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Original article

Study on the fragmentation of granite due to the impact of single particle and double particles

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ABSTRACT

Particle Impact Drilling (PID) is a novel method to improve the rate of penetration (ROP). In order to further improve the performance of PID, an investigation into the effect of single and double particles: (1) diameter; (2) initial velocity; (3) distance; and (4) angle of incidence was undertaken to investigate their effects on broken volume and penetration depth into hard brittle rock. For this purpose, the laboratory experiment of single particle impact rock was employed. Meanwhile, based on the LS-DYNA, a new finite element (FE) simulation of the PID, including single and double particles impact rock, has been presented. The 3-dimensional (3D), aix-symmetric, dynamic-explicit, Lagrangian model has been considered in this simulation. And the Elastic and Holmquist Johnson Cook (HJC) material behaviors have been used for particles and rocks, respectively. The FE simulation results of single particle impacting rock are good agreement with experimental data. Furthermore, in this article the optimal impact parameters, including diameter, initial velocity, distance and the angle of incidence, are obtained in PID.

1. Introduction

With the development of conventional drilling methods, research on this field has been conducted by a few research groups in recent years. Though efforts had been made to improve the properties of drilling, some problems, such as the slow rate of penetration, short service life of drill pipes, long drilling cycle and high drilling cost, still exist when encountered with hard formations. In drilling process, formation hardness and drilling difficulty increase exponentially with the drilling depth. Generally, high drilling cost derives from interdependent operations that are time sensitive. And as we know, the longer it takes to penetrate the formation, the more it costs [1,2]. However, compared with the conventional drilling technology, PID rates can be 1/3 to 1/5 the time to drill the interval that represents 80% of the drilling time and expense. The value of drastically reducing the number of days to drill a well and thereby reducing much of costs associated in drilling those well is huge [3].

To improve this new technology, a large amount of laboratory tests had been conducted, such as A.H. Hanuka [4], Li Xibing [5], Wang Wenlong [6], Yonghong Zhao [7], who had carried out researