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Effect of Speed, Feed and Depth of Cut on Cutting Forces While Machining Al-7050 T7451

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ABSTRACT

Different products are manufactured using the machining process. It is a value addition process in which material is removed from parent material in the form of chips to make a product or a component. Machining processes are of two types, namely conventional machining and non-conventional machining. The fundamental principle of conventional machining like drilling, milling, turning, shaping and non-conventional machining like ultrasonic machining, chemical machining, electron beam machining is manufacturing a product by removal of material. Cutting parameters play a crucial role in machining processes. They have a significant effect on cutting forces generated during the machining process, which will in turn affect the machining induced residual stresses. In this current work the force variation was determined using a piezo-electric dynamometer, when the different machining parameters were varied. The paper aims at examining the cutting forces generated during milling of Aluminium 7050 T-7451. Aluminium is chosen as it is very widely used and has many applications in the aerospace industry. Using appropriate techniques, a mathematical model which can predict the cutting forces for different cutting parameters was modelled. Future work involves investigating residual stresses.

KEYWORDS

Cutting parameters, Mathematical model, Cutting forces.

INTRODUCTION

Various factors contribute to the lifespan of any component. In most cases the failure occurs due the fatigue and residual stress which are induced in the component. The residual stresses depend on different parameters. One of the most affecting parameters are the cutting forces generated during the machining process. For any machining process, machining parameters play a pivotal role in the production of a component with accurate dimension and finish. The relative motion between the workpiece and the tool generates the cutting forces. In addition, cutting forces also affect the tool life, the surface integrity and machined surface roughness which will affect the performance and fatigue life of the component. Therefore, it is important to study the effect of cutting parameters on the cutting forces to optimize the cutting parameters required for carrying out the machining operation on the component. Z.T. Tang et at [1] studied about the residual stress induced in the workpiece during the machining operation focused on effect of cutting parameters, In the experiment the residual stress are measured by X-ray diffraction method and the cutting force using a dynamometer and the induced residual stresses were explained by the thermo-mechanical coupling effects.

Caruso et al. [2] carried out 2D finite element simulations for AISI H13 tool steel to predict surface residual stresses and to investigate the influence of cutting speed, uncut chip thickness and tool wear. The finite element model is validated using experimental results. S.Caruso et al [3] had performed the experiment on the AISI 52100 steel to study the effect of cutting speed, hardness influence, tool geometry and microstructural changes in the residual stress in which it indicates that cutting speed has significant effect on the residual stress as the cutting speed increases high residual stresses are inducted in the machined component. Gururaj et al [4] carried out the simulation of the thin-wall machining of Al 7075-T6 alloy and cutting forces generated during the machining process for different cutting process parameters using the Finite element method(FEM) using the

Johnson-Cook material constitutive model. D.Sreeramulu et at [5] had simulated a three-dimensional oblique cutting operation to study the temperature variation produced and the cutting forces using Finite element method software and also performed the experiments of cutting operation on the work piece of the material Al 7050-T6 and tool with material of coated titanium carbide. The experiment and FEM outcomes are compared. I. Perez et at [6] the work studies about the effect of cutting speeds on the surface integrity of the Al 7050 T7451 during the machining operation of milling under the dry cutting conditions.

In addition carried out the experiments and understood the influence of the mechanical load and residual stresses on the surface integrity using various cutting conditions. Prakash et at [7] developed a 2D finite element model to predict the residual stresses for different cutting conditions. The variation of cutting forces for three different speeds and feeds at a constant width of cut are shown. The developed FE model is also used to predict the temperature distribution. Prakash et at [8] predicted the machining induced residual stresses in the machining of AISI 1045 steel. Experiments were conducted and residual stresses were found using X ray diffraction principle. A 3D FE model and a mathematical model were developed to predict the residual stresses induced. The results showed the finite element model can predict the residual stresses with good amount of accuracy. This eliminates the need for expensive experimentation. Xianghui Huang et at [9] developed a Finite element model of high speed milling of the Aluminium alloy 7050-T7451 to study the effect of parameters such as rake angle, relief angle and clearance angles on the cutting forces which are generated during the process also a 2D orthogonal model to study the effect of the machining parameters on the cutting forces along with 3D oblique cutting simulation, carried out the experiment and validated the model with only 10.4% of the error. Our current work is an attempt to develop a mathematical model to predict the cutting forces that will be induced during the end milling of Aluminium 7050 T-7451. This is our first step towards understanding residual stresses as the changes in cutting forces developed during machining represent the effect of cutting conditions on the residual stresses.

