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Investigations on grinding process of woven ceramic matrix composite based on reinforced fiber orientations

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ABSTRACT

Fiber orientations play the decisive role in grinding process of woven ceramic matrix composites, but the influence of woven fibers in grinding process is not clear. This paper studies the surface quality and grinding force by comparing different woven surfaces. Through a series of experiments in optimized sampling conditions, we analyze characteristics of the material surface topography height, wave distribution and surface support properties in details. And we find some outstanding characteristics of the surface microstructure. We also study the influence of grinding processing parameters on surface microstructure. The results show that machining surface which contains more parallel fibers is rougher and more keenness than gauss surface. Grinding wheel speed and depth of cut have great influence on surface topography and surface support properties. And it is discovered that grinding forces are also highly dependent on fiber orientations. The mechanism of the grinding phenomena is also analyzed in this paper according to knowledge of fracture mechanics and mechanical damage phenomenology. The research obtained will be an important technical support on improving the processing quality of woven ceramic matrix composites.

1. Introduction

Fiber-reinforced ceramic matrix composites (FRCMC) are widely used in aeronautic and space applications due to their excellent corrosion resistance, high temperature resistance [1] (C.G. papakonstantinou pointed out the curing temperature of SiC/SiC composite fabricated by CVI is as high as 1400 °C) and excellent mechanical properties. Although near-net-shape components can be produced, they usually require a subsequent machining to form the desired geometry, assembling tolerance and surface integrity. Grinding is especially needed to acquire high dimensional accuracy and surface finish.

Different from the machining of traditional single materials, it has been reported that the strong anisotropy and inhomogeneity of FRCMC causes many specific problems in machining, such as fiber pullout, matrix craze, interfacial debonding and fiber fracture. So it is an important issue to control the machining surface quality of composites in the manufacturing industry. Bhatnagar et al. [2] used a shear test to evaluate the in-plane shear strength of LFRC specimens and proposed a model for the prediction of cutting forces. Zhang et al. [3] found that the grinding forces for the multidirectional composites increase nearly linearly with raising the grinding depth. Hu and Zhang [4] studied the grindability of the multidirectional carbon fiber-reinforced plastic (CFRP) composites and found that the longitudinal surface roughness of ground multidirectional composites varied strongly with the local fiber orientations. Hu and Zhang [5] investigated the grinding performance of epoxy matrix composites reinforced by unidirectional carbon fibers and found that the surface integrity was highly dependent on the fiber orientation and the depth of grinding.

Lamon [6] identified three main damage modes under tension which appear in succession as the load increases on 2D woven C/SiC and SiC/SiC and they [7] investigated the influence of the random variables on tensile stress–strain behavior predictions. Then they [8] studied Matrix multiple cracking and fragmentation, characterized and modeled for unidirectional composites, when cracks are perpendicular to the loading direction and to fibers axis. Venu Gopala Rao et al. [9] found that the degradation of the matrix adjacent to the fiber occurred first, followed by failure of the fiber at its rear side. Sung et al. [10] evaluated the damage monitoring system based on the acoustic wave propagated by the impact damage and analyzed the output signal on the time-frequency domains through the wavelet transform method. Pineau et al. [11] proposed virtual testing applied to transverse multiple cracking of tows in woven ceramic composites, then the results were compared to

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experimental observations. Boccaccini and Winkler [12] found that crack deflection was thus one of the toughening mechanisms acting in these composites. Isik and Ekici [13] presented a new comprehensive approach to select cutting parameters for damage factor in drilling of GFRP to control surface quality.

According to the different mechanical properties of the matrix and reinforcement materials, the measurement methods and the assessment criterion of the metal materials' grinding surface are not suitable for FRCMC. Therefore it is necessary to establish a measurement method and assessment criterion for advanced composites. Some works had been done in this area. For example, Cao et al. [14] proposed a new method of evaluating grinding surface quality and found that the surface topography can be predicted by woven fibers orientation. Chuan-zhi, et al. [15] analyzed the main factors that affect the machined surface roughness of C/C composite based on the 3D evaluating parameters. Zhou et al. [16] used multiracial spectrum to characterize the surface morphology of carbon fiber reinforced plastic (CFRP).

Up to now nothing has been done to study systematically on the surface characteristics, microstructure measurement and grinding force of FRCMC based on weaving rules of reinforced fibers. This paper aims to acquire a better understanding of FRCMC grinding process. It recommends optimization parameters of sampling conditions. Compared with two machined surfaces contained different fiber orientations, this paper studies the surface characteristics and grinding force. It also investigates the relationship between grinding process and the composites surface quality. The study benefits the design, manufacture and application in the composites field.

