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Feasibility study of the ultrasonic vibration filing of carbon fiber reinforced silicon carbide composites

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ABSTRACT

In this paper, ultrasonic vibration filing (UVF) is considered as a new method for inner surface machining of deep cavity component, which is made of carbon fiber reinforced silicon carbide composites (C/SiC). The mathematical models obtained by kinematics analysis are taken out to reveal the machining principle of UVF. The surface formation mechanism is explained by surface residual height theory. The surface roughness, machining force and the surface microstructure are investigated and compared between UVF, common filing (CF) and common grinding (CG). It can be found that different grain size has a large influence on the surface morphology, which indicated the machining quality could be improved by control of the grain size. Ultrasonic vibration amplitude is considered as the most important ultrasonic parameter in UVF, it has a big influence on surface quality and machining force. According to the research, UVF is an effective machining method for inner shape processing of deep cavity workpiece, as well as improving the topography of the machined surface. Compared with traditional machining methods, UVF have an obviously improvement in surface quality and shape precision.

1. Introduction

1.1. Introduction of carbon fiber reinforced silicon carbide (C/SiC) composites

Carbon reinforced silicon carbide (C/SiC) matrix composites are widely used inaero engine, rocket motor and reusable shuttles due to their superior mechanical and thermal properties. The Ceramic matrix composites (CMC) have many superior properties including high melting point, low density, good strength-to-weight ratios, high stiffness, excellent corrosion resistance, high temperature resistance and mechanical properties [1]. Those advantage characteristics makes CMC an attractive alternative to traditional materials such as advanced ceramics and high alloy steels [2]. Due to the excellent properties, CMC seem to be the most interesting materials in thermal protection system.

The functional properties of CMC like low thermal expansion, low friction coefficient and good tribological behavior play an increasing importance for new commercial applications like brake disks, advanced friction and clutch systems of brake industry [3]. A large number of inner surfaces need to be machined in CMC for many applications (especially in aircraft component machining). CMC are very difficult to machine due to their superior properties. Therefore, it is very important to develop cost-effective machining processes for CMC.

1.2. Introduction of ultrasonic vibration assisted machining

Many problems can arise in the creation of a part with a deep-cavity feature. The sidewalls can act as barriers, chip removal can become very difficult as machining proceeds; tool holders and adapters can even collide with the part. In grinding situation, the grinding wheel must be small enough and the tool holder must be long and thin enough to make sure that every corner of the workpiece can be machined. When the length to diameter ratio of the deep cavity workpiece is big enough, traditional machining method can't guarantee the shape precision and surface quality. For these reasons, the machining of deep-cavity components by traditional methods poses many challenges.

As a non-traditional machining method, Ultrasonic vibration assisted machining (UAM) have many advantages such as improved machining accuracy of the workpiece [4], reduced cutting force [5], reduced subsurface damage [6], and lengthened cutting tool's life [7]. In UAM, the material removal rate is greatly improved [8];surface damage such as thermal burns, physical and chemical properties changes can be avoided [9]. In addition, the surface roughness can be reduced by control the vibration amplitude and vibration frequency [10]. The ultrasonic cleaning

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function can help wash away the chips and remove excess heat more efficiently [11].

1.3. Purposes of paper

UAM is considered as an effective method for CMC processing [12], but there is no research focus on the deep-cavity workpiece machining. In this paper, we stated the conception of ultrasonic vibration filing (UVF) and firstly use it on C/SiC composites processing. The fundamental mathematic models are established to explain the working function of UVF, the performance of UVF on deep-cavity components machining is investigated by experiments. The models present the material removal mechanism in UVF and they also revealed the relationships between the ultrasonic vibration and surface formation. In this research, common filing (CF) and common grinding (CG) are compared with UVF to reveal the different machining quality of deep-cavity workpiece processing.

2. Model development

As shown in Fig. 1, there are two kinds of grain motions such as filing tool feed movement and the simple harmonic oscillation.

For simplicity, make the following assumptions for the object of study and the filing process:

(1) The grains on the filing tool evenly distributed on the surface;
(2) Ultrasonic vibration in the machining process is kept in a stable condition, i.e., amplitude and frequency have no changed;
(3) Abrasive grains are rigid spheres of the same size, and grain shape is invariable in the filing process.

