# Experimental study on grinding performance of high-density Nomex honeycomb core

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**Keywords:** high-density Nomex honeycomb core; grinding parameters; processing quality; grinding force

**Abstract.** High-density Nomex honeycomb core is a kind of high hardness and large resin content honeycomb whose density is greater than 80kg/m$^3$.This kind of honeycomb has higher strength and stiffness and is usually applied in heavy load and other critical applications. Due to its hard brittleness of the resin and flexible property of the fiber, it is difficult to machining once molding and curing. This paper presents an experimental research on grinding high-density Nomex honeycomb core by using diamond wheel to find the relationship between grinding parameters and processing quality and grinding force. Single factor experiments are conducted including spindle speed, feed rate and cutting depth. Under the experimental conditions, when spindle speed increases from 2000rpm to 8000rpm, processing quality improves significantly and cutting force has a tendency to decrease. Feed rate and cutting depth have the same effect on the tendency of processing quality and grinding force: with the increasing of feed rate changes from 50mm/min to 350mm/min and cutting depth changes from 0.1mm to 0.9mm, processing quality becomes worse and cutting force rises as well.

## Introduction

Nomex honeycomb core material is widely used in the areas of aerospace, vehicle, high-speed trains and weapon industry because of its high specific strength and specific stiffness, excellent fatigue resistance, sound fatigue resistance and flutter resistance, heat insulation and protection, sound absorption and elimination, as well as electromagnetic wave absorption and transmission [1,2,[3]. High-density Nomex honeycomb core is a kind of high hardness and large resin content honeycomb whose density is greater than 80kg/m$^3$. This kind of honeycomb material has higher strength and stiffness due to its large resin content, therefore, it is usually applied in heavy load and other critical applications in the area of aerospace which need special mechanical properties, for example, plane's floor and fighter's radar cover [4].

Dipping and molding are former processes of curing in the manufacturing of high-density Nomex honeycomb core, which is contrary to other low-density Nomex honeycomb core [5]. To obtain high-density for higher mechanical strength and stiffness, the content of impregnated resin in this kind of honeycomb core is correspondingly large, and the property of hard brittleness comes along with it. Due to its hard brittleness of resin and flexible property of fiber, high-density Nomex honeycomb core is difficult to machining once molding and curing. YU [6] studied milling process of glass fiber aramid paper honeycomb, but different from brittleness of glass fiber, aramid fiber's flexible property is not suitable for this process. ZHANG [7] studied charization of surface microscopic of Nomex honeycomb after ultrasonic assisted cutting, but this technology is only feasible for low-density Nomex honeycomb, which has lower strength and stiffness.

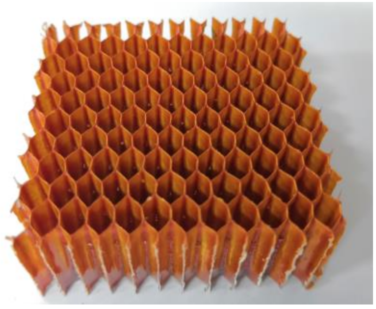


Fig.1 A sample of high-density Nomex honeycomb core

At present, high-density Nomex honeycomb core is usually cut into the desired width by a wire saw [8]. Furthermore, to get specific shapes, diamond grinding wheel is used by some aerospace enterprises to manufacture this class of honeycomb core. However, there are still some defects for this process: the widening of double-wall aramid paper under the action of cutting force influences the accuracy of bonding surface and unseparated chips and fiber drawings increase the workload of manual cleaning. For now, the effect of grinding parameters on cutting deformation and surface quality is not clear, so it is necessary to conduct systematic research to provide guidance for the processing of high-density Nomex honeycomb core.

## Experiment Details

**Experimental Conditions.** In this experiment, the workpiece is high-density Nomex honeycomb core whose density is 100kg/m$^3$, and the side length of lattice is 2mm. Its size is 50mm×40mm×18mm. A three-axis vertical machine with a maximum spindle speed of 12000rmp is used to do the designed experiments, and the machine tool is a cup-type diamond grinding wheel (its structure diagram is shown in Fig.2). The graininess of the selected grinding wheel is 80# and its diameter is φ50. The grinding force is measured by piezoelectric dynamometer (Kistler-9119AA2), which consists of piezoelectric sensor, charge amplifier, data acquisition card, and computer. The honeycomb workpiece is stuck on fixture by paraffin, and the fixture is connected with piezoelectric sensor of the dynamometer. Figure 3 shows the overview of grinding experimental setup.

