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Study on Force and Fracture of Impacted Diamond Grits

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Abstract. In this paper, toughness index of diamond was measured by Toughness Index Measurement Apparatus. Forces on diamond grits at different impact condition were analyzed theoretically. Post-impact diamond grits were divided into three types by screening: un-broken, micro-fractured and completely fractured diamond, which correspond to failure modes: no significant wear, micro-fractured and macro-fractured in diamond tools. Thus the correlation between the fracture types of impacted diamond and its failure modes in diamond tool was established. The effects of impact parameters on the fracture types were also studied. The results show that fracture types of diamond grits are related to the steel balls mass and impact frequency. With the increase of steel ball mass or impact frequency, the ratio of un-broken diamond decreases and that of micro-fractured diamond increases gradually.

Introduction

Diamond abrasive is widely applied in advanced machining fields. To get the optimum machining quality and property of tool, the researches including wear mechanism of diamond grits and bond, the grinding temperature and grinding force have been carried out broadly [1-4]. This provides important theoretic and practical foundation for selecting optimum diamond type and improving the tool's efficiency and lifetime.

In most of stone and construction applications, the diamond strength is an important parameter to evaluate its quality. Since diamond grits and their production are usually subjected to impact and abrasive wear during practical grinding process, the quality control device used for monitoring production has to simulate both forms of wear [5]. Toughness Index Measurement Apparatus used to determine grits impact strength can meet the above requirement. However, in order to assess the application and properties of diamond, it is still worth deeply investigating the relationship between the fracture types of impacted diamond grits and tools' properties. The present work is to analyze and discuss the force and fracture types of impacted diamond grits.

Experimental and Results

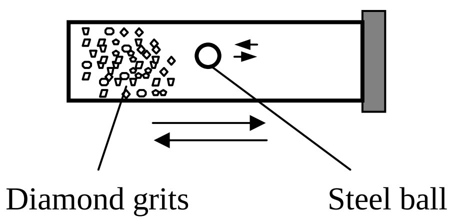


Fig.1 Schematic diagram of the toughness index measurement apparatus

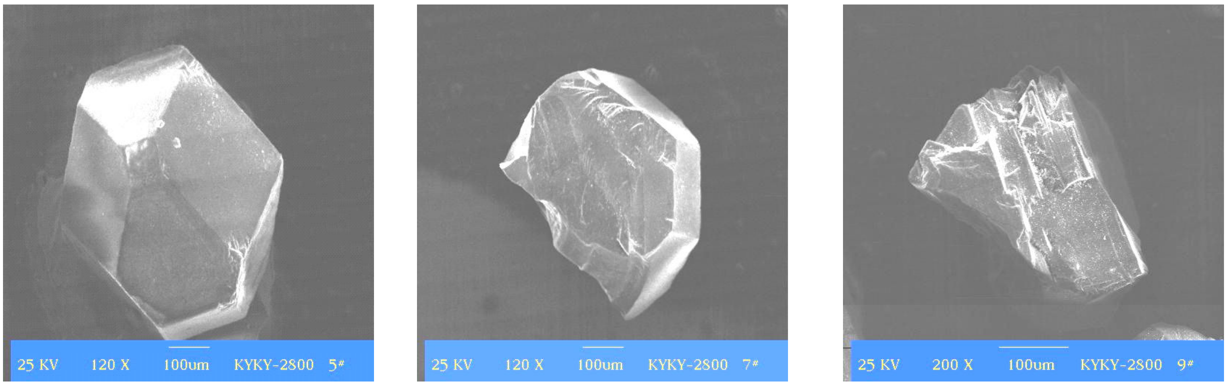
Fig.1 showed the schematic diagram of the Toughness Index Measurement Apparatus, whose vibration frequency can be adjusted accurately. Diamond grits together with steel balls were placed into the sealed steel chamber, then the vibration frequency was set up and the steel chamber began to move to-and-fro at a certain speed. The toughness index of diamond grits refers to the impact number of half-broken-ratio, i.e. 50% of tested diamond grits was un-broken.

