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An evaluation of cutting edge and machinability of inclined planetary motion milling for difficult-to-cut materials

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Abstract

Recently, the applications of difficult-to-cut materials (e.g. CFRP and titanium alloy) are increasing in the aviation and automotive industries. Conventional drilling tools occur burr and/or delamination on their materials. The inclined planetary motion milling consists of two independent spindle motions which are tool rotation and revolution. Eccentricity of the tool rotation axis is realized by inclination of few degrees from revolution axis. The movement of eccentric mechanism can be reduced by comparison with that of the orbital drilling. The inclined planetary motion milling reduces inertial vibration and decreases cutting force. According to the geometrical cutting principle, it can be decreased delamination and burr of their materials, comparing to orbital drilling. In the study, the authors revaluated optimum cutting condition for titanium alloy by use of the experimental design and carried out its repeatability test. And the authors developed on measurement and evaluation method for cutting edge profiles and examined the comprehensive discussion of the relationship among change to cutting edge wear and surface texture and circularity on drilling hole, tool rotation torque after based on the practical drilling experiments.

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Keywords: CFRP; Orbital drilling; Herical milling; Inclined planetry milling; Tool wear

1. Introduction

Recently, the applications of difficult-to-cut materials (e.g. CFRP and titanium alloy) are increasing in the aviation and automotive industries. Conventional drilling tools occur burr and/or delamination on their materials. Field-portable size machine tools utilized in aviation production site have been required. The orbital drilling is one of an effective drilling technique for the industries. However this technique has some disadvantages such as increase of cutting force due to cutting with tool center point, inertial vibration generated by revolution and its high installation cost. In order to improve the disadvantages, the authors have proposed the inclined planetary motion milling.

The inclined planetary motion milling consists of two independent spindle motions which are tool rotation and revolution. Eccentricity of the tool rotation axis is realized by inclination of few degrees from revolution axis. The movement of eccentric mechanism can be reduced by comparison with that of the orbital drilling. The inclined planetary motion milling reduces inertial vibration and decreases cutting force. According to the geometrical cutting principle, it can be decreased delamination and burr of their materials, comparing to orbital drilling.

The author has established a cutting model of the orbital drilling and clarified its machinability and proposed the cutting tools having particular cutting edge for CFRP drilling according to the past studies [3-5]. Delaminations of workpiece and mechanical vibration by the cutting principle of orbital drilling were examined throughout the past studies result. In order to bring solutions to the orbital drilling technique, the authors have modified cutting mechanism principle of the orbital drilling, which named as the inclined planetary milling. Its axis of tool rotation is not parallel to the axis of planetary revolution. The benefit of the inclined planetary milling mechanism is reduction of unbalanced mass of eccentricity from that of the helical milling and it improves revolution speed and drilling quality. It also reduce vibrations by revolution and thrust cutting force,

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which is generated on a bottom face of a cutting tool. In previous study, the authors also have tried to verify the availability of drilling into titanium alloy, however the tool wear and tool life time of the inclined planetary motion milling have not been evaluated. Evaluation of tool wear is important for difficult-to-cut materials to improve the machinability and it could be beneficial information for extension of the tool life time.

In the study, the authors revaluated optimum cutting condition for titanium alloy by use of the experimental design and carried out its repeatability test.

In addition, the measurement and evaluation methods for cutting edge profiles were developed and the comprehensive discussion of the relationship among change to cutting edge wear and surface texture and circularity on drilling hole, tool rotation torque after based on the practical drilling experiments were examined.

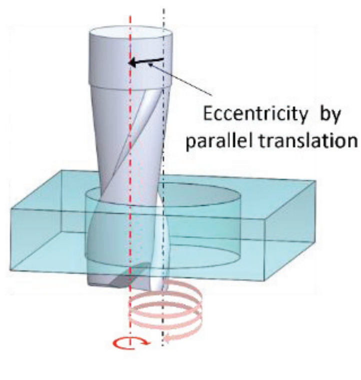
2. Inclined planetary milling

2.1. Principle

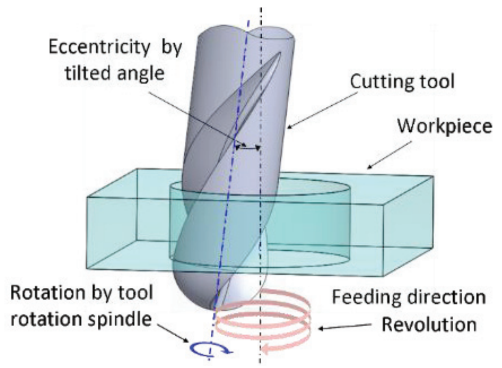
The drilling methodology of the inclined planetary milling is similar to helical milling techniques by use of a machining centre. Both of them consist of a tool rotation spindle and a revolution motion unit. The difference of them is how to realize eccentricity of their mechanisms as shown in figure 1. In the case of helical milling, the axis of tool rotation spindle shifts parallel to the axis of revolution. On the other hand, the tool rotation axis of the inclined planetary milling is inclined from the revolution axis and a tip of a cutting tool is shifted eccentrically. The inclined angle is adjustable from 0 to 3 degrees. In the case of the helical milling, the outermost cutting edges penetrate workpiece and the bottom layer is delaminated. On the other hand, in the case of the inclined planetary milling, penetration is caused by the inner cutting edges not the outermost cutting edges because of inclined tool rotation axis. When penetration occurred, the inner cutting edges penetrate firstly then the outermost edges enlarge the drilled hole and the sequence can avoid generation of delaminations and burrs. The diameter of a target bore is controlled by a tool diameter and the eccentricity, which consists of the inclined angle and the tool length from the centre of inclination as shown in figure 2.

2.2. Inclination angle

Control of inclination is necessary to obtain an arbitrary eccentricity of the inclined planetary milling. Figure 2 illustrates schematics of geometrical milling model of the inclined planetary milling with a square end-mill (a) and a ball end-mill (b) where *r*: tool radius, *D*: diameter of hole to be drilled, ϕ: inclination angle and *L*: distance between tool tip and inclination pivot. For the case of square end-mill, the inclination angle (ϕ) is calculated by eq. (1) considering with the shape of cutting tool, r, and L and eq. (2) represents for the case of ball end-mill.

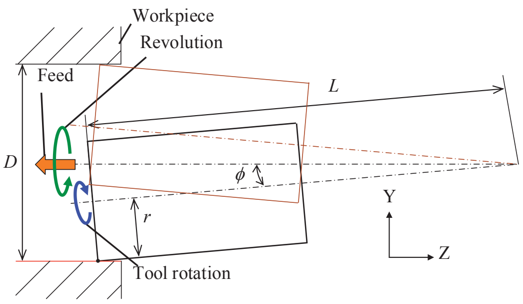


(a) Helical milling

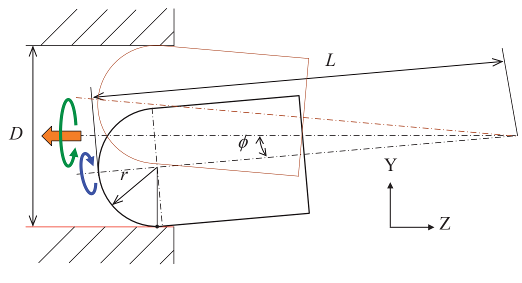


(b) Inclined planetary milling

Fig. 1. Difference of interpolated bore milling method



(a) Square end-mill



(b) Ball end-mill

Fig. 2. Schematic of cutting by inclined planetary milling