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3D Finite Element Modelling of Drilling Process of Al2024-T3 Alloy with solid tooling and Experimental Validation

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Abstract

Drilling is an indispensable process for many manufacturing industries due to its importance for assembling components. This study presents a 3D finite element modelling (3D FEM) approach for drilling process of aluminium 2024-T3. The 3D model of tool for two facet HSSCo and four facet HSS were generated base on the detailed geometry. The simulations were carried out for both drills in different cutting conditions. The numerically obtained thrust forces were compared against experimental results. The tool stress distribution, chip formation and temperature distribution in the chip area were determined numerically. The results confirm the ability and advantage of 3D FE modelling of simulating the drilling process.

Keywords: Finite element modelling, drilling, force, chip, temperature distribution.

1. Introduction

The drilling process is one of the most significant machining process for many industries such as medical and aerospace, and has considerable economical importance in the industry [1]. Several studies performed experimental drilling investigation to consider the effect of machining parameters, tool materials and coatings. However, numerical simulation (e.g. by using finite element modelling) of metal cutting process is frequently preferred to achieve information about machining process.

The main advantage of this technique is reduction in development cost and time, mainly due to the availability of high computational power, to predict parameters such as stress, cutting force, temperature, strain and strain rate, which are difficult or impossible to detect experimentally [2].

The benefits of 3D FE modelling have been highlighted in previous research. Ozden et al. [1] studied the 3D finite element modelling of the drilling process to investigate the effects of machining parameters on drilling Ti6Al4V with coated carbide twist drills. Another study aimed to emphasize the importance of 3D drilling modelling performance of the twist and three flute drills of Al7075-T6 aluminium alloy [3].

In this study, a 3D Lagrangian finite element-based model of the drilling process was carried out in order to demonstrate the priorities and reliability of 3D FE model developed. The model was implemented and experimentally validated by using data on cutting forces. The drilling performance of two and four facet drills were evaluated in terms of the thrust force and chip formation.

2. 3D finite element modelling

The 3D model for drilling Al2024-T3 alloy was simulated using an explicit dynamic, time integration method by employing a Lagrangian FE formulation to perform coupled thermo-mechanical transient analysis. The AdvantEdge® FEM software (by Third Wave Systems) was used to implement the FE model.

2.1. Tool modelling and cutting configuration setup

In this study, the selected cutting tools were Dormer HSS and HSS cobalt. Table 1 shows the detail of characteristics of the tool geometry. Fig. 1 shows the 3D CAD model of the tool and initial FE model geometry setup.

The workpiece boundary nodes were fixed in the *X, Y* and *Z* bottom directions, and the tool enforced to constrain the motion of the drill in all directions except the *Z* translation and *Z* rotation. The feed was applied by moving the tool along the *Z* direction toward the workpiece. Tool and workpiece were kept in dimensions to maintain steady state cutting conditions and minimum simulation time. The cutting tool was considered as a rigid body and the workpiece was considered as a viscoplastic material. Tool and workpiece were meshed with 4-nodes tetrahedral elements type. The total number of workpiece elements and nodes were 7216 and 1639 respectively. In terms of tool mesh the 4-facet and 2-facet drills were generated with 34255 elements-9439 nodes, and 31006 elements-9185 nodes respectively. After preliminary evaluation tests carried out in previous studies [4], the initial meshing parameters of the workpiece were set as 2 mm and 0.001 mm in terms of maximum and minimum element size, respectively. The maximum element size of the drill was set at 1 mm and the minimum at 0.001 mm. A higher mesh density was considered in the area where the chip was expected to form, i.e. near the cutting zone and tool cutting edge radius, in order to increase the accuracy of the computed outputs. In the Lagragian formulation, the primary mesh altered significantly due to elemental distortion, hence an adaptive-meshing technique was applied to avoid the inaccuracies problems [5].

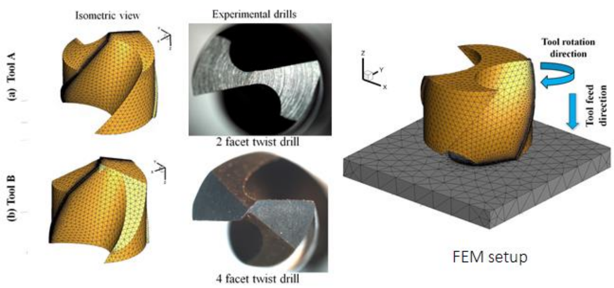


Figure 1. Tool 3D model and experimental image (a) two facet HSSCo (b) four facet HSS and FE model for drilling setup

2.2 Constitutive material and friction models

The constitutive model used for calculating the Aluminium 2024-T3 flow stress is known as Power Law (Eq. 1) [6]. This model is based on the stress update method that extends small-strain stress update algorithms to the finite deformation range at a kinematic level to provide a constitutive model for different materials. The default formulation of this constitutive model is:

$$\sigma(\varepsilon^{p}, \dot{\varepsilon}, \mathrm{T}) = g(\varepsilon^{p}).\Gamma(\dot{\varepsilon}).\Theta(\mathrm{T}) \qquad (1)$$

The friction phenomenon at the chip-tool interface was modelled using the Coulomb law. Based on the experimental research results and related studies [7] a constant friction factor of 0.7 is used in the finite element (FE) model.