Types of Impacted Diamond Grits. Corresponding to Wilks' failure modes of grits in diamond tool, the impacted diamond grits were first divided into three types according to the screening process [6-7]. Every definition is described as follows:

Un-broken diamond shown in Fig.2a is defined as the residue on the selected sieve after screening for 3 minutes, whose size is equal to that of on-size grit. This type corresponds to no significant wear one in diamond tools.

Micro-fractured diamond shown in Fig.2b is the part between two sieves, among which the upper size is that of the on-size grit and other is that of the half of average grits. The corresponding failure mode is micro-fractured in diamond tools.

The remainder except above two kinds of grits is called completely fractured diamond, as shown in Fig.2c, which corresponds to macro-fractured one in diamond tool.



(a) un-broken (b) micro-fractured (c) completely fractured diamond

Fig.2 SEM images of impacted diamond grits:

Force Analysis of Impacted Diamonds. The collisions between diamond grits and steel balls or the chamber make some diamond grits fracture during impact processing. Supposing the motion of the chamber as a simple harmonic vibration and the whole chamber as a point, its displacement can be expressed as:

$$x = A \cdot \mathrm{Sin}(\frac{2\pi}{T} t) .$$

where *A* is amplitude, *T* vibration cycle and *t* vibration duration. In impact test, the amplitude is 10 mm, while the impact frequency is 2000 rpm, the corresponding vibration cycle *T*=60/2000 s. Thus, the displacement of the chamber can be given by:

$$x = 10 \times 10^{-3} \mathrm{Sin}(\frac{2\pi \cdot 2000}{60} t) .$$

Therefore, the vibration velocity of chamber can be given by:

$$v = \frac{dx}{dt} = 10 \times 10^{-3} \times \frac{4000\,\pi}{60} \cos(\frac{4000\,\pi}{60} t) . \quad (1)$$

Before discussing the collision between steel balls and diamond grits, it is necessary to evaluate the mass of each diamond grit. And it can be given by:

$$m = \frac{0.2}{n} . \quad (2)$$

where *n* is diamond particle number per carat.

The particle number per carat of 40/50 diamonds is 2280, that of 30/40 diamonds 807. So, based on Eq.2, each grit mass of 40/50 and 30/40 US mesh diamonds is 8.77×10^{-5}g, 2.48×10^{-4}g respectively. Compared with the minimum mass of steel ball (0.176g), the mass of diamond grits is so small that we can neglect the effects of diamond grits when discussing the change of momentum and kinetic energy in course of collision between steel balls and diamond grits.

Field [8] has pointed out that the fracture time of diamond grits usually is about 20 μs. So collision duration of steel ball and diamond grits is assumed to be 20 μs. Based on the momentum law $p = mv = ft$, where *m*, *v* and *t* are already known, the impact force of steel ball acted on grits can be calculated easily. But it is possible that a steel ball collides with one or more diamond grits. For this reason, assuming that the impact force is divided equally by the impacted grits, thus force acted on single grit can be achieved. As the impact frequency is 2000 rpm, this force under different conditions is shown in Table 1.

Table 1 Force acted on per diamond grit when colliding with different weight balls

Ball mass[g]	Force [N]		
	Collision with one grit	Collision with two grits	Collision with three grits
5.455	542.9	271.5	181.0
3.552	353.5	176.8	117.8
2.083	207.3	103.7	69.1
1.053	104.8	52.4	34.9
0.509	50.7	25.4	16.9
0.253	25.4	12.7	8.5
0.176	17.5	8.8	5.8

As known from impact force acted on diamond grits, the big steel balls possibly make diamond fracture after collision only one time, which easily leads to macro-fractured of diamonds. But, if the steel balls are very small, the impact force is also little. Only after repetitious impact and wear do diamonds fracture gradually. Therefore, impacting the grits with steel balls of different mass can stimulate the force acted on diamond abrasive in tool.

