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Investigation of the sawing performance of a new type of diamond frame saw machine

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ABSTRACT

Generally the frame sawing with diamond segmented blades is the equipment in soft stones sawing process. In this work, a new type of frame saw machine used for cutting granite is introduced. The sawing trajectory and the theoretical relationship between the average chip thickness and the sawing parameters are established. Utilizing the new frame saw machine, an experimental study was carried out to investigate the sawing forces and segments wear in different strokes. It is concluded that no matter in forward stroke or in backward stroke, only half of the stroke is sawing the stone. The sawing forces of segments increase with the increase of the feed speed and cutting length, and show a decrease trend with the increase of the rotation speed of the crank. What's more, the forces in backward stroke are higher than that of forward stroke. Well-developed matrix tails are formed behind the diamond grits, while the wear of segments at the front end of the blade is severe than that in the middle and at the rear end, the shapes of the diamond segments changed from trapezoidal into rectangular.

1. Introduction

According to the 2016 data of China, the marble slab production exceeds 350 million square meters in above-scale enterprises, the granite slab production over 730 million square meters. With the wide application of natural stones as building construction and decoration material, stone processing machines and tools have been widely used in stone processing industry. And the processing of stone has been mainly depended on diamond circular saws, diamond wire saws, diamond frame saws and so on. The cutting tools are mainly sawblades and diamond segments [1] or steel cables and diamond beads [2].

The research on sawing forces and segments wear is helpful to obtain a better understanding of the sawing process and optimize of machining process of the machines. And the sawing process can be described as the cutting of the diamond tool with different depths of cut. Some scholars have studied the chip thicknesses and sawing performance of diamond tools for many years.

Jerro et al. [3] showed a mathematical approach to define theoretical chipping geometries that was described by means of chip area and thickness in circular sawing. These parameters were put into relationship with sawing force. Turchetta [4] theoretically analyzed the average chip thickness of single diamond grit in circular sawing, established a model of sawing forces and the average chip thickness. Another study by Polini and Turchetta [5] investigated the relationship of sawing force and energy with the machining parameters by a diamond mill, and established power functions among the force, the energy and the equivalent chip thickness. Xu et al. [6] investigated the forces in circular sawing of gray granite, indicted that the normal force per grain was nearly proportional to the calculated undeformed chip thickness. Wang et al. [7] systematically studied the cutting mechanism of marble frame saw. The kinematic behavior of the blade was discussed and the factors that influence the sawing force by the single point tool and segment cutting test with different parameters were analyzed. Xu et al. [8] focused on the force ratio in the circular sawing of several kinds of granites. The results indicated that with the increase of wheel speed, the normal force decreased steeply and the tangential force was nearly constant. Thus, the force ratio increased linearly. Turchetta [9] investigated the relationship between sawing forces and machining parameters for different values of tool wear. The results demonstrated that a high increase in sawing force components as tool wear increased. An experimental study was carried out by Huang et al. [10] to investigate the machining characteristics and tool wear in the diamond wire sawing of granite. The results indicated that the material removal of granite in diamond wire sawing was dominated by brittle fracture and the tool wear was characterized by the nonuniform wear of diamond beads. Karakurt et al. [11] built models for the sawing forces

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of circular saw depending on the operating variables and the rock properties. The results indicated that higher sawing forces were obtained for higher cutting depth and traverse speed and for lower peripheral speed and flowrate of cooling fluid. The most significant operating variable affecting the sawing force was determined as cutting depth. Buyuksagis and Goktan [12] carried out a study to investigate sawing performances of different types of marbles using circular saws. The result demonstrated that shallow cutting depths and low workpiece travel speeds were highly inefficient in terms of specific energy. Özçelik [13] carried out sawing tests with diamond frame saw on different marbles, investigated the relationships among the marble textural and mineralogical properties, unit wear on diamond segments and average sawing speed. Ersoy and Atıcı [14] examined the effects of operating variables and rock parameters on the performance of circular saws. The results indicated that the performances are significantly affected by cutting variables. Li [15–17] investigated the quality and performance of polycrystalline diamond tools manufactured by different methods, and carried out series sawing tests to investigate the wear mechanisms, cutting performance of polycrystalline diamond. The results show that adhesive-abrasive process and chemical diffusion were the main mechanism of wear of diamond tools. Some researchers also focused on wear characteristics [18–20], sawing performance predictions [21–23], and sawability prediction with various methods [24–27].

As discussed above, these studies are concerned with circular saws and multi wire saws in marble and granite processing. Unfortunately, the literatures of frame saw machine mentioned above are the application of marble processing, not involved in granite.

