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# Prediction of Cutting Force by Using Finite Element Method in End-Milling of AISI 1018 Medium Carbon Steel

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**Abstract:**

The objective of this paper are to predict the cutting force using predictive model of finite element method (FEM) and validate thru experiments, and to analyze the influence of cutting parameters during the circular end milling of AISI 1018 medium carbon still employing uncoated carbide tool. Three level of cutting speed, feed rate and depth of cut are designed accordingly. Result of cutting forces is evaluated and validated. Analysis also been made by considering the percentage of error in FEM and experimental work by Dynoware Software. The results obtained by simulation using Abaqus software and experimental work, it shows small percentage of error and it is suggested that the predictive model is reliable whereas the FEM value captures the qualitative trends fairly well in regard to the change of cutting speed, feed rate and depth of cut.
**Keywords:** *Cutting force, Finite Element Method, end milling machining, AISI 1018*

## I. INTRODUCTION

With the development of technology, all of the knowledge are integrated together with the computational technology due to enhanced the computational capacity in predicting and solving problems in shorter time and yet precise. Modeling and simulation of machining processes provide more comprehensive and accuracy in predicting the effects of cutting conditions on the machining performance, such as cutting forces, temperatures, tool wear, residual stresses, and chip and burr formations [1]. The product quality and productivity are importance on manufacturing phase. To produce high quality and productive product, certain analysis need to be conducted to ensure the correct method, tool and parameters will be used. The effect of the cutting parameters such as cutting speed, feed rate and depth of cut can be predicted in order to obtain good surface finish of product, minimize the cutting force and tool wear and etc.

The simulation analysis using FEM do not need to perform many experimental tests that will cost a lot of expenses and reducing the machining time. Therefore, FEM have found to be powerful tool for evaluating the process capabilities without need of conducting the traditional way of doingexperiments which is trial and error experiments. This FEM software is used as a practical tool by researchers, engineers and machine tool manufactures.

Cutting force is one the aspect that drew another attention in monitoring surface texture and product finishing. Cutting forces produced are dependent on cutting conditions and parameters. These parameters are obtained and specifically selected based on type of machined material and cutting tool that will be used for machining process as different materials and cutting tools will give different optimum parameters [2]. In a study on the effect of tool wear on machining forces, crater wear was found to be the dominant wear pattern affecting the machining forces, whereas flank wears exerted minimal influence [3].

A built-up edge was correlated with the cutting force whereby the magnitudes of cutting forces are influenced not only by the process and tool-dependent parameters, but also by the material-dependent parameter such as materials

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hardness and properties. These influences were also reflected on the surface roughness of the work piece [4]. Therefore, measuring actual cutting forces can serve as a good indicator of the actual machining status and thus be useful in predicting the surface roughness of the work piece. A lot of work has been focusing in measuring the cutting forces by using a dynamometer this area where example can be seen wherein a dynamometer is mounted at the tool stock to in-process detection of the 3-D cutting forces at the cutter. By applying the neural network technique, it was found that the cutting force changes were closely associated with the progression of the tool wear [5].
The aim of this paper is to predict the effect of cutting speed and feed rate on the cutting force during the end milling of AISI 1018 medium carbon steel by using Finite Element method (FEM) predictive model . The numerical data of the cutting force obtained from the simulation is then compared with experimental data validation purposes.

## II. EXPERIMENTAL SETUP

### A. FEM Software

ABAQUS Version 6.14-5 software was employed to perform the simulation and analysis process by using Finite Element Method in order to get the prediction of the cutting force on the work piece AISI 1018 medium carbon steel then the validation was made by experimental work. Solid Work 2015 Edition software was used to design the uncoated carbide insert type cutting tools. The workpiece was attached on the Kistler 9267b dynamometer and the cutting force data was recorded using as Dynoware software during the experimental work was carried out.

### B. Cutting Tool, workpiece material and machining parameters selection

In the experimental work, uncoated tungsten carbide R217.69 – 1212.0 – 06 – 2A manufactured by SECO was employed during the experimental work. The cutting tool insert was attached to the toll body with a diameter of 18 mm. An AISI 1018 medium carbon steel with a dimension of 150 mm x 100 mm x 50 mm was supplied and used for the experiment in order to get the data of cutting force. The chemical composition of AISI 1018 are shown in table 1 and was determined by Spectrometer Foundry-Master.

Table 1: Chemical composition of work piece (AISI 1018)

| Element | Iron, Fe | Carbon, C | Silicon, Si | Manganese, Mn |
|---|---|---|---|---|
| % | 98.2 | 0.245 | 0.221 | 1.17 |

| Sulphur, S | Chromium, Cr | Molybdenum, Mo | Phosphorus, P |
|---|---|---|---|
| 0.0036 | 0.0351 | < 0.0050 | 0.0088 |

Table 2 tabulates the cutting parameter such as cutting speed, feed rate and depth of cut. The number of experiment was obtained by using Taguchi Method in order to minimize the number of experiment instead of using Full Factorial Method to avoid the huge amount of experiment need to be done to cut down the cost of the machining process.

Table 2: Cutting parameters and level

| Level | Cutting Speed (m/min) | Feed Rate (m/mm) | Depth of cut ( mm) |
|---|---|---|---|
| 1 | 50 | 100 | 0.5 |
| 2 | 63 | 250 | 0.75 |
| 3 | 75 | 450 | 1.0 |

It is very crucial to consider the suitable parameters in the experiment work to obtain a good result and to optimize machining quality. In this study, the parameters for cutting condition which is cutting speed, feed rate and depth of cut was obtained through the study of the journals related to end milling process. In this experiment, nine experiments were conducted based on calculation of L9 orthogonal array of Taguchi Method.

### C. Cutting Force

Three-components of dynamometer Kistler 9257B is manufactured by Kistler Instrumente was used to measure and analyses the cutting force. It consists of three element force sensors fitted under high preload between a base plate and a cover plate. The forces include force components where it is measured practically without displacement.

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## III. RESULTS AND DISCUSSION

### A. Simulation and validating of cutting force Software

Graph and data from the experimental work obtained by dynoware are gathered to be analysed and make comparison to determine the percentage of error between simulation and experimental work. The cutting force in x direction which is Fx is only consider in this test Fx because of their high value compared to Fy and Fz. This is also resulted because of the movement of the machining process of end milling travel on X-axis. The cutting force was compared at different feed rate at certain depth of cut. This is because feed rate is the factor that affects the value of the cutting force the most. Table 3 shows the comparison of cutting force between Dynoware and FEM at depth of cut of 0.5 mm.

Table 3: Result of comparison between Dynoware and FEM at depth of cut of 0.5 mm

| Feed rate, mm/min | CS, m/min | Experiment, N | Simulation, N | Error % |
|---|---|---|---|---|
| 100 | 50 | 63.17 | 59.27 | 6.58 |
| 250 | 75 | 162.51 | 145.63 | 11.59 |
| 450 | 63 | 204.5 | 187.34 | 9.15 |

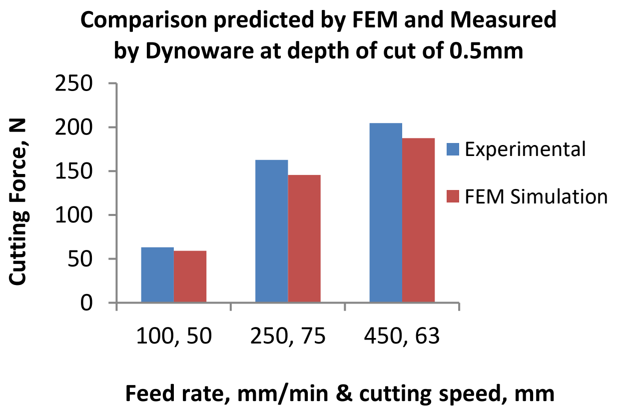


*Figure 1: Comparison predicted by FEM and Dynoware at depth of cut of 0.5mm*

Figure 1 shows the data validation of the cutting forces obtained from FEM simulation and experimental work.Both result obtained show the cutting force increases as the as the feed rate increase at depth of cut of 0.5 mm. It shows that theoretical percentage of error of 11.59 % was obtained from feed rate at 250 mm/min and cutting speed of 75 m/min.. It can be seen that the value is highest compared to the other two cutting parameters which are slightly lower percentage error of 9.15% and 6.58%. Table 4 shows the comparison of cutting force between Dynoware and FEM at depth of cut of 0.75 mm.

Table 4: Result of comparison between Dynoware and FEM at depth of cut of 0.75 mm

| Feed rate, mm/min | CS m/min | Experiment, N | Simulation, N | Error % |
|---|---|---|---|---|
| 100 | 63 | 111.8 | 98.13 | 13.93 |
| 250 | 50 | 168.80 | 148.66 | 13.54 |
| 450 | 75 | 232.12 | 215.74 | 7.59 |

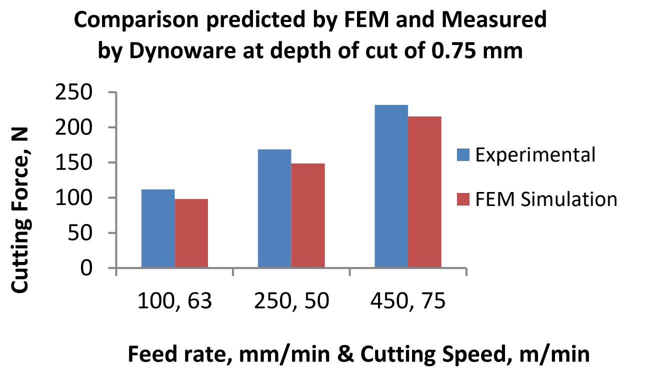


*Figure 2: Comparison predicted by FEM and Dynoware at depth of cut of 0.75mm*

Based on figure 2, the graph show the data validation of the result obtained, both of the result show the trend of steadily increasing as the feed rate increase at depth of cut of 0.75 mm. It shows that the most critical percentage of error is obtained from feed rate at 100 mm/min and cutting speed of 63 m/min which show the highest percentage of error which is 13.93% of error. It can be seen that the value is highest compared to the other 2 cutting parameters which is slightly lower percentage error of 13.54% and 7.59%. Table 5 shows the comparison of cutting force between Dynoware and FEM at depth of cut of 1 mm.

