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An Experimental Validation and Optimisation Tool Path Strategy for Thin Walled Structure

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ABSTRACT

This work was carried out with the aim to optimise the tool path by simulating the removal of material in a finite element environment which is controlled by a genetic algorithm (GA). To simulate the physical removal of material during machining, a finite element model was designed to represent a thin walled workpiece. The target was to develop models which mimic the actual cutting process using the finite element method (FEM), to validate the developed tool path strategy algorithm with the actual machining process and to programme the developed algorithm into the software. The workpiece was to be modelled using the CAD (ABAQUS CAE) software to create a basic geometry co-ordinate system which could then be used to create the finite element method and necessary requirement by ABAQUS, such as the boundary condition, the material type, and the element type.

Keywords: Thin-walled workpiece, tool path, genetic algorithm

INTRODUCTION

Thin-walled components are widely used in the aerospace industry. However, the thin-walled components of airplane, with complicated structure and high precision, are very easy to deflect under the forces during the cutting process. The deflection results in a decrease in the machining precision and efficiency, which is a fact that acts as a barrier in achieving higher performance airplane requirement. The thin-walled components were deflected due to poor rigidity and the effect of changing in the cutting force. Despite this difficulty, the thin-walled components are still used as the main components for the airplane part because of the characteristics of the part, such as high intensity and light weight.

The deflection of the workpiece and machining efficiency of the thin-walled components always contradict with each other and this machining scenario must be solved instantly. Altintas (1992) *et al*. devoted their efforts to investigate the analysis and the prediction of cutting forces and deflections in end milling of thin-walled components. The researchers used the theoretical analysis and the Finite Element Method (FEM) to calculate the deflection of the component and tool, and it was verified that the machining errors almost coincided with the experimental values. These results are very useful in predicting the machining accuracy as well as for simulation the end milling process.

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Some idiographic methods have been presented in the current study. As for the problems of high efficiency and high precision machining of thin-walled components, beside the new approach of ultra-high speed machining, other efficient methods such as the numerical control (NC) compensation using of the FEM, tool path optimization, and cutting parameters optimization can be applied using common CNC machining.

The thin-walled section parts can be fabricated using the sheet metal process. However, this particular process involves a secondary process i.e. assembly process. By machining the part, it is possible to machine a large product and this ends up with the thin-walled product. Machining a large product requires a huge amount of machining time, and thus, it is not appropriate. To overcome this problem, it is advisable to use high speed machining. This machining process normally introduces a self excitation vibration or chatter. The chatter can be avoided using several techniques. One of the methods used to eliminate chatter is by varying the cutting input parameters. This method has been carried out by Smith & Tlusty (1992), as well as Tarng & Li (1994). The technique involves recognizing the changes of the spindle drive current (Soliman & Ismail, 1997), and when the chatter is encountered, the machine parameters are changed to compensate the error. However, the drawback of this particular technique is that it requires pricy sensor that leads to high manufacturing cost.

Alternatively, the problem could be solved by controlling the workpiece stiffness, i.e. in manually controlling cutting tool path strategy (Smith & Dvorak, 1998). In the recent years, Ariffin (2006) in his work has successfully combined finite element method (FEM) and genetic algorithm (GA) to automatically create tool path by incorporating workpiece stiffness. However, the tool path strategy is sensitive to the workpiece geometry features, such as round, fillet, and chamfer. In addition to that, the tool path has to consider the tool travelling distance, which is crucial in for the cost calculation.

Based on above problem statement and taking advantage of a successful work carried out by Ariffin (2006) at the University of Sheffield, United Kingdom, an extension of the method was performed while a new model of tool path strategy was developed and the parameters of the geometric features and tool travelled distance were also incorporated.

Meanwhile, the work of genetic algorithm optimisation has successfully been created and implemented at the University of Sheffield Server by Ariffin (2006). The work consisted of finite element simulation for a thin-walled section specimen taken from Smith & Tlusty (1992). It has been proven that this particular technique can be applied to find the workpiece stiffness.

