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Investigation on Cutting Forces in Concrete Sawing Process

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Abstract. Diamond saw blades are widely used in cutting concrete materials in civil engineering industry. Concrete is a kind of difficult-to-cut composite material. The cutting forces in concrete cutting processes by single-diamond tools and sawing processes by circular diamond blade were investigated in this paper to provide basic information for properly selecting sawing conditions and optimizing blade structure. The signals of cutting forces under different conditions were acquired and analyzed. The results show that the properties of composition in asphalt concrete have significant influence on instantaneous cutting forces. The effect of cutting speed on cutting forces is smaller than feed speed and depth of cut in concrete sawing processes.

Introduction

Diamond saw blades are widely used in cutting concrete material for the civil engineering industry. They have been applied in cutting expansion and contraction grooves in concrete, sawing joints and anti-skid grooves of highways and airport runways, and machining concrete precast parts, etc. Concrete is a kind of composite material, which consists of hard phases (broken stone, sand, etc.) and soft phases (asphalt, etc.). Concrete is sawn under dry cutting in most applications to eliminate the need for water supply and sludge clearance problem. The diamond grits in the saw blade segments, therefore, are subjected to severe impact mechanical load and high temperature, which act to weaken the diamond grits and lower the blade life and working efficiency. There is a demand for optimizing cutting conditions and blade structure to cut concrete with great efficiency and low cost.

Most of the research work to date on sawing concrete has focused on the tool wear sand sawing mechanism [1-6]. There exist three main problems in dry cutting concrete, that is, high cutting temperature, high noise, and concrete swarf and chips on the blade surface. These problems cause low blade life and sawing efficiency, and pollution to the environment. More and more recent research work has been concentrated on improving saw blade structure [7-10] to solve the problems above. But few work on the cutting force in concrete sawing processes has been published.

The cutting forces in concrete cutting process by single-diamond tools and sawing processes by circular diamond blade were investigated in this paper to provide basic information for properly selecting sawing conditions and optimizing saw blade structure. The signals of cutting forces under different conditions were acquired by a piezoelectric force dynamometer. The factors affecting cutting forces of concrete were analyzed.

Experimental Setup

The experimental work involved cutting process with single-diamond tools and sawing process with circular diamond saw blades. This investigation aims to collect cutting force data to assess concrete machinability and diamond grit behavior in concrete sawing process.

The cutting experiment was performed on a machining center with single-diamond tools. The cutting speed was selected in the region from 0.02 m/s to 0.08 m/s, and the depth of cut from 10 μm to 80 μm. Dry cutting was applied in all of the concrete cutting processes. The sawing experiment was conducted on a bridge stone-sawing machine. The saw blade used was 350 mm in diameter with 24 segments and ferro-based bond. The concrete materials were sawn by means of down cutting at

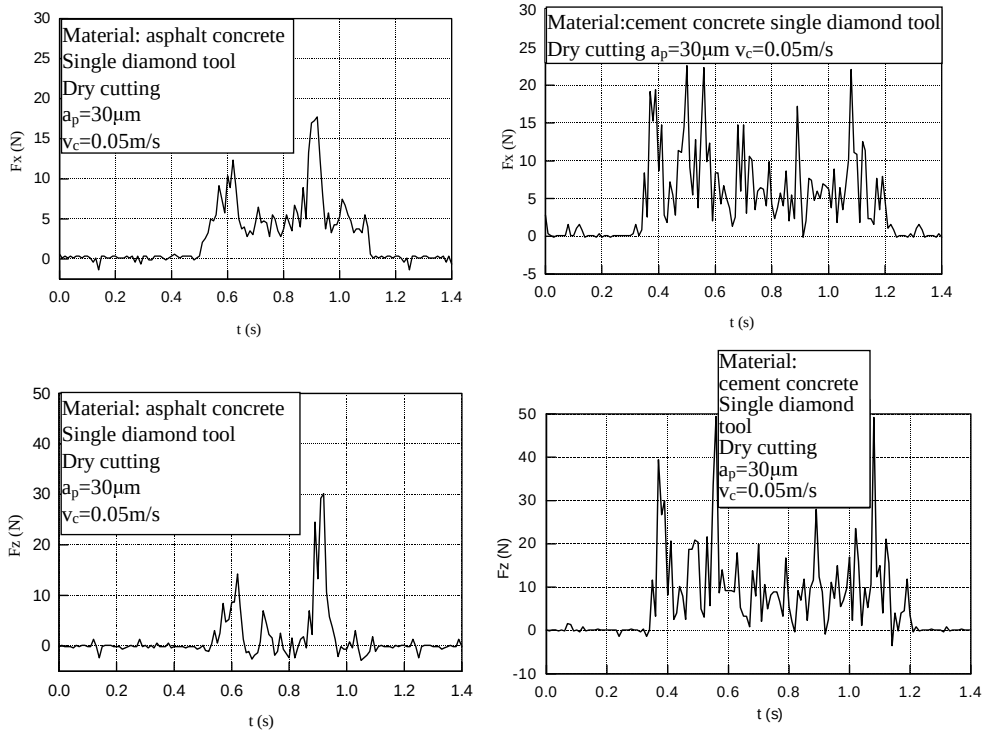
cutting speed v_c from 11 m/s to 25.6 m/s with feed speed v_f from 400 mm/min to 1200 mm/min and depth of cut a_p from 10 mm to 50 mm. Both water cooling cutting and dry cutting were used in the sawing experiment.