Table 5: Comparison between Dynoware and FEM at depth of cut of 1 mm

| Feed rate mm/min | CS, m/min | Experiment, N | Simulation, N | Error % |
|---|---|---|---|---|
| 100 | 75 | 125.34 | 106.23 | 17.98 |
| 250 | 63 | 159.74 | 147.78 | 8.09 |
| 450 | 50 | 199.87 | 174.56 | 14.49 |

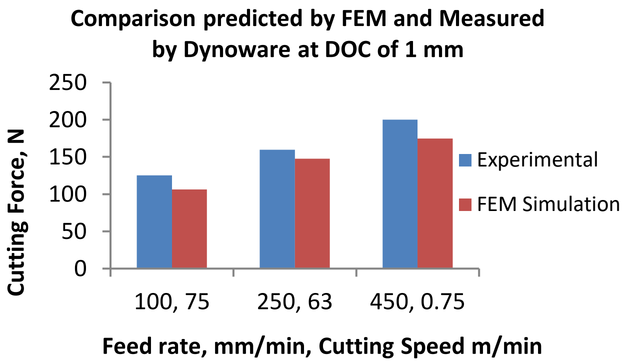


*Figure 3: Comparison predicted by FEM and Dynoware at depth of cut of 1 mm*

Based on figure 3, the graph show the data validation of the result obtained, both of the result show the trend of steadily increasing as the feed rate increase at depth of cut of 1 mm. It shows that the most critical percentage of error is obtained from feed rate at 100 mm/min and cutting speed of 75 m/min which show the highest percentage of error which is 17.98% of error. It can be seen that the value is highest compared to the other 2 cutting parameters which is slightly lower percentage error of 14.49% and 8.09%.

Regarding to simulation and experimental result obtained in this research, a different level of cutting parameters will affect to the cutting force during machining of AISI 1018 Medium Carbon Steel. During this experiment, cutting forces were observed to increase with the increasing of cutting speed,depth of cut and feed. This can be explained by the cutting speed, feed and the depth of cut affected the length of the contact area in the axial feed and rotational direction respectively. Therefore, when the length of contact area increases, it is resulting in increases of the cutting force. The increasing of cutting speed will lead to higher rate of thermal softening in the shear zone and as a result, the properties of the work piece are reduced at higher cutting speed. Besides that, the effect of feed and depth of cut also significant to the cutting force. It is suggested that when the feed and depth are large, it produces a large cross sectional area of the uncut chip which require large force to face the resistant of the material during cutting. If the feed increase, the section of sheared chip increase because the metal resists the rupture more and requires larger effect for chip removal and will produce higher cutting force. Also, it can be seen that on the graph, as the feed rate increase at certain depth of cut, the cutting force also increase.

## IV. CONCLUSION

The prediction of cutting Forces of AISI 1018 medium carbon steel machining was obtained by simulation using Abaqus software. Result obtained by experimental work shows that most significant factor for the increasing and decreasing of cutting force are cutting speed, feed and depth of cut. Furthermore,when comparing the cutting forces obtained form the experimental work with the FEM simulation, it shows that result obtained by Abaqus software was less than 20% error. It shows that the relation of feed rate and cutting force whereas when the feed rate increase, the cutting force will also increase. Thus, the objective of this paper is achieved.

### REFERENCES

[1] Necati Uçak, Adem cicek, Finite element simulations of cutting force, torque, and temperature in drilling of Inconel 718, Procedia CIRP 82 (2019) 47–52
[2] Patel, C. H., & Patel, C. P. (2013). Parametric Optimization of End Milling Of AISI 1018 Mild Steel by Various Lubricants with Solid Carbide End Mills ., 3(4), 728–732.
[3] Gye, H.-R., Song, B.-U., Lim, Y.-S., Shin, Y.-W., Jang, S.-H., & Seo, T.-I. (2013). Prediction of Cutting Force and Tool Deflection in Micro Flat End Milling. International Journal of Materials, Mechanics and Manufacturing, 1(1), 13–16. https://doi.org/10.7763/IJMMM.2013.V1.3
[4] Yang, Y., Li, X., Jiang, P., & Zhang, L. (2011). Prediction Of Surface Roughness In End Milling With Gene Expression Programming. Proceedings of the 41st International Conference on Computers & Industrial Engineering, 441–446.
[5] Jalili Saffar, R., Razfar, M. R., Zarei, O., & Ghassemieh, E. (2008). Simulation of three-dimension cutting force and tool deflection in the end milling operation based on finite

element method. Simulation Modelling Practice and Theory, 16(10), 1677–1688. https://doi.org/10.1016/j.simpat.2008.08.010
[6] Eview, L. I. R. (2016). Analysis of Tool Wear in End Milling of AISI 1018 Steel, 7(6), 32–36.

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