3. Experimental procedure for FEM validation

Dry drilling experiments of Al2024 were carried out using a CNC Deckel Maho DMC 835 machining centre. A four component rotary Kistler dynamometer type 9123C and data acquisition unit used to record thrust force and torque (see Fig. 2). Experiments were performed with constant cutting speed (94.2 m/min) and feed rates (0.04, 0.4 mm/rev).

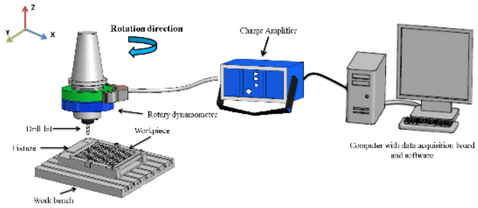


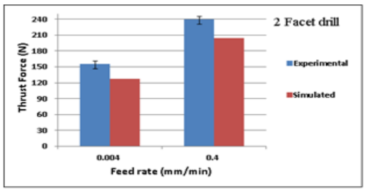
Figure 2. The schematic representation of the experimental set-up.

Table 1 Cutting tool specifications

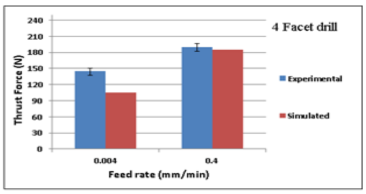
	Tool A	Tool B
Material	HSSCo	HSS
Code	A920	A120
Geometry	2 Facet	4 Facet
Diameter (mm)	6	6
No of flutes	2	2
Helix angle	40°	30°
Chisel edge angle	130°	130°
Point angle	130°	130°
Web thickness (mm)	0.6	1

4. Validation and discussion of the results

Fig. 3 shows the numerical force results at different cutting conditions. In both experiments and simulations no coolant was applied and dry condition was carried out. The discrepancy between experiments and the model is approximately 20%. The simulated results were underestimated.



(a)



(b)

Figure 3. Comparison of FE Model and experimental thrust force

The maximum deviation between the experimental and numerical results is obtained from the drilling processes under drilling conditions V_c = 94.2 m/min and f_z = 0.4 mm/rev with the 2-facet drill. The variation of the thrust force result was obtained at different cutting conditions. In the higher cutting condition, thrust force increased, as expected however the variation of the force depending on the drill type. The thrust forces obtained with the 4-facet drill were about 15-20% less than 2-facet drill.

Fig. 4 shows the chip formation, thrust force and torque at different angular position of the 2-facet (Fig. 4(a)) and 4-facet (Fig. 4(b)) drills. The thrust force variation is also visible in the numerical results. The 4-facet drill reaches to the steady state condition in less angular length of cut than 2-facet drill. In terms of chip formation with 4-facet drill tends to be curlier than 2-facet drill.

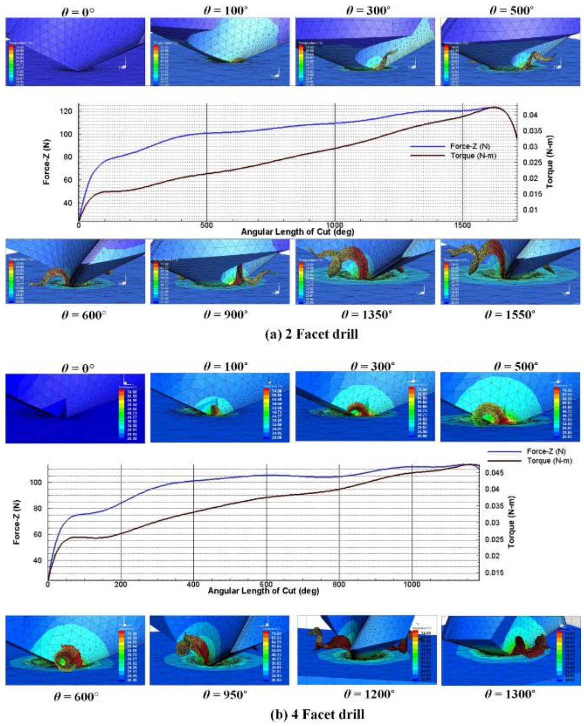


Figure 4. Chip formation, thrust force and torque obtained at the end of the simulations (a) 2-facet drill (b) 4-facet drill at f_z = 0.04 mm/rev

5. Conclusion

3D finite element modelling of the drilling process of aluminium 2024-T3 alloy with two and four-facet drills geometry were carried out at different cutting conditions. Comparable results of FE model and experimental thrust force were observed. The performance comparison of the simulations result reveals the 4-facet drill geometry mainly in terms of thrust force and stress distribution along the cutting edges demonstrates a better performance. Higher force obtained at the same cutting condition with 2-facet drill and the maximum stress occurs on the chisel and cutting edges.

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