Two kinds of concrete, namely, asphalt concrete and cement concrete were tested. The asphalt concrete consists mainly of coarse and fine broken stone grains and asphalt. Its compressive strength is 5.1 Mpa. The cement concrete contains cement used as a binder, sand and stone grains. Its water-cement ratio is 0.33 by weight. Its compressive strength is 35 Mpa. The concrete blocks with 80 mm long × 60 mm wide × 20 mm deep were used in cutting tests and the blocks 200 mm long × 80 mm wide × 60 mm deep in sawing tests.

A piezoelectric force dynamometer (YDM-III99) is connected to a 3-channel charge amplifier. The force signals are acquired to a computer using a fast data acquisition card and software.

Results and Discussion

Cutting Forces in Cutting Process of Concrete.



(a) (b)

Fig.1 The cutting force signals of asphalt concrete and cement concrete in cutting process

The Features of Cutting Forces. Fig.1 shows the cutting force signals of the asphalt concrete and cement concrete cut by single-diamond tools. When asphalt concrete is cut, the horizontal cutting forces F_x at cutting speed direction and vertical cutting force F_z at cutting depth direction change in a relatively wide range but at a low frequency, as shown in Fig.1a. They depend obviously on the composition of concrete being cut. The relation between F_x, F_z and the composition of asphalt concrete is shown in Fig.2. F_x and F_z rise abruptly when a hard phase, such as stone grain is being cut, and drop to a low level while asphalt, the soft phase is being cut. F_z even drops to zero instantaneously while the tool is cutting in the boundary of a hard phase and asphalt or meets a pore or cavity in the concrete, especially in the case small depth of cut is applied. The changes of the cutting forces are caused by the difference in hardness of different composition phase.

When cutting cement concrete, the cutting forces fluctuate frequently, as shown in Fig.1b, which exhibits the typical cutting force feature of brittle materials, such as granite. The average cutting

forces are generally larger than those of asphalt concrete. Comparing with asphalt concrete, cement concrete is denser and more brittle. The cut surfaces of cement concrete are observed mainly with fracture characteristics. As a result, the cutting forces of cement concrete fluctuate more frequently than those of asphalt concrete.

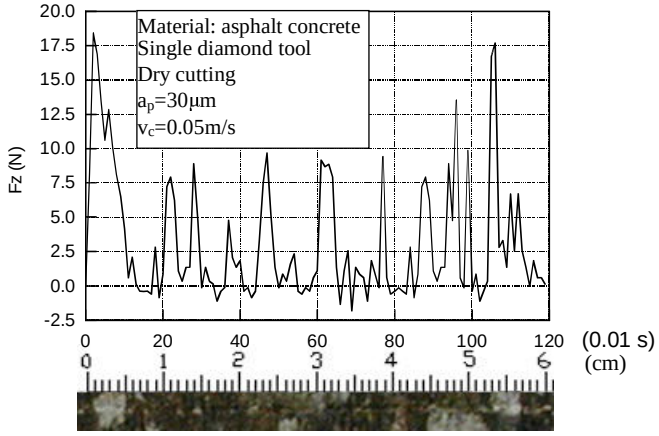


Fig.2 Relationship between cutting force signals and composition phases of asphalt concrete in cutting process