2.1. The grain trajectory model of single abrasive

Based on the UVF kinematics analysis, establish the single abrasive grain trajectory model.

$$x = v_w t \tag{1}$$

$$y = A\sin(2\pi f t + \varnothing_0) \tag{2}$$

where v_w is feed rate, f is ultrasonic frequency, $\varnothing_0$ is ultrasonic vibration initial phase, A is ultrasonic amplitude, and t is time. According to the model can get the grain trajectory curve:

As shown in Fig. 2, the trajectory of single grain is in the same plane, assuming the ultrasonic vibration initial phase $\varnothing_0=0$, the trajectory length of single grain contact with material can be defined in the following equation:

$$L = \int_0^t \sqrt{{v_w}^2 + (2\pi f A\cos(2\pi f t))^2}\,dt; \tag{3}$$

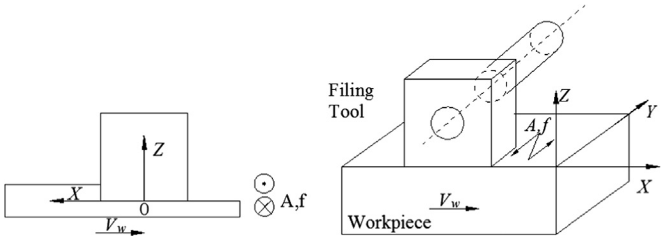

Fig. 1. The motion model of axial ultrasonic vibration filing.

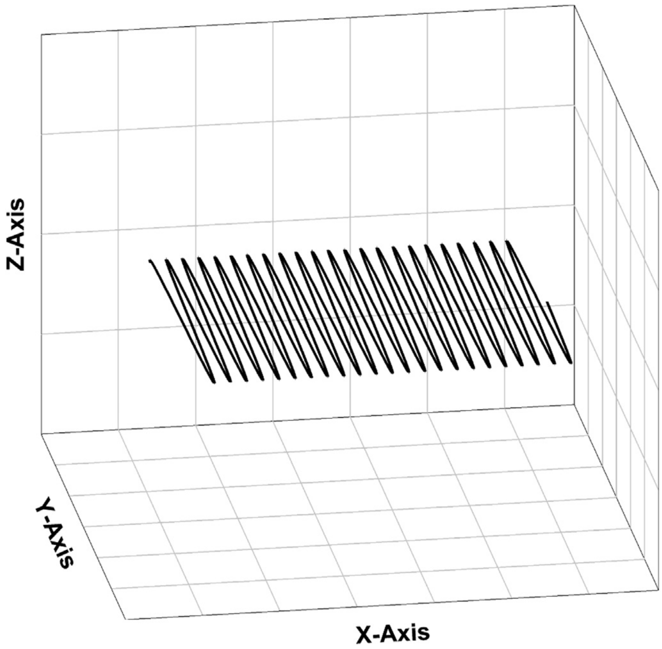

Fig. 2. The trajectory of single grain contact with the work piece.

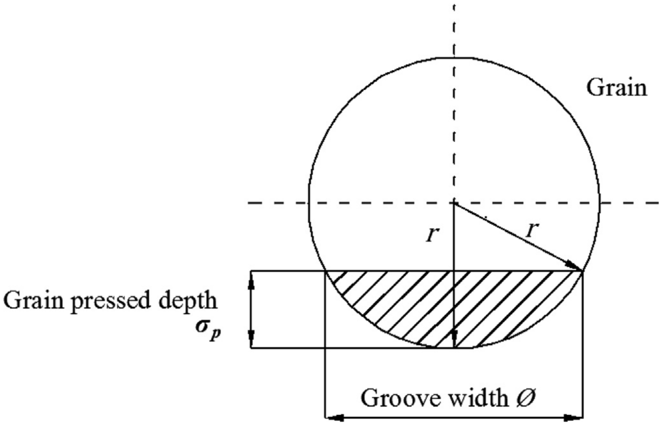

Fig. 3. The grain pressed depth.

2.2. Material removal rate modeling

Fig. 3 shows the pressed depth of single abrasive grain. Assume the depth of grain pressed into the material is σ_p, grain radius is r, and the grain trajectory groove width $\varnothing$ can be obtained:

$$\phi = 2\sqrt{r^2 - (r - \sigma_p)^2} \tag{4}$$

The cross sectional area of grain pressed into the material can be deduced:

$$S = r^2 \arccos\frac{(r - \sigma_p)}{r} - \frac{1}{2}\phi(r - \sigma_p) \tag{5}$$

Single grain material removal volume can be defined:

$$V = SL = \left[r^2 \arccos\frac{(r - \sigma_p)}{r} - \frac{1}{2}\phi(r - \sigma_p)\right] \int_0^t \sqrt{{v_w}^2 + (2\pi f A\cos(2\pi f t))^2}\,dt \tag{6}$$

Assuming the distributing density of dynamic grain on the wheel surface is N_{ds}, the contact area between filing tool and machining surface is S_1, the grain number through the dynamic filing area in unit time is $N=N_{ds}S_1$, the material removal volume in