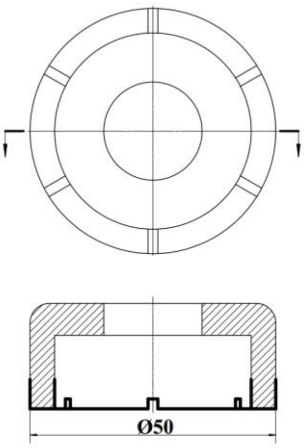



Fig.2 Structure diagram of cup-type diamond wheel

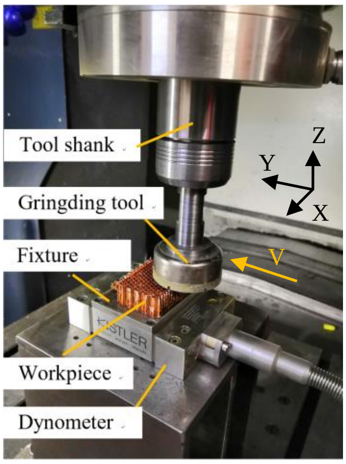



Fig.3 Overview of experimental setup

**Design of Experiments.** In this study, 3 groups of single factor experiments are carried out to study the grinding performance of high-density Nomex honeycomb core, in which the grinding parameters consist of cutting speed, feed rate, and cutting depth. In order to explore the influence of grinding parameters on grinding force, gringding force is measured online by the aforementioned grinding force measurement system during the experiment. Table 1 shows the experimental parameters of grinding high-density Nomex honeycomb core.

Table 1 Experimental parameters of grinding high-density Nomex honeycomb core

| Experimental group | Spindle speed (r/min) | Feed rate (mm/min) | Cutting depth (mm) |
|---|---|---|---|
| 1 | 2000, 5000, 8000 | 50 | 0.1 |
| 2 | 8000 | 50, 200, 350 | 0.1 |
| 3 | 8000 | 50 | 0.1, 0.5, 0.9 |

In the plane, the L direction of the honeycomb core is the same as that of the double aramid paper and the W direction is perpendicular to the L direction. In this experiment, the L direction is the feed direction because of its higher strength and stiffness [9]. The grinding process of high-density Nomex honeycomb core is shown in figure 4.

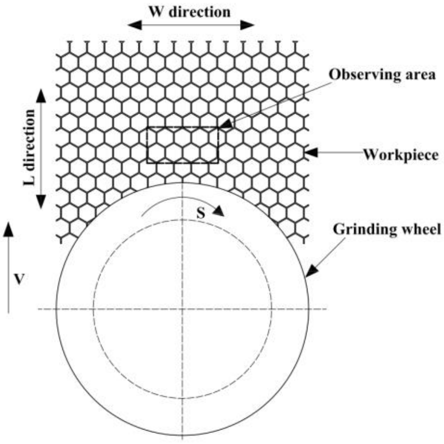



Fig.4 Diagram of grinding process

After the grinding experiment, digital microscope with large depth-of field (KEYENCE VHX600E) is aplied to observe the surface morphology after processing, and the observing area is the center of the workpiece. Three kinds of processing defect including average width of observed double-wall aramid paper, average width of ten bigger unremoved chips, and numbers of longer fiber drawing (longer than 300μm) are tallied. The physical picture and diagram of three kinds of processing defect are shown in figure 5 and figure 6.