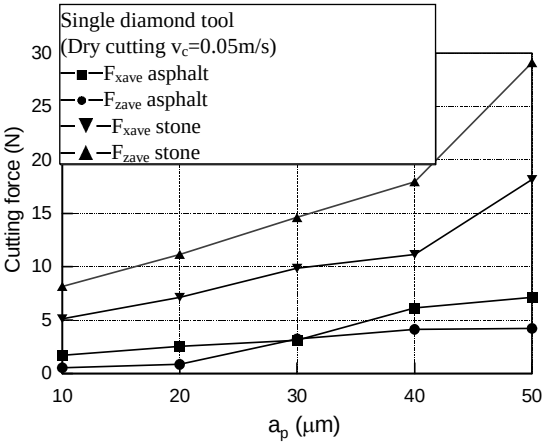
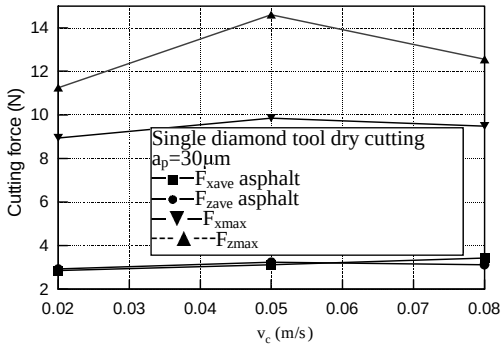


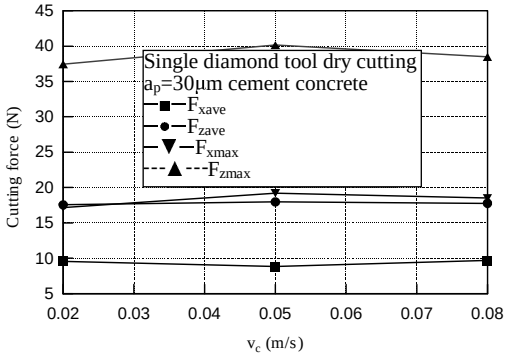
Fig.3 Relationship between cutting forces and depth of cut in asphalt concrete cutting process

The Factors Affecting the Cutting Forces in Concrete Cutting Process. (1) Depth of cut a_p. As the cutting forces are significant different when the stone grain or asphalt material in asphalt concrete is cut, the average cutting forces of stone grain and asphalt material are considered, respectively, as shown in Fig.3. With the increase in the depth of cut, both F_x and F_z increase. When a stone grain is being cut, F_x is smaller than F_z as concluded from other brittle material cutting processes. On the contrast, F_x is lager than F_z when asphalt material is being cut. Asphalt material is a kind of plastic material. It is mainly removed by plastic deformation under the press and cutting action of the diamond cutting edge.

(2) Cutting speed v_c. As the maximum cutting forces are obtained normally when the hardest phase of the concrete is cut, the effect of cutting speed on the maximum cutting forces depends on the property of the hardest phase in the concrete. The maximum cutting forces when cutting in the stone grains of asphalt concrete are referred to as the maximum cutting forces of asphalt concrete. The maximum cutting forces show different trends with the increase of cutting speed when cutting asphalt concrete and cement concrete, as shown in Fig.4. The maximum cutting forces F_{xmax} and F_{zmax} show an increase trend in general with the increase of cutting speed when asphalt concrete is cut, and the average cutting forces when cutting in asphalt material increase slightly, as shown in Fig.4a. The cutting speed has insignificant influence on the cutting forces when cutting cement concrete, as shown in Fig.4b.



(a) Asphalt concrete



(b) Cement concrete

Fig.4 Relationship between cutting forces and cutting speed in cutting process

(3) Workpiece material. As discussed above, the composition and structure of concrete have a significant effect on the cutting forces. The mechanical properties of the composition influence the cutting mechanism and consequently the cutting forces. The pores and cavities existed in concrete cause the cutting forces to fluctuate instantaneously.

Cutting Forces in Sawing Concrete Processes. F_x and F_z measured in the sawing experiment are transformed into tangential cutting force F_t and radical cutting force F_n to evaluate the load on the diamond grits of each segment.

