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3D Finite Element Modelling of Microdrilling on AISI D2

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***Abstract*-A 3D finite element model of microdrilling AISI D2 by using finite element method has been developed. The microdriling cutting tool was created by using CATIA whereas the finite element analysis was generated by using ABAQUS/EXPLICIT software. The constitutive Johnson – Cook material model regarding strain, strain rate and temperature to predict material plasticity and chip separation is used. The objectives of this study are to develop and analyse microdrilling simulation using Finite Element Method. In addition, the model is used to study the effect of chip formation by applying different type of meshing. Furthermore, to study the effect of different point angle tool geometry on cutting force and von misses stress distribution on AISI D2 work piece.**

Keywords: Microdrilling, FEA, Cutting Force, Simulation, Chip Formation

Introduction

Metal cutting is one of the most widely used manufacturing techniques in the industry and there are lots of studies that have been done investigating this complex process in both academic and industrial world. Through modeling machining operation, the machining performance can be predicted in order to obtain optimum productivity, quality and cost. Predictions of important process variables such as temperature, cutting forces and stress distributions play significant role on designing tool geometries and optimizing cutting conditions.

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Drilling is one of the most fundamental machining technologies and is moving toward high precision/high speed applications for productivity enhancement. The drilling cutting tools play a critical role for increasing the productivity of a cutting process. Although the price of a cutting tool itself is relatively low, the costs caused by tool failures are considerably higher. Therefore, from the viewpoint of cost and productivity, modeling and optimization of drilling processes are extremely important for the manufacturing industry. The poor removal of chips in deep drilling of small diameter is often the cause of tool breakage and poor quality surface. There are a lot of studies being conducted in area of drilling in order to identify a machinability of drilling. These macrodrilling studies include in the area of modeling of drilling process, vibration drilling, twist drill shape, modeling of drilling tool, tool wear, surface roughness, burr formation etc.

The demand for micro drilling i.e. drilling holes of diameter less than 1mm is gaining importance because of the increase in the use of miniature and micro devices. The major areas of application of micro drilling are automobile, aeronautics, electronics and medical fields. The process of micro drilling using drill bits is used for materials that have good machinability. The process requires simple set up and is characterized by shorter cycle durations. The EDM process is suited to difficult-to machine materials. However, the cycle times are longer and output is low. Thus, it can be used for producing holes of diameter smaller than those made using drill bits. The laser micro drilling process can produce the smallest holes of all the three processes and the productivity is more owing to shorter cycle times. The heat affected zone (HAZ) is also very small. The finite element numeric method is capable to predict mechanical stress, cutting forces and thermal. These are important information to analyze the desired cutting operation to prevent rapid tool wear and select best cutting parameter.

The objectives of this study were to develop and analyse microdrilling simulation using Finite Element Method. The effect of chip formation by applying different type of meshing also investigated. Finally, the effect of different point angle tool geometry on cutting force and von misses stress distribution on AISI D2 work piece also being investigated.

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Finite element model and adaptive meshing

In this study, finite element method was used to model and simulate three dimensional metal cutting operations. ABAQUS/Explicit v6.4 couple with explicit dynamic ALE modeling approach was used to conduct the FEM simulation. The explicit dynamic algorithm method was used to calculate the velocity and displacement by using central-difference operator. Through explicit dynamic software (time consuming analysis), the finite element equations are reformulated so that they can be solved directly to determine the solution at the end of the increment, without iterations. Deformable micro tool and workpiece with Ø100µm and Ø600µm, 50mm thickness round cylinder as workpiece were used as a finite element models. Two tools models are used, with different point angle 116° and 118° respectively. The tool material is tungsten carbide coated with titanium nitride (WC-TiAlN), which is widely used for cutting tools, and wear resistance surfaces, because is high melting temperature (≈2900°C) and extremely hard. Tetrahedral element mesh type (C3D10M) was used for both type of cutting tool with number of elements 8971 and 6614respectively.The workpiece material is AISI D2, as the most common tool steel known in industry. This tool steel is hard to be machined, that is why the tool of coated WC with TiAlN as recommended for machining tool steel workpieces. Different types of mesh element shape were used as shown in Table 1.

