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Research on Cutting Force Model of Triangular Blade for Ultrasonic Assisted Cutting Honeycomb Composites

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Abstract

The triangular blade is a primary tool for ultrasonic assisted cutting honeycomb composites. The machining parameters optimization for cutting force minimization, it is proven important for a better surface quality, higher machining efficiency and lower tool wear to be obtained. Based on the analysis of the ultrasonic assisted cutting of honeycomb composites and the triangular blade movement law, the cutting force theoretical model was established. The relationship between the cutting force and the machining parameters was expressed explicitly. The experiments of blade cutting of honeycomb composites with ultrasonic and non- ultrasonic assistance were executed by the control variable method. The effects of the cutting depth, the blade inclined angle and the deflection angle on the cutting force were verified, which were reflected by the cutting force theoretical model. The theoretical foundation was provided for further optimizing other process parameters during ultrasonic assisted machining, such as both the acoustic and tool structure parameters.

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Keywords: Cutting force model; Ultrasonic assisted cutting; Machining parameter; Triangular blade; Honeycomb composite

1. Introduction

The honeycomb composite has been widely utilized in aerospace and other fields, due to excellent performance, such as in high specific strength, high specific rigidity, low density, corrosion resistance, impact resistance and good insulating properties. The honeycomb composite is typical hard-to-machining material. It has an axial uniform distribution of the hexagonal prism grid with orthotropic characteristics and the supportive matrix is full of short fibers. During the traditional NC (numerical control) high-speed milling [1], it is proven difficult for the composite to be stably fixed on the machine tool workbench and the milling constitutes a dusty operation. Certain problems during NC high-speed milling are prone to occur onto the machined surface, such as the fiber breakage, the matrix cracking and the grid collapse. These defects and damage highly reduce the mechanical properties of structural parts and consequently both the product safety performance and service lifetime are affected.

With an aim towards these problems during high-speed milling, a new processing technology, called ultrasonic assisted cutting, became apparent in recent years [2]. The problems during the traditional processing were solved to a certain extent. Certain corporations exist producing the NC machine integrated ultrasonic cutting process, such as the GFM, Creno and Dukane. They provide the optimal process solution for certain honeycomb composites. However the process solution varies along with the honeycomb composites of various mechanical properties in general. The manufacturers should understand the mechanism regarding the ultrasonic assisted cutting honeycomb composites in order for this new process to be improved.

The cutting force is a most important physical quantity demonstrating the processing state. The cutting force affects the holding state of honeycomb composites, the machining surface quality and the tool life. Certain scholars studied the mechanical properties of honeycomb composites [3, 4] and the behavior impacted by an external force or energy [5, 6]. Liu presented a mechanistic model for the cutting force in RUM (rotary ultrasonic machining) of brittle materials [7]. Schulze determined the machining force for various parameters on the short glass fiber reinforced polyester [8].

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In contrast, any previous literature regarding both the cutting force and the machining parameters selection during the ultrasonic assisted cutting of honeycomb composites, scarcely exist. For lack of scientific theory, the machining parameters selection was generally obtained through a large number of experiments during the actual production, which was of high cost and time-consuming. The establishment of the process resource quickly and accurately is the bottleneck of popularizing this process technology in a wider scope.

In this paper, based on the analysis of process technology and tool kinematics of ultrasonic cutting honeycomb composites with a triangular blade, the theoretical model of the ultrasonic assisted cutting force was established. The experiments were designed to be executed about cutting force with ultrasonic and non-ultrasonic assistance. The cutting force theoretical model was well demonstrated based on the experimental records. In addition, the effects of the cutting depth, the deflected angle and the inclined angle on the cutting force were analyzed through the experimental comparison. The research has a high significance on the mechanism of ultrasonic assisted cutting of honeycomb composites deep comprehension and the guide for the reasonable machining parameters selection.

2. Ultrasonic assisted cutting process

2.1. Ultrasonic assisted cutting technology with triangular blades

The triangular blade is a main tool type for the ultrasonic assisted cutting of honeycomb composites. It is mainly utilized during the rough machining of honeycomb structures, on the blanking and boundary trimming.

As shown in Fig.1, in order for the plane P on a honeycomb composite to be machined, the triangular blade is driven according to the following steps. Firstly the blade is rotated at an angle ψ encircling the axis Z' of tool coordinate system under the NC system control. Consequently, the blade is deflected at an angle α encircling the axis X' retaining the corresponding neutral surface consistent with the plane P. In order for the honeycomb composite to be stably fixed on the worktable for the machining stability to be ensured, the blade is usually inclined encircling the axis Y', forming the angle θ between the direction of the advancing speed and the blade central axis.

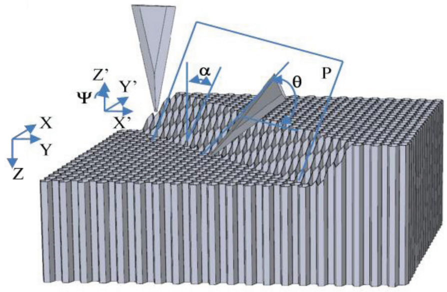

Fig. 1. Ultrasonic assisted cutting of honeycomb composite diagram

Following the attitude proper adjustment, the blade is moved into the honeycomb composite according to the programmed tool path and vibrates simultaneously at the ultrasonic frequency along the corresponding central axis. The former movement is controlled by the NC system, whereas the latter vibration is controlled by an acoustic system. The blade separates the cuttings from the work material of the honeycomb composites under the combination of these two movements.

2.2. Cutting process analysis based on kinematics

When the ultrasonic vibration with both the amplitude A and the frequency f affects the blade and the blade moves along the tool path with the speed $\boldsymbol{v_e}$ and the inclined angle θ, the blade displacement and velocity along the cutting direction are respectively:

$$s = A\sin(2\pi ft)\cdot\cos\theta + v_e t \tag{1}$$

$$v = 2\pi fA\cos(2\pi ft)\cdot\cos\theta + v_e \tag{2}$$

With various combinations of the cutting speed, the amplitude, the frequency and the inclined angle, two circumstances might exist:

- $v_e \geq 2\pi fA\cdot\cos\theta$

The blade speeds to the same direction with the $\boldsymbol{v_e}$ throughout cutting, which indicates the blade contact with the work material all the time. It is a continuous cutting process.

- $v_e < 2\pi fA\cdot\cos\theta$

The blade speeds to the opposite direction with the $\boldsymbol{v_e}$ in a certain period of the ultrasonic cycle. It was interpreted that the blade gradually disengaged from the work material during this period. The periodic discontinuous cutting process was formed between the blade and the work material in this situation. This contact mode of the tool and the work material was expected during the ultrasonic assisted machining.