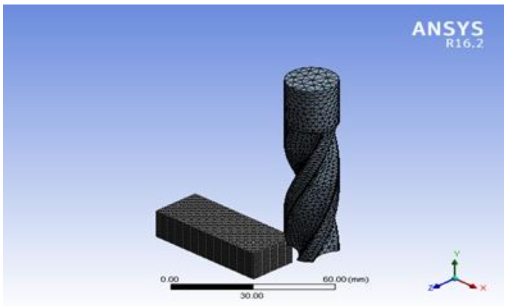

Fig. 3. Meshed tool and workpiece.

The finite element analysis produced a maximum equivalent (Von mises) stress value of 495.42Mpa and a minimum equivalent (Von mises) stress of 7.71Mpa on the work piece. The equivalent stress increases with time progressively as shown in Fig. 4.

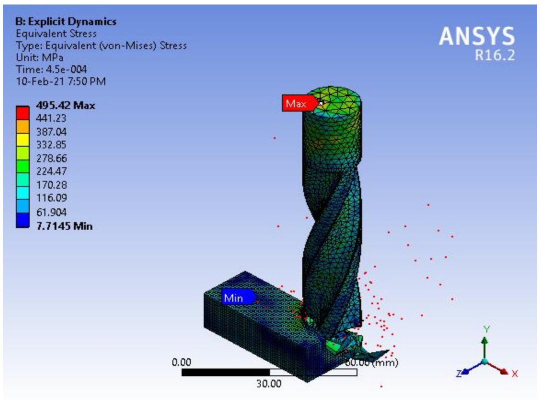

Fig. 4. Equivalent Von Mises stress results.

The total deformation result is shown in Fig. 5. It reveals the level of deformation exerted by the aluminium tool on the workpiece. A maximum total deformation of 79.49mm and a minimum value of 0.133mm were exerted on the titanium workpiece.

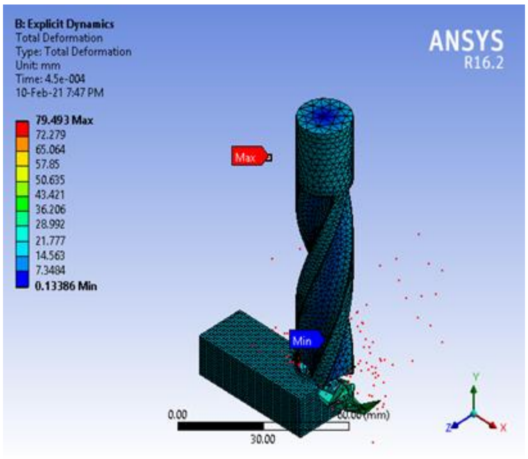

Fig. 5. Total deformation result.

The simulation produced an equivalent (Von mises) strain of 3.95mm and 0.000145mm as maximum and minimum values respectively as depicted in Fig. 6.

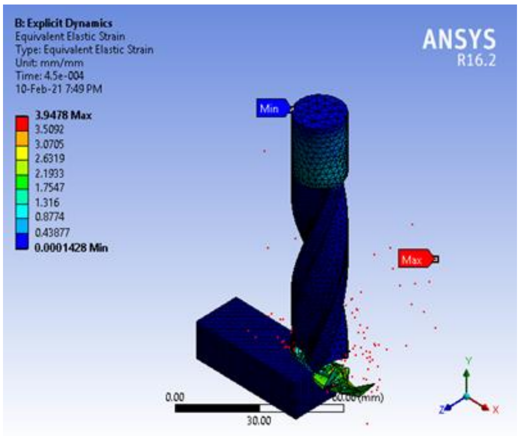

Fig. 6. Equivalent Von Mises strain values obtained.

4. Conclusion

The study showed that an increase in cutting force leads to a reduction of cutting speed. All shaping parameters applied in the study were significant as confirmed by their obtained p-values and f-values as shown in Table 2.0. The developed mathematical model was adequate with R2 and adj R2 values of 98.0% and 89.0% respectively. The predicted R2 value was 0.89. The obtained results were found to be in conformity with the results obtained in [10]. The maximum and minimum stress values of the shaping tool are 495.42Mpa and 7.71Mpa respectively. Also, a maximum deformation of 79.49mm and strain of 3.95mm were obtained for the workpiece. The values were similar to that obtained in [11].Graphical results from ANSYS workbench showed that at the predicted cutting force of 6800N incursion into workpiece surface begins to gather great momentum with deformation of the work piece becoming highly visible.

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