Effect of Cutting Speed on Cutting Forces in Sawing Concrete Processes. It can be seen in Fig.5 that F_n reveals a decrease trend when increasing the cutting speed. With the increase of cutting speed, the size of undeformed chip cross-section becomes small [1]. Consequently, the mechanical load on a diamond grit decreases. In addition, diamond grits may fracture to many new cutting edges due to the impact load at a higher cutting speed, which leads to the decrease of cutting force. But F_t does not exhibit noticeable trend at the experimental cutting speed range.

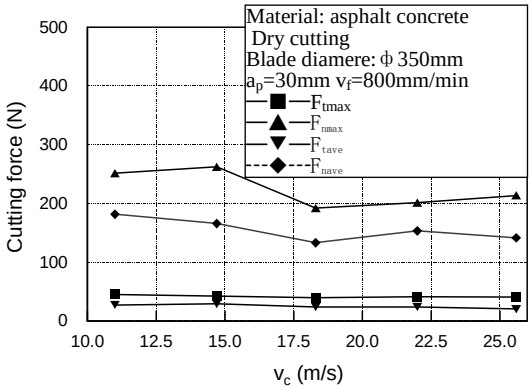


Fig.5 Relationship between cutting force and cutting speed in sawing process

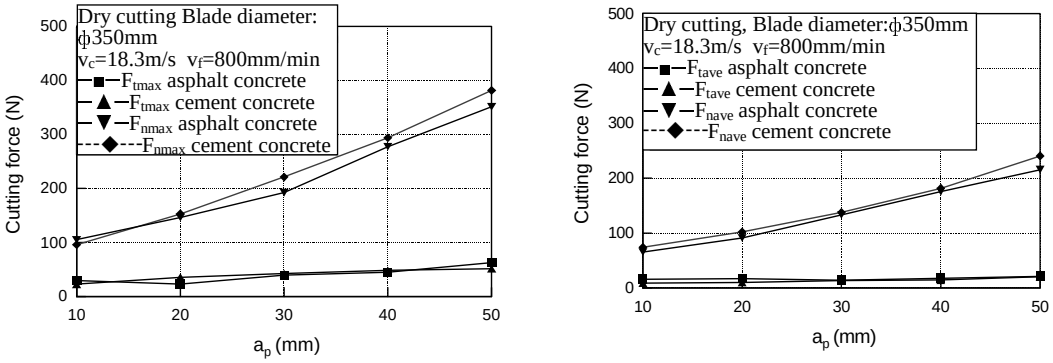
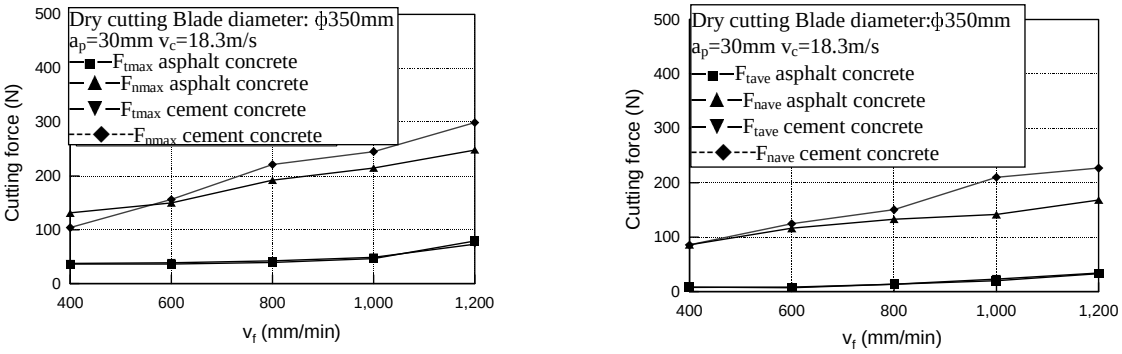


Fig.6 The relationship between cutting force and depth of cut in sawing process

Effect of Depth of Cut on the Cutting Forces in Concrete Sawing Processes. As shown in Fig.6, F_n increases obviously with the increase of depth of cut when asphalt concrete or cement concrete is cut. It can also be analyzed based on the theoretical size of the undeformed chip cross-section, or the depth of cut per diamond grit increases. When the depth of cut is increased, the depth of cut per diamond grit increases. Consequently, the mechanical load per diamond grit increases. The similar trend is also shown in Fig.3. In general, F_n in sawing cement concrete is larger than that in sawing asphalt concrete, which is consistent with the result obtained in cutting process. F_t increases slightly when increasing the depth of cut, which is not thoroughly consistent with the trend of cutting process shown in Fig.3. The sawing process of concrete is more complicated than cutting process. The soft and hard phases are cut at the same time under different actual conditions in a sawing process of concrete. The change of cutting parameters influences the wear characteristics of the diamond grits as well. The increase in the depth of cut causes the increase in percentage of

diamond grits with wear flat surface [10]. Blunted diamond grits increase the sawing forces, especially the radial cutting force F_n.