PREVIOUS RELATED WORK

The problems involved in machining have been described by Tlusty *et al*. (1996) who identified the main problems that occurred when long end–mills were used in high-speed milling of thin features. Rao (1995) proposed a method for machining thin webs that are supported either by positioning them directly against the table of the machine tool or using specially designed fixtures. Fairman (1995) studied the main factors contributing to the occurrence of vibrations during machining. Although the method used was varying the axial and radial depths of cut as well as the spindle speed and tool geometry, it did not successfully produce a chatter free part. Altintas *et al*. (1992) developed a dynamic model for simulating peripheral milling for very flexible plate type structures, but the work was confined to a low spindle speed range. Kline *et al*. (1982) proposed the use of plate and beam static theory to develop a FEM to statically model the plate and beam theory for the end mill. Ariffin (2006) developed and used the FEM simulation for a thin wall section specimen taken from Smith & Dvorak (1998). It was shown that the simulation combined with optimisation algorithm (GA) had worked very well in finding the optimal tool path for a complicated product and as a result, the manufacturing cost was greatly decreased.

In addition, the researchers have also proposed some general principles that should be followed when designing parts by incorporating thin features. In particular, the design should allow such features to be supported somehow by their adjacent features/structures during the machining, such as that performed by Tlusty *et al*. (1996) for machining thin feature using the stiff, uncut portion of the workpiece to support the flexible section being cut. Thus, the stiffness of the webs would be much higher in the direction of the axial cutting forces.

SIMULATION

In this research work, the simulation was carried out using FEM software called ABAQUS. In this software, the first step was to model the workpiece. For this simulation, the dimensions of the workpiece are 600 mm x 300 mm x 25 mm. The next step was to mesh the model as shown in *Fig. 1*. After that, all the constraints and the load were incorporated into the model. The fully constrained model is shown in *Fig. 2*.

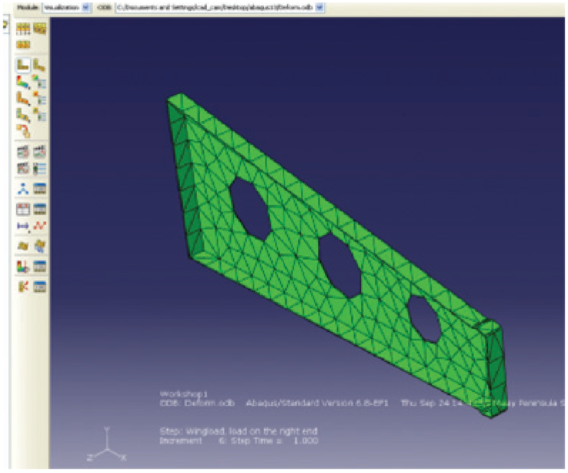

Fig. 1: Workpiece with appropriate mesh

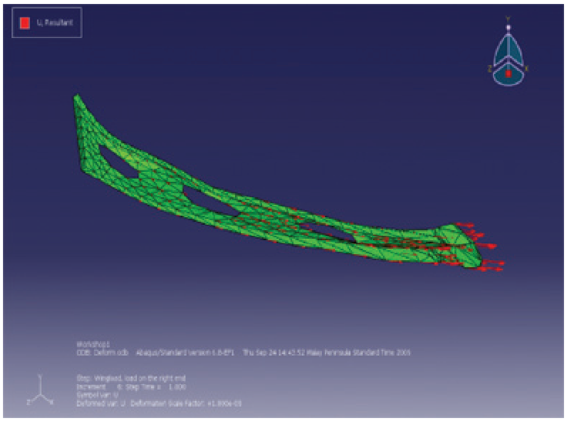

Fig. 2: Constraint and load condition

The next step was to run the analysis and to check the results. The results of the ABAQUS could either be in the contour plot format or in term of a text file or even in the form of a graph, as shown in *Fig. 3* (the contour plot) and *Fig. 4* (the chart results). *Fig. 3* displays the residual stress results and the energy plot is illustrated in *Fig. 4*.