In the ALE approach, the general governing equations are solved for both Lagrangian and Eulerian boundaries in same fashion. The adaptive meshing technique does not alter elements and connectivity of the mesh. This technique combines the features of pure Lagrangian analysis in which the mesh follows the material, and Eulerian analysis in which the mesh is fixed spatially and the material flows through the mesh. The FEM simulation model is created by including workpiece thermal and mechanical properties, boundary conditions, contact conditions between tool and the workpiece as shown in Figure 1. Johnson cook material model was adopted in order to describe the plastic behavior at high strains, strain rate and high temperatures that can be utilized for simulation of machining process. By utilizing this model, the cutting force, Von Mises stress, temperature and chip formation can be observe with any types of cutting condition. This model normally utilized for analysis of plastic deformation which is perfectly rigid. This constitutive equation was established as equation (1) follows:

$$\sigma = (A + B\varepsilon^n)(1 + C ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_O})(1 - (T^*)^m) \quad (1)$$

Elastic-plasticterm viscosityterm softeningterm

Estimation of friction in a machining process is very complicated and has remained a challenge. It is widely accepted that the friction at the tool-workpiece interface can be represented by a relationship between the normal and frictional stress over the cutting edges of the tool. In this study, because of the high cutting speed and larger size of element in cutting area, the continuous chip generated cannot be observed during the cutting process, but can be modeled instead. Therefore the friction between the chip and end-mill has been taken into account. Based on the coulomb friction model in equation (2), it is assumed that the frictional stress on the cutter is proportional to the normal stress with a constant friction coefficient.

$$\tau_{fric} = \mu\, p \quad (2)$$

where τ_{fric} is the friction shear stress, µ the COF and p the normal contact pressure

Table 1: Details of element mesh shape on workpiece

Element Shape	Name code	Geometric Order	No. of Element	No. of Node
Hexahedral	C3D8R	linear	20090	24714
Hex-dominated	C3D8R	linear	19320	23442
Wedge	C3D6	linear	33330	20604
Tetrahedral	C3D10M	Quadratic	91264	131518

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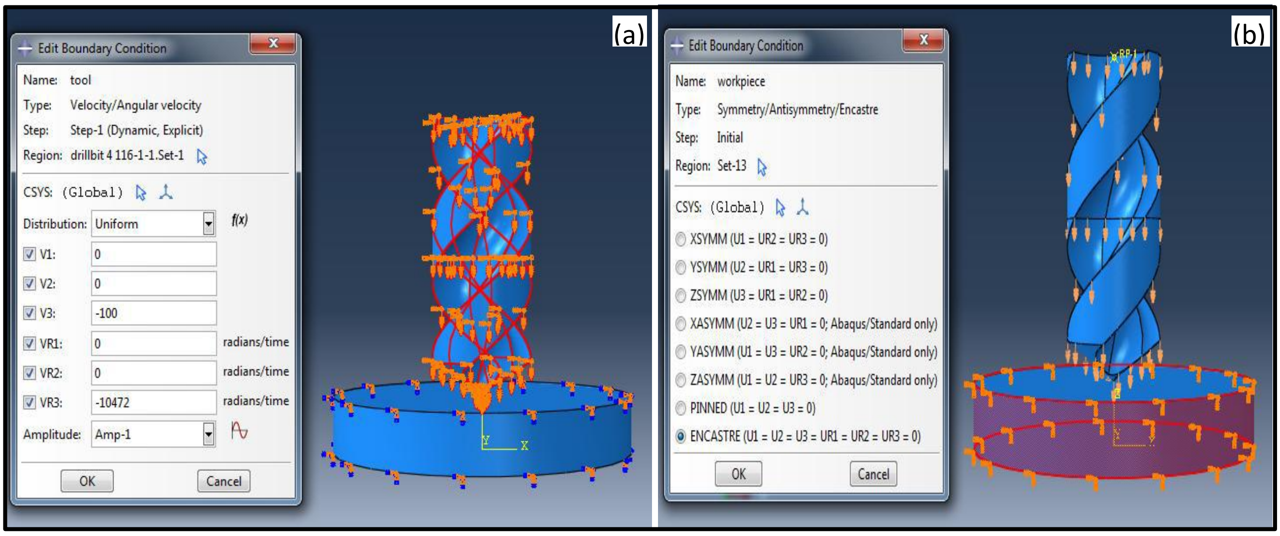

Figure 1: Boundary condition (a) Cutting tool (b) workpiece

Simulation result and discussion

a. Influences of different shape of meshing on chip formation

Figure 2 shows the result simulation based on step time increment. Chip formation was formed when the micro cutting tool cut through the material workpiece. It shows different type of meshing on the workpiece used such as Hexahedral, Hex-dominated, Wedge and Tetrahedral. At the beginning of the cutting, simulation shows for all type of meshing are the chip formation produced are continuous chip, then suddenly it changes to discontinuous chip at the end of experiment. Compare to the Tetrahedral, this type of meshing produce continuous chip from the beginning until end of step time increment. This situation happens probably due to the number of node and element generated where larger number of node and element will get finer result but takes longer time of analyzing. Tetrahedral with geometric order in quadratic has largest number of node and element thus give better result compare to other shape of meshing. Thus, Tetrahedral has been chosen as shape of meshing for work piece in the model of simulation to get result of cutting force and Von Mises Stress.

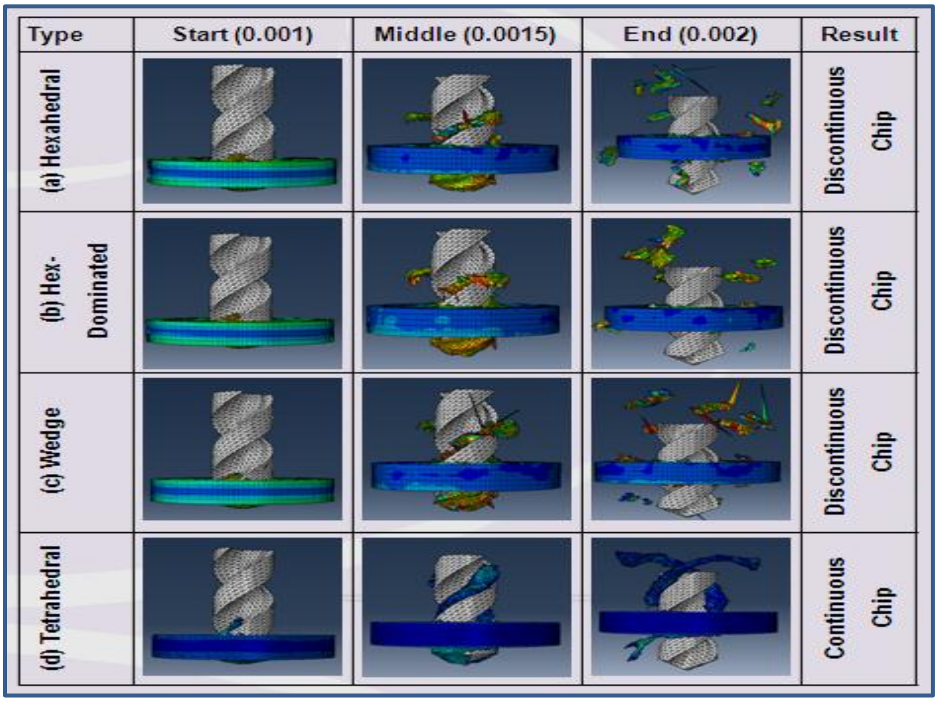

Figure 2: Chip formation produced in step time increment based on type of mesh

Influences of tool geometry on cutting forces generation

Figure 3 shows the cutting forces result for tool bit with point angle 118° and 116° during start of drilling and end of process respectively. While Figure 4 shows the comparison of cutting force result. The FEM analysis result shows that the different point angle of tool bit affect the cutting force generation on the workpiece. The magnitude of the cutting force generated at the beginning of cutting process is 10.04N for tool bit with point angle 118° while for tool with point angle 116° the value is 5.44N,. It's mean that the value of cutting force at tool bit with point angle 118° is twice higher compared to tool bit with point angle 116° at the beginning of process. Meanwhile, the magnitude of the cutting force start to increase at the middle of step time increment which is the maximum cutting force for tool bit with point angle 118° is 75N and tool bit with point angle 116° is 70N.

At the end of step time increment, the magnitude of cutting force form for tool bit with point angle 118° is 20.77N and this value is higher compare from the value of cutting force at the beginning process. The percentage of cutting force increase is 51.66%. For the tool bit with point angle 116°, the same situation happened which is the value of cutting force higher at the end of the process compare to value of cutting force at the beginning of this experiment. The value of cutting force for the tool bit with point angle 116° at the end of process is 14.42N and the percentage of cutting force increase is 62.27%. By comparing the values of cutting force at between of two type of tool at the end of experiment, it appears that tool bit with point angle 118° produce higher value compare to tool bit with point angle 116°.

The value of cutting force is lower at the beginning process due to the tool geometry used is sharp and in good condition. The increasing of the cutting forces generation during the micro drilling process is due to appearance of tool wears on cutting tool. The cutting force produce will cause the tool become easily fractured. The tool tip chipping will happen even the cutting force generate is small. When the cutting force gradually increase throughout the process of machining, the tool will break because of it reach the maximum principle stress value at the part.

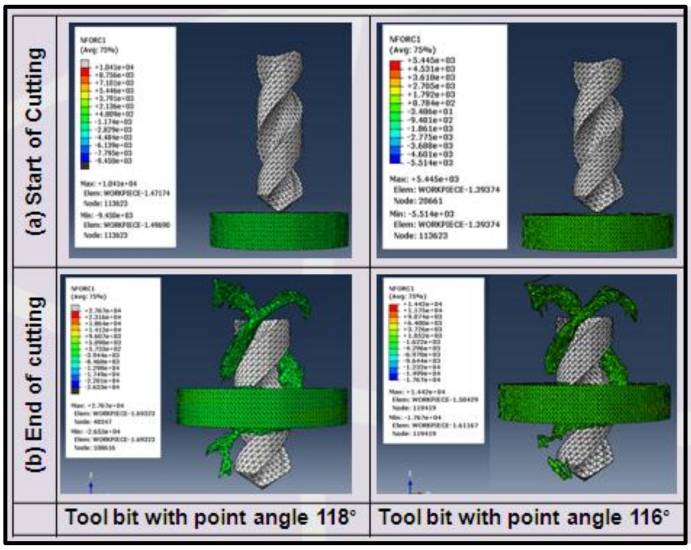

Figure 3: Cutting force simulation result

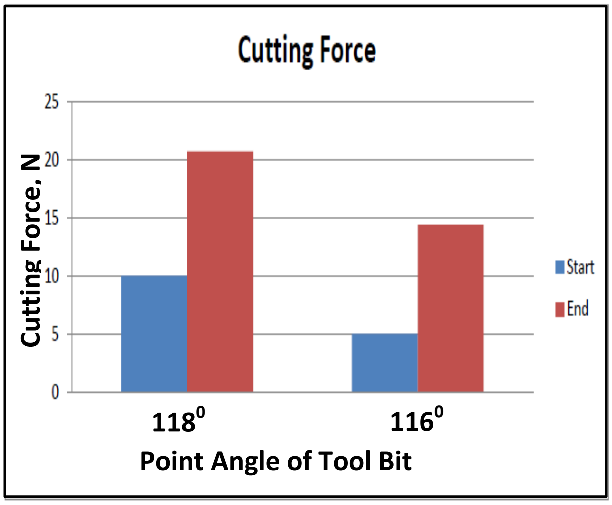

Figure 4: Comparison cutting force result

Influences of tool geometry on Von Mises stress distribution

Figure 5 shows the Von Mises stress simulation result for tool bit with point angle 118° and 116°. While for Figure 6 shows comparison of Von Mises Stress magnitude result between tool bit with point angle 118° and 116°. The value of Von Mises stress distribution on the work piece during micro drilling process show a significant increase from beginning until at the end of the cutting process. Both types tool geometry is almost same Von Mises stress result at the beginning of process which is less than 5MPa. At the end of the cutting process, the result of Von Mises stress for both type of tool is increasing. However, the highest percentage in value of the Von Mises stress is at tool bit with point angle 116°. The value increase about 51.62% from 3.62 MPa to 7.64 MPa. Besides that, the Von Mises stress result on tool bit with point angle 118° is higher than tool bit with point angle 116° at the end of cutting process with the percentage of different is 7.06%. In fact, the range of point angle used in conventional drilling process is range between 116° and 118°. As a result, it is can be consider that the tool bit with point angle 116° is more suitable used in micro drilling process for AISI D2 work piece. The predicted values of Von

Mises for the developed model are in good agreement with results by Md Irfan [4] and P. Seema Rani [5].

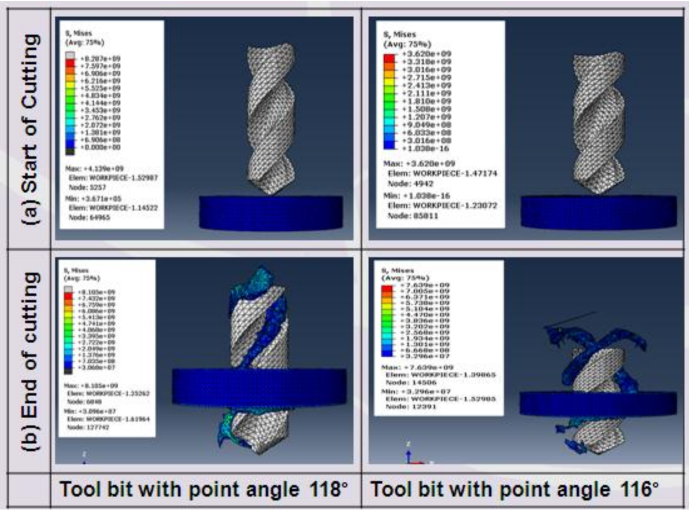

Figure 5: Von Mises Stress result

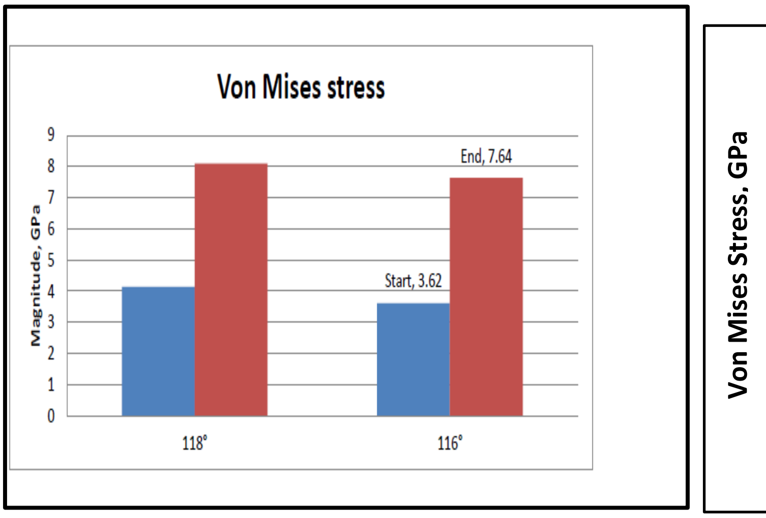

Figure 6: Comparison Von Mises Stress result

IV. Conclusion

Three-dimensional models of simulation for micro drilling process have been successfully developed by using finite element method. The result of simulation in term of cutting force and Von Misses stress has been identified and analyzed. The result will become finer (tetrahedral) by using the right shape of meshing on the work piece during the simulation process. Different type of geometry on cutting tool gives different result with different taken time of analysis. The result obtained shows clearly that the micro drill with point angle 116° have less Von Misses stress and cutting force. Having less stress can give longer tool life to drill bit before breakage while less cutting force will prevent cutting tool from wear. Thus micro drill with point angle 116° is more suitable used in micro drilling process compare to micro drill with point angle 118°.

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