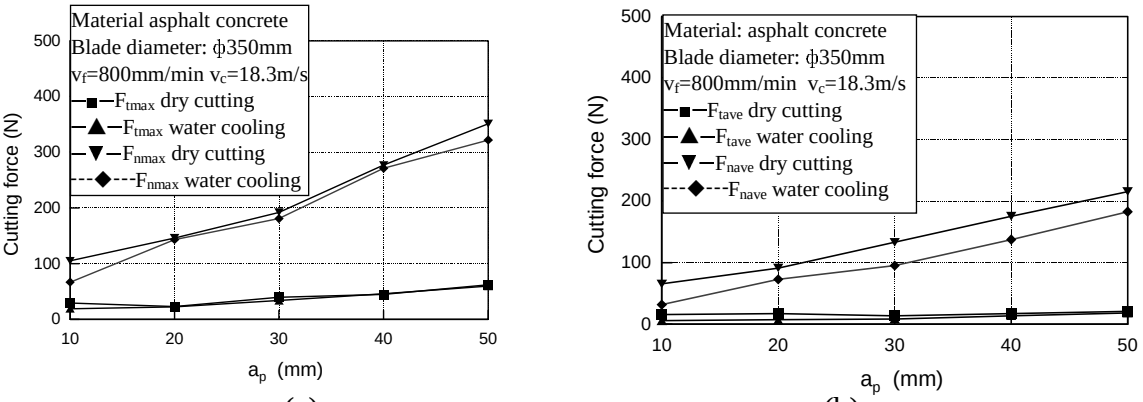
Effect of Feed Speed on the Cutting Forces in Concrete Sawing Process. When the feed speed is increased, both F_n and Ft increase in the sawing processes of cement concrete and asphalt concrete. It follows simultaneously that the size of the undeformed chip cross-section increases. Under the same condition, the maximum and average radial cutting force F_{nmax} and F_{nave} of cement concrete are larger than those of asphalt concrete. But the tangential cutting force does not show obvious difference. The possible reason should be analyzed further from the investigation results of the wear characteristics of diamond grits.



(a) (b)

Fig.7 Relationship between cutting force and feed speed in sawing process

Effect of Cooling Condition on the Cutting Force in Concrete Sawing Processes. The cutting forces, especially the average radial cutting forces decrease remarkably when water is applied to the sawing area, as shown in Fig.8. With the action of water, the removal of the concrete swarf from the working surface of the segment is much easier than in dry cutting process, which raises effective grit cutting edges and reduces the friction between the concrete and segments. In addition, the sawn surface of concrete is formed by small fracture and found with smaller unevenness than that by dry cutting [9]. That may be caused by the action of hydraulic-wedge of water penetrating into the pores and micro cracks of concrete, which lower the strength of surface layer of the concrete and cause the material easy to fracture into smaller chipping. Consequently, the cutting forces decrease under water cooling condition. In the application that water is not available, the improvement of the blade structure for reducing the friction between blade and concrete, and removing concrete swarf efficiently should be taken into account for reducing cutting forces and heat, and prolonging the blade life.



(a) (b)

Fig.8 Effect of cooling condition on cutting force in sawing process

Conclusions

1. The instantaneous cutting forces in asphalt concrete cutting process are influenced significantly by the properties of concrete composition. The cutting forces rise abruptly when a hard phase is being cut and drop to a low level when asphalt is being cut. The cutting forces of cement concrete are larger and fluctuate more frequently than those of asphalt concrete.

2. With the increase in the depth of cut, cutting forces rise in the cutting process of concrete. The cutting speed, feed speed and depth of cut have noticeable influences on the cutting force as they affect the size of the undeformed chip cross-section in concrete sawing processes. The effect of cutting speed on cutting force is generally smaller than that of feed speed and depth of cut.

3. The cutting forces, especially the average radial cutting forces decrease significantly when water is applied in concrete sawing processes.

Acknowledgment

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