Brook [28] analyzed the principle of frame saw for cutting rock, and indicated that there is the potential to use synthetic diamond compacts to achieve hard granite cutting in frame saw machine. Konstanty et al. [29,30] presented a theoretical model of frame saw, and proposed severe wear conditions of segments than the circular saw since there is no build–up of matrix tail and forces act on diamond in alternate directions. Based on the previous work done by our research group [31,32], a new prototype of frame saw machine was designed for sawing granite, and a preliminary effect was achieved. The eccentric hinge guide mechanism is introduced into the new prototype machine to realize the trailing of diamond.

In this paper, the primary goal is to investigate the machining characteristics of the new diamond frame saw machine. To be better understanding of the sawing process, the sawing trajectory and the model of the average chip thickness of a single grit in each stroke were established. In the following, a series of sawing experiments were conducted under different sawing conditions. The effect of operating variables and the contribution of each stroke on the sawing forces were analyzed, and the wear of segments in different positions of the blade was also examined.

2. The new type of diamond frame saw

Fig. 1 shows the sawing system of the frame saw. The diamond blade welded with segments moves forward and backward alternatively by the rotation of the crank connecting rod mechanism, and the block is controlled by the lifting mechanism with upward movement, at the same time. The eccentric hinge guide mechanism is introduced into the frame saw machine, which is the innovation that is different from previous equipment. And each member of the guide mechanism has a certain proportional relationship.

2.1. The trajectory of new type of diamond frame saw

The diamond blades move along a complicated path under the eccentric hinge guide mechanism. The ADAMS software was adopted to analyze the sawing trajectory. The motion curves of the center of the front and rear hinges are presented in Fig. 2. The stroke of the blade was 600 mm, and the rotation speed of crank was 70 r/min. The simulation time was 1.714 s, having two forward strokes and backward strokes.

As can be observed in the diagram, the horizontal displacement of the two hinge mechanisms is same, which is affected by the crank connecting rod mechanism, while the vertical displacement is different. The vertical displacement of the front hinge is higher than the rear hinge. This causes a maximum 8.5 mm height difference of the blades in a stroke, this value is far more than the feed rate (the maximum feed rate in one stroke is $f = v_f/2n_k \approx 14\,\mu m$), thus the blades will be lifted. And considering the effect of the eccentric tensioning force of the blades, the blades will separate from the stone surface when the vertical coordinates are zero, as shown in Fig. 2(c). Specific trajectory analysis had been discussed in detail in document [31].

The blades are lifted in the process of moving from left to right. Under the action of the feed movement, segments saw the stone, while the blades separate from the stone surface after about half of a stroke. After a period of time, the blades contact with the stone for sawing again. In the whole movement of reciprocating, the blades are in the condition of sawing stone, separating from the stone, sawing stone and separating from the stone. No matter in the forward stroke or in the backward stroke, only half of the stroke is sawing the stone.

The complex trajectory with the continuous feed movement will lead to different cutting area in the forward and backward stroke, which in turn leads to changes in sawing force. This conclusion will be verified in the sawing force test.

2.2. Theoretical analysis of the average chip thickness of single diamond grit

The breakage of stone and the formation of the chip are dominated by the indenting and cutting of diamond grits on the segment surface, which is determined by machining parameters.

The grit protrudes h_p from the surface and indents the stone for a

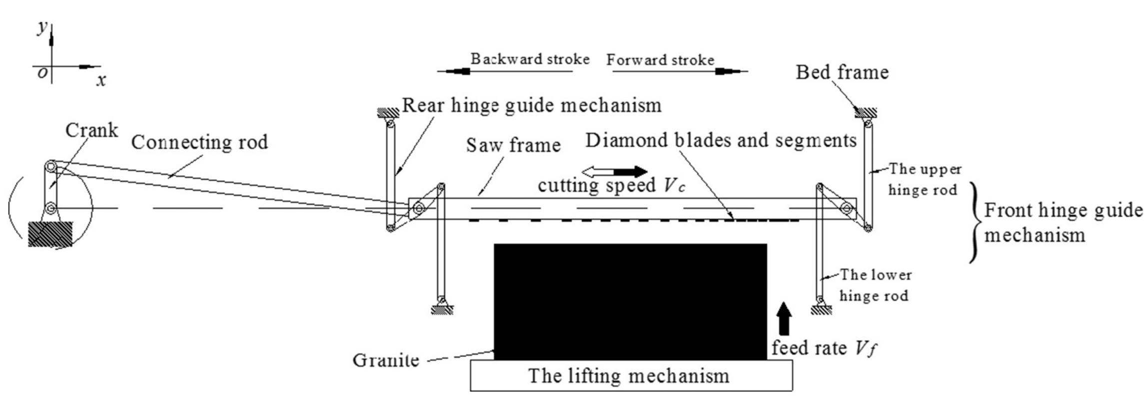

Fig. 1. The sawing system of the new diamond frame saw.