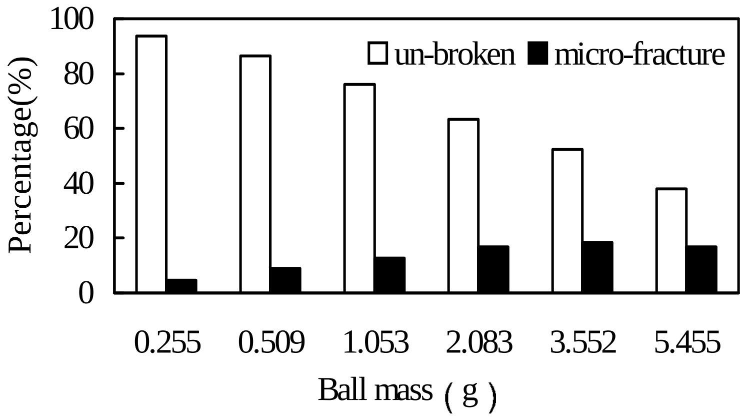


Fig.3 Fracture types of MBD6 40/50 US mesh diamod grits colliding with different mass balls

Fig.3 shows fracture types of MBD6 40/50 US mesh diamond grits after impacting with different mass steel balls. The number of cycles is 777. The experimental results illustrate that with the increase of mass of the steel balls (i.e. the increase of impact force), the ratio of un-broken diamond decreases continuously, while that of micro-fractured increases gradually. The change of the force between steel balls and diamond grits with impact frequency is shown in Table 2.

Table 2 Forces on MBD6 40/50 US mesh diamond grits at different impact frequency

Impact frequency [rpm]	Forces[N]		
	Collision with one grit	Collision with two grits	Collision with three grits
1700	176.6	88.3	58.9
1850	192.4	96.2	64.1
2000	207.3	103.7	69.1
2150	223.2	111.6	74.4
2300	239.0	119.5	79.7

Once the mass of steel balls is fixed, the impact force that steel balls operate on diamond grits every time increases along with the increase of impact velocity.

When the mass of steel balls and the impact number are fixed, the effect of impact frequency on fracture of diamond is shown in Fig.4. With an increase of impact frequency, the ratio of un-broken diamond decreases, and micro-fractured diamond increases. Correspondingly, we can stimulate the influence of tool velocity on diamond in practical tool through studying the force and fracture of diamond resulting from impact frequency.

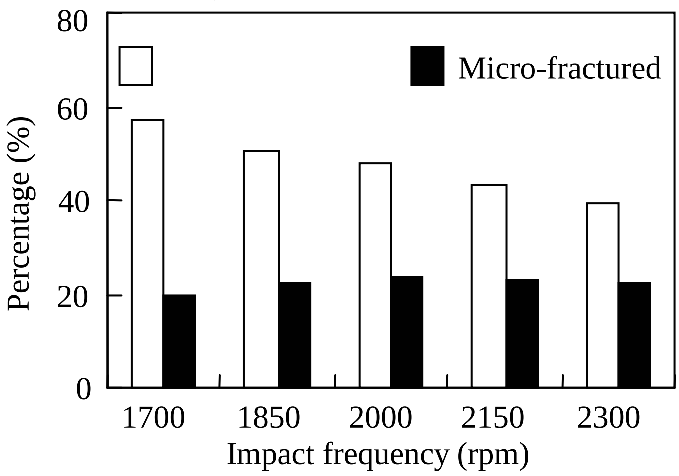


Fig.4 Fracture types of MBD6 40/50 US mesh diamond at different impact frequency

Conclusions

1. Impacted diamond grits are divided into three types: un-broken, micro-fractured and completely fractured. The correlation between the fracture types of impacted diamond and its failure modes in diamond tool was established.

2. With the increase of steel ball mass, un-broken ratio of diamond grits decreases and micro-fractured ratio increases gradually.

3. Fracture types of diamond grits are also related to impact frequency. With the increase of impact frequency, the ratio of un-broken diamond decreases and that of micro-fractured one increases gradually.

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