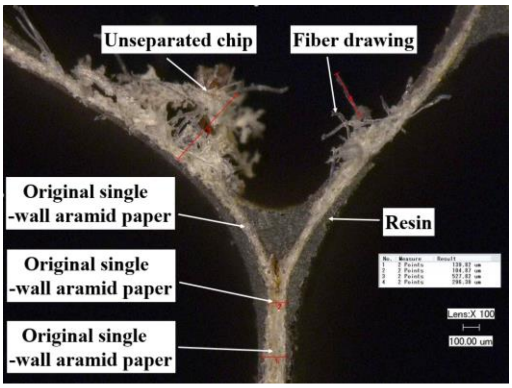



Fig. 5 Physical picture of processing defects

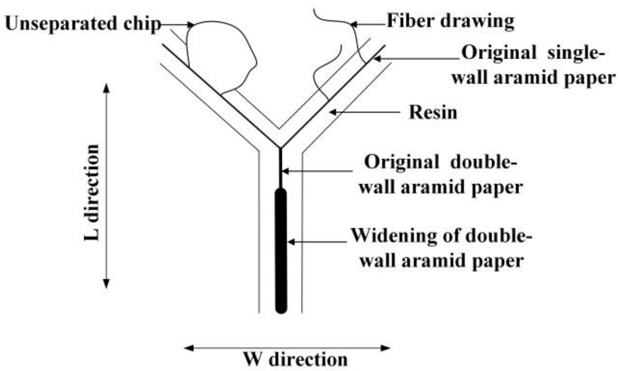
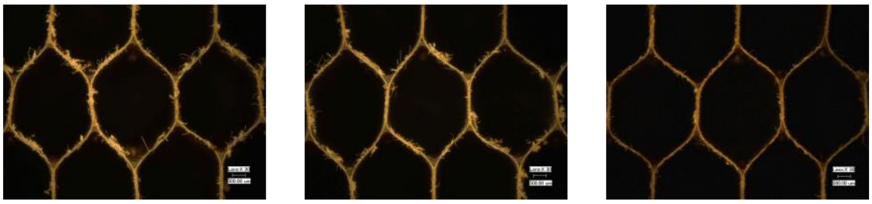



Fig. 6 Diagram of processing defects

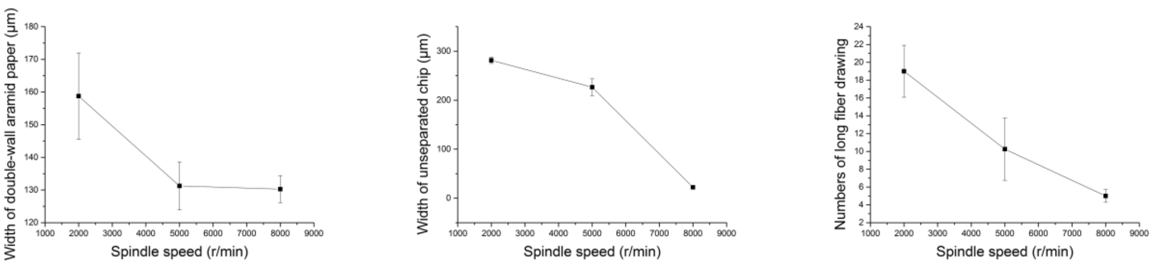
## Results and Discussion

**Influence of Spindle Speed on Processing Quality.** Figure 7 shows the surface morphology of processed high-density Nomex honeycomb core in different spindle speed. As we can see, when spindle speed increases from 2000rpm to 8000rpm (cutting speed increases from 5.23m/s to 20.92m/s), processing quality is obviously getting better. When the cutting speed is too small, chips are difficult to remove, that is to say, the grinding effect is too weak. Figure 8 shows influence of cutting speed on three kinds of processing defect. It is obvious that high-speed grinding can restrain the forming of these processing defects.



**(a) n=2000r/min** **(b) n=5000r/min** **(c) n=8000r/min**

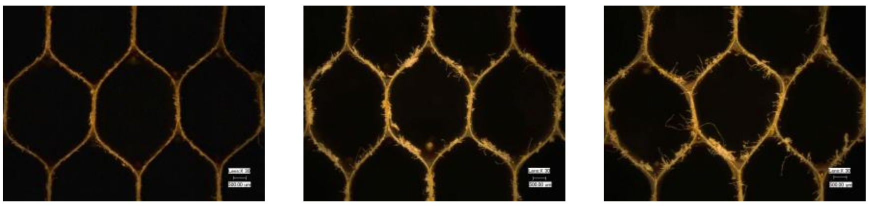
Fig.7 Surface morphology of different cutting speed




(a) Widening of dounle-wall aramid paper (b) Unseparated chip (c) Fiber drawing

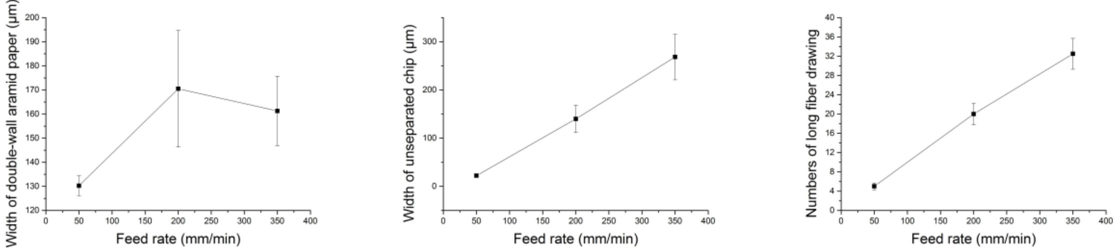
Fig.8 Influence of spindle speed on three kinds of processing defect