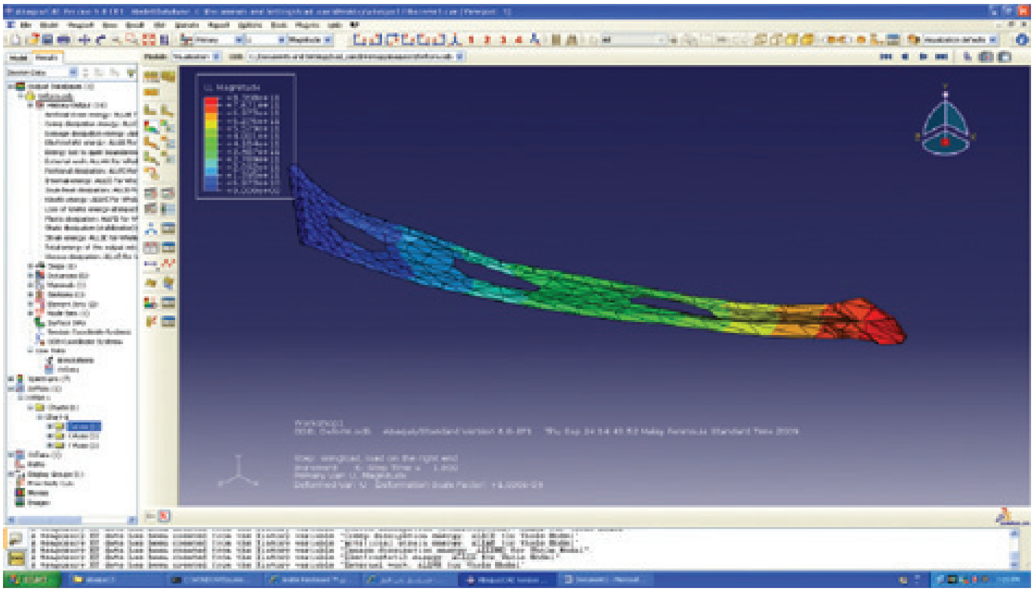

Fig. 3: The residual stress distribution after milling

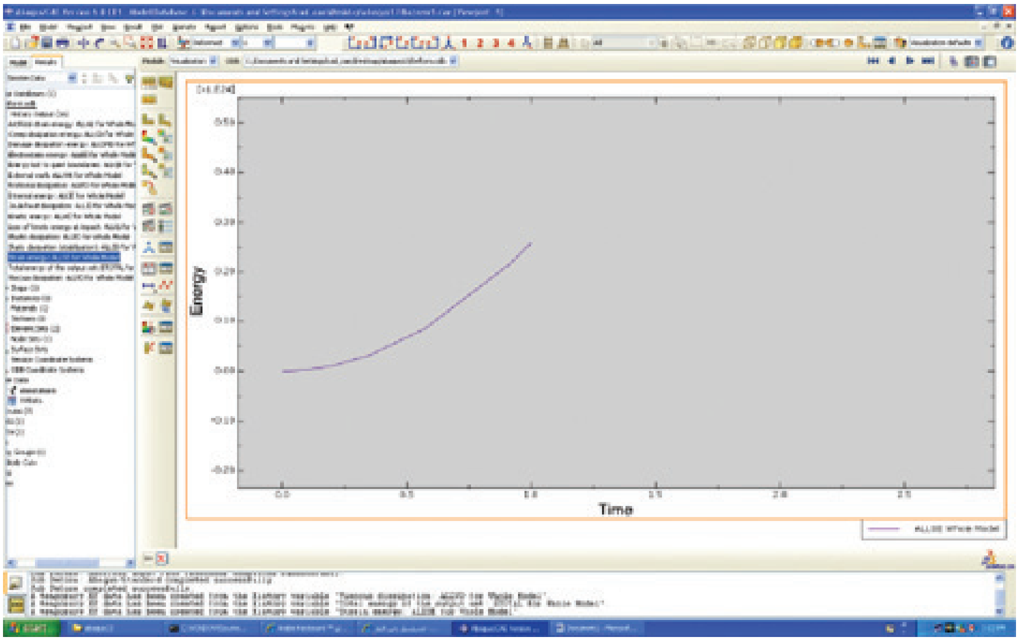

Fig. 4: Energy plot versus time

EXPERIMENTAL

The experimental results for the cutting parameters are listed in Table 1. In the simulation, the tool itself was assumed to have a rigid body, and therefore, it did not contribute to the acquired result.

TABLE 1
Parameters setting for the milling process cutting

Tool diameter	8 mm
Rake angle	15
Clearance angle	25
Tool helix angle	25 mm
Cutting edge radius	0.01 mm
Milling depth	26 mm
Feet rate	70 mm/min
Spindle speed	2000 rpm
Milling width	1 mm
Cutting environment	Dry cutting

The block having the same dimensions with the simulation model was machined to a 1 mm thick of thin-walled section. Detailed information of the specimen after the machining process is tabulated in Table 2.