2. Experimental details

2.1. Specimen

2.5D woven SiO_2/SiO_2 composite is utilized here because of its designable braiding technology. Braided precast bodies (Fig. 1) are woven together by weft yarn and warp yarn. The process is to weave weft yarn system vertical suspension, according to the design of the line and column for weft yarn into initial configuration. Then it is needed to put the warp yarn to position transformation with each other, each transformation is a position to lead a weft yarn.

Based on woven characteristics, vertical surface (surface A) and parallel surface (surface B) compared with weft yarn are selected to be the machined surface. There are microscopic photographs of two surfaces snapped by KEYENCE VHX-1000 shown in Fig. 2. So parallel fiber bundles are the main fiber bundles in surface A, and vertical fiber bundles are the main fiber bundles in surface B.

2.2. Grinding procedure

NC optical profile grinding machine MK9025 is employed for the diamond wheel grinding experiment and the experimental conditions are listed in Table 1.

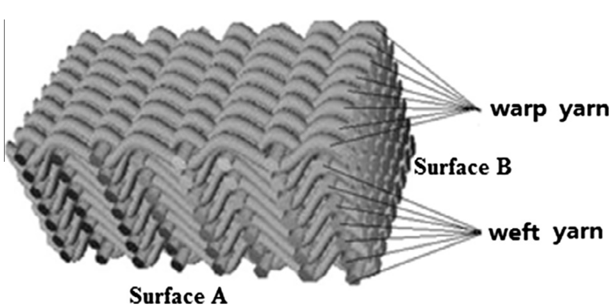

Fig. 1. 3D structure of 2.5D braided precast body.

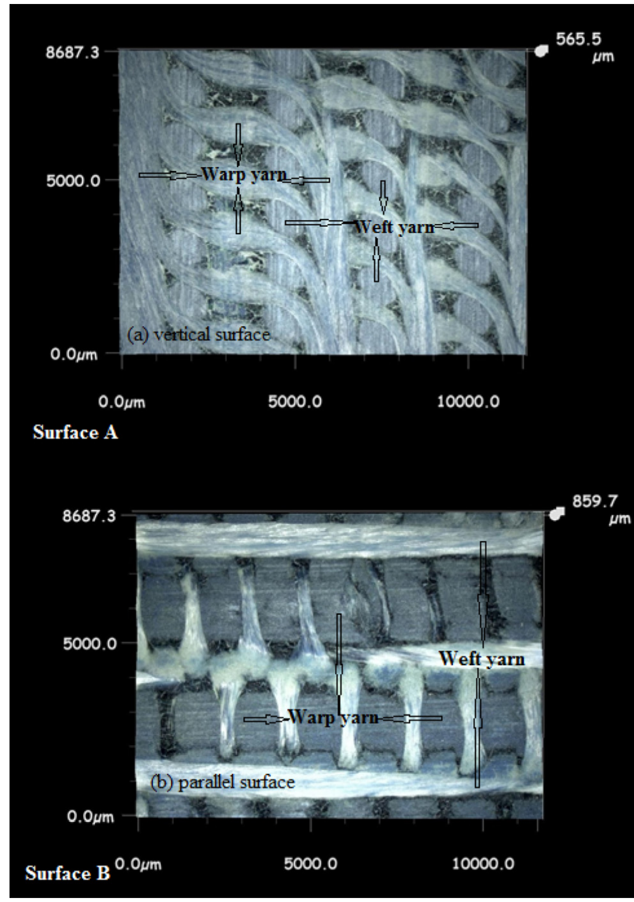

Fig. 2. Microscopic photographs of machined surfaces.

2.3. Surface microstructure measurement

NANOVEA ST400 is used to measure the 3D micro-topography. It uses an optical measurement principle called Axial Chromatism. There are some technical parameters such as vertical measurement range is 27 mm, vertical resolution is 280 nm, lateral resolution is 2.6 μm, and scanning speed is 1 m/s. According to the dark signal, the scanning frequency was 200 Hz. The topographical signal includes roughness, waviness and shape error. After filtering the shape error by leveling button, gauss filter is used to separate the roughness signal and waviness signal.

2.4. 3D micro-topographical mathematical models

Due to the instability and boundedness of two-dimensional evaluation parameters, three-dimensional morphology evaluation parameters are used to evaluate the waviness and roughness. Some 3D micro-topographical mathematical models are established according to international standard ISO 25178 in this paper. In the following formulas, the area is defined as A, the distance between every sampling point (x, y, z) and reference plane is defined as $H(x_i, y_j)$, the number of sampling points within sampling area is $M \cdot N$.

Root mean square height of the surface S_q is the reaction of profile deviation degree to the reference plane, is equivalent to the standard deviation σ in statistics, so it is an ideal evaluation parameter.

$$S_q = \sqrt{\frac{1}{MN}\sum_{j=1}^{N}\sum_{i=1}^{M}H^2(x_i, y_j)} \quad (1)$$