EXPERIMENTAL METHODOLOGY

An experiment is a system, which has certain input variables and an output variable. In some cases there may be more than one output variable. In the present work, the end milling operation is our system and the independent variables are speed, feed and depth of cut. The dependent variable is the cutting force. For the current work the experiments were conducted using the design of experiments technique to develop a mathematical model for predicting the cutting forces induced during the machining process. The design of experiments is a powerful techniques that is used in the present research to the build the model [10]. It is considered as the best tool for optimising the solution under multiple variable conditions using minimum effort. It is commonly applied in a variety of industrial problems. The primary aim of the using DOE is to reduce the experimental expenses.

Steps involved in design of experiments:

Step 1

This step involves determining the dependent and the independent variables. The dependent variables are the output variables that are to be measured, in the present work cutting forces are the variables that are measured. These are otherwise termed as responses. The independent variables are the variables that can be varied, in our case they are speed, feed and depth of cut.

Step 2

This step involves the design. Design meaning the number of experimental runs that will be performed, determining the number of factors and their levels. In the present work, Taguchi technique was used to design the set of experiments

Taguchi technique

This method was introduced by Dr. Genichi Taguchi, hence the name. Taguchi orthogonal array is a design where it is a fractional factorial design. If there are multiple factors and multiple levels, Taguchi orthogonal array allows you to select a subset of the set of experimental runs that is available, yet allowing us to get the effect of the full design. This helps the researcher to examine the effect of each factor and interactions of the factors on the response. But when the number of runs is logistically expensive the researchers choose the fractional factorial design. In the current research work a L9 orthogonal array is considered [11].

Step 3

After designing the experimental design, the next step would be measuring the responses. The experiments are conducted in the order of the experiment design and the responses are measured and tabulated

Step 4

After measuring the responses, the data is analysed using statistical methods to arrive at conclusions.

Experimental design

As discussed in the previous section, three factor and three levels were considered for the current research work, the factors and their respective levels are given in Table 1.

Table 1. Parameters and their respective levels.

Parameters	Low	Medium	High
Cutting speed, V (RPM)	1000	2000	3000
Feed, (m/min)	50	100	150
DOC, d (mm)	0.3	0.6	0.9

Table 2. L9 Orthogonal array

Experiment No.	Factor 1	Factor 2	Factor 3
1	1000	50	0.3
2	1000	100	0.6
3	1000	150	0.9
4	2000	50	0.6
5	2000	100	0.9
6	2000	150	0.3
7	3000	50	0.9
8	3000	100	0.3
9	3000	150	0.6

EXPERIMENTAL SETUP CONTENT

The study on the effect of cutting parameters on cutting forces has been carried on Aluminium 7050 T-7451. A total of nine experiments were done using nine identical workpieces for different cutting parameters. For the experimentation, 9 workpieces of Aluminum 7050 T7451 were obtained in the form of blocks of 35mmX70mmx60mm. The specimens were subjected to single pass orthogonal milling in a CNC operated vertical milling machine.

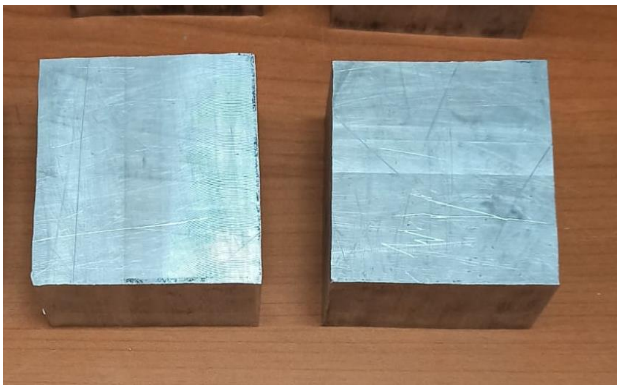

Figure 1. Specimens used for machining

For each experiment different tools were used to eliminate the effect of the tool wear that might arise during the machining. Dry cutting conditions were chosen in order to avoid the influence of cutting fluid on cutting forces. A piezoelectric dynamometer was used to measure the cutting forces continually while milling. For cutting force measurement during milling, only three force components are relevant (oblique cutting). In this work a stationary, table-top, multi-component piezoelectric Kistler dynamometer (Model 9257B) was used.