**Influence of Feed Rate on Processing Quality.** The surface morphology of processed high-density Nomex honeycomb core in different feed rate is shown in figure 9. It is evident from the picture that processing quality becomes worse along with the increasing of feed rate. When the feed rate is 350mm/min, the defect of fiber drawing is more serious and unseparated chips are bigger. However, when feed rate increases, the width of double-wall aramid paper doesn’t change too much. Figure 10 shows the influence of feed rate on three kinds of processing defect.



**(a) f=50mm/min** **(b) f=200mm/min** **(c) f=350mm/min**

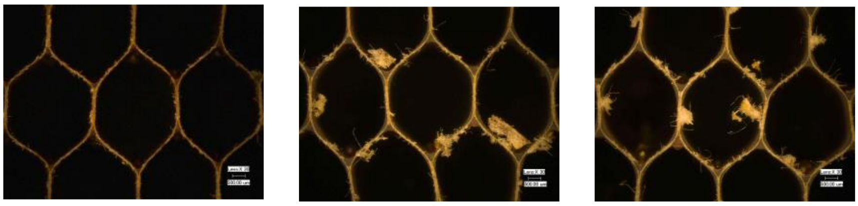
Fig.9 Surface morphology of different feed rate




(a) Widening of dounle-wall aramid paper (b) Unseparated chip (c) Fiber drawing

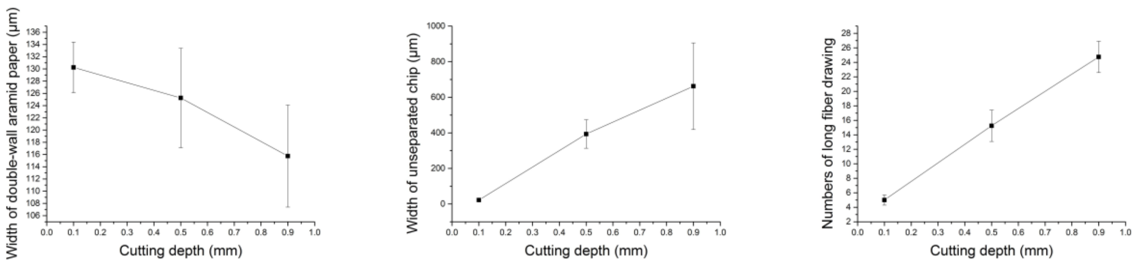
Fig.10 Influence of feed rate on three kinds of processing defect

**Influence of Cutting Depth on Srocessing Quality.** Figure 11 shows the surface morphology of processing defect of processed high-density Nomex honeycomb core in different cutting depth. As is seen, when cutting depth increases from 0.1mm to 0.9mm, there appears more and more big unseparated chips and long fiber drawings. But on the contrary, the width of double-wall aramid paper has a tendency to become small. The influence of cutting depth on three kinds of processing defect is shown figure 12.



**(a) ap=0.1mm** **(b) ap=0.5mm** **(c) ap=0.9mm**

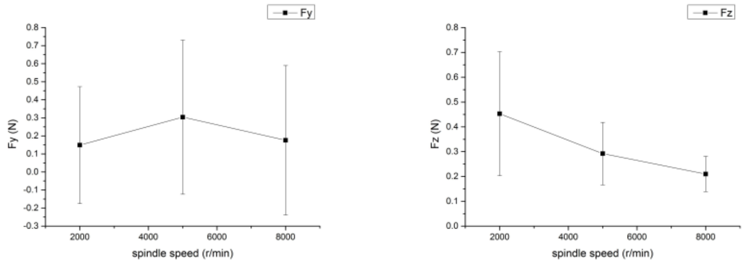
Fig.11 Surface morphology of different cutting depth