TABLE 2
Dimension parameters of the specimen after machining

Total length	516.03 mm
Deforming length	516.03 mm
Gage length	516.03 mm
Width	200 mm
Thickness	1 mm

The tensile tests were carried out according to the ASTM 3039-95 standard. The specimens were subjected to uni-axial tension, as shown in *Fig. 5*.

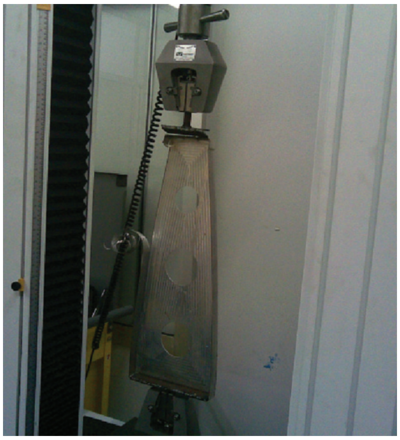

Fig. 5: Specimen under tensile test

Table 3 shows the strength of the material after the test has been carried out. The experiment has confirmed the simulation results that the ultimate stresses are almost the same. In the simulation, the stress was 1130.00 MPa, but this was 1139.40 MPa during in the actual testing.

TABLE 3
The results obtained during the tensile test after machining

Ultimate tensile strength (MPa)	Yield strength (MPa)	Young's modulus (MPa)
1139.40	547	432

Details of the results gathered for the actual testing are shown in *Fig. 6*, in which the graph illustrates the load that was applied against the extension until the break of the specimen.

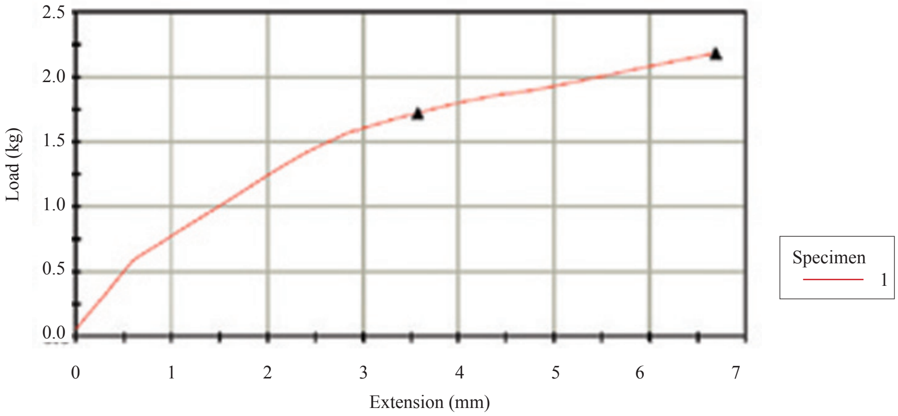

Fig. 6: The graph showing the tensile test result

Meanwhile, the condition of the specimen after the test is shown in *Fig. 7*. It is evidenced that the weakest point breaks when it cannot withstand the load.

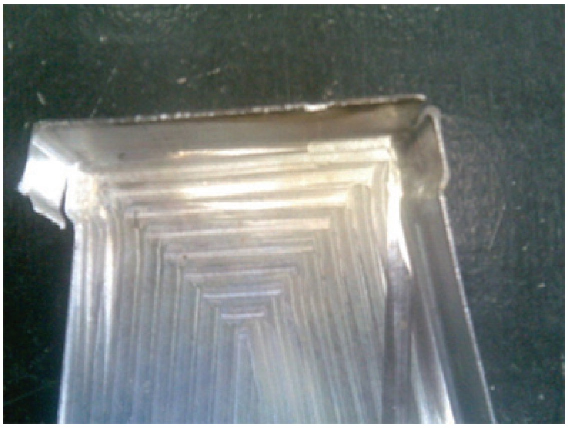

Fig. 7: Thin-walled work piece after the tensile test

CONCLUSIONS

The tensile test of the thin-walled workpiece was successfully simulated using the finite element models. A comparison of the results from the simulation and the experiment shows that there is a reasonable agreement between the simulation and the actual test. The correct tool path that is used for the milling process will ensure the quality of the produced product in term of the surface finished and also the strength of the product. In the future, this work could be extended by adding other tool path, such as the zigzag cut to compare it with the old tool path contour-parallel cut.

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