Table 3. Results of the experiment of milling of aluminum 7050 T7451

Exp no	Factor I	Factor II	Factor III	Fx	Fy	Fz	Frms
1	1000	50	0.3	26.92	22.22	21.84	41.16
2	1000	100	0.6	35.8	26.38	22.81	49.97
3	1000	150	0.9	53.83	42.62	22.2	72.15
4	2000	50	0.6	41.66	29.91	27.77	58.32
5	2000	100	0.9	105.2	69	51.12	135.79
6	2000	150	0.3	48.71	28.09	40.28	69.167
7	3000	50	0.9	74.43	93.57	158	198.13
8	3000	100	0.3	104.7	56.5	154.6	195.07
9	3000	150	0.6	86.7	82.57	253.8	280.62

Fx-:X directional force
Fy-Y directional force
Fz-Zdirectional force
Frms-Root Mean Square of Fx,Fy and Fz forces

STATISTICAL ANALYSIS

Regression analysis is a statistical analysis method which uses data to develop a model which can predict, takes one or more independent variables and a dependent variable and creates a mathematical equation which is used to estimate the dependent variable values [12,13]. Regression analysis is applied to the data of the experimental outputs done by using the excel software the summary output is given below in the Table 4

Table 4. Statistical analysis

Multiple R	0.996695
R square	0.993402
Adjusted R square	0.982405
Standard Error	11.24

As per the Regression Statistic in table (4.1) indicates that the 99% of the change in RMS value of the forces will be dependent on speed,feed,depth of cut, product of speed ,feed and depth and the square of speed which is indicated by the R square in the Table 4. In the Table 5 significance F indicates that the independent variables considerations will actually have the effects on the root mean square forces which the value is 0.001809.

Table 5. Anova

	df	SS	MS	F	Significance F
Regression	5	57160.97	11432.19	90.33511	0.001809
Residual	3	379.6595	126.5532		
Total	8	57540.63			

Table 6. Coefficients of the regression summary output

	Coefficients	Standard Error	P-value
Intercept	144.29932	35.316	0.026491
Speed	-0.13422213	0.0322	0.025172
Feed	-0.2519134	0.1488	0.189147
Depth of Cut	-43.424389	23.225	0.1583
Speed*feed*depth of cut	4.5E-5	8.0008E-6	0.01016
Speed*speed	0.0007017	0.0001232	0.010766

With the help of the summary output of the regression analysis a mathematical model is developed to predict the Frms value. Frms value is chosen as it has the combined effect of forces acting in all the three directions.

The mathematical equation developed by the regression statistical analysis is given by

Frms ={144.29932 }- {0.1342213*Speed }-{ 0.2519134*Feed} - {43.424389*Depth of cut} +{ 4.5E-5*speed*feed*depth of cut} +{ 0.0007017*speed*speed}

Table 7. Predicted cutting forces V/S cutting forces

Exp No	Predicted Frms	Frms	% Error
1	41.474497	41.16	0.764
2	47.41572943	49.97	5.111608
3	74.399977357	72.15	-3.1039
4	65.28431569	58.32	-11.9416
5	123.8325774	135.79	8.812535
6	74.16310691	69.167	-7.2341
7	203.1331069	198.13	-2.52516
8	185.027854	195.07	5.14797
9	285.6617391	280.62	-1.79566

CONCLUSION

The developed mathematical model can predict the force variation to a very good accuracy. The comparison between the values shows good accuracy. The research was conducted on Aluminum 7050 T7451 using a end mill cutter (4 flutes), the future work that can be done is to develop a mathematical model in order to predict the residual stresses induced and also to develop a finite element model that will predict the cutting forces and residual stresses.

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