(a) Widening of dounle-wall aramid paper (b) Unseparated chip (c) Fiber drawing

Fig.12 Influence of cutting depth on three kinds of processing defect

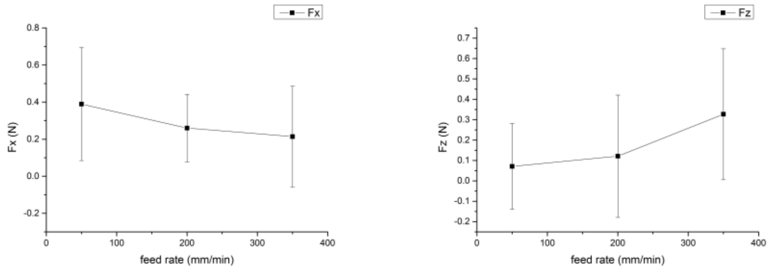
**Influence of Spindle Speed on Grinding Force.** The high speed cutting theory holds that, in general, with the increase of the cutting speed (spindle speed in this experiment), the strength of the processed material will be reduced under the heat softening of the matrix, so the cutting force is gradually reduced [11]. In this study, Fx is the horizontal force perpendicular to the feed direction, and it can be ignored because it is relatively small. Fy is the mean force of stable cutting in feed direction, and it decreases with the increasing of spindle speed, while it is small when spindle speed is 2000rpm. This is because when spindle speed is small, the cutting speed is small too, and the grinding effect is weak. It can also be seen from figure 13 and figure 8 that the tendency of Fy with the change of spindle speed is roughly the same as that of fiber drawing. However, the axial mean force of stable cutting Fz decreases apparently with the increasing of spindle speed and its decline tends to be slow when spindle speed is big enough. What's more, Fz also reflects the broadening of double-wall aramid paper.




**(a)** **(b)**

Fig.13 Influence of spindle speed on grinding force

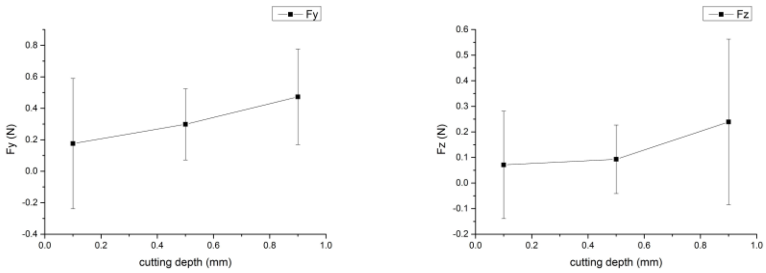
**Influence of Feed Rate on Grinding Force.** Figure 13 shows the influence of feed rate on grinding force. As we can see from the picture, feed force Fy and axial force Fz both increase with the increasing of feed rate. This is because the tearing and squeezing of the grinding wheel to the fiber material is more serious when the feed rate increases. This also explains why the three kinds of processing defect become worse.




**(a)** **(b)**

Fig.14 Influence of feed rate on grinding force

**Influence of Cutting Depth on Grinding Force.** Figure 15 shows that the influence of cutting depth on grinding force is the same as that of feed rate. With the increase of grinding depth, the area of material involved in grinding increases, and the contact area between tool and material increases, which makes the cutting force increase. The increasing cutting depth aggravates the forming of processing defects.




**(a)** **(b)**

Fig.15 Influence of cutting depth on grinding force

## Summary

In this paper, to study the influence of grinding parameters on processing quality and grinding force, three groups of single factor experiments are conducted including spindle speed, feed rate and cutting depth. Grinding forces Fy and Fz and three processing defects including widening of dounle-wall aramid paper, unseparated chip, and fiber drawing are tallied after the grinding experiment, here are some conclusions:

(1) The higher the grinding speed, the better the processing quality and the smaller the grinding force. When the grinding speed is too small, the feed force Fy is also small, and the chip is not easy to separate, which seriously affects the machining quality.
(2) The influence of feed rate and cutting depth on processing quality and grinding force are roughly the same: the bigger the grinding parameters, the worse the processing quality and the bigger the grinding force.
(3) Feed force Fy is the main force to affect the processing defect of fiber drawing and axial force Fz is the main force to affect the broadening of double-wall aramid paper, whill Fy and Fz both affect the size of unseparated chip.
(4) In order to obtain good processing quality and small grinding force of grinding high-density Nomex honeycomb core, high spindle speed (cutting speed), small feed rate and small cutting depth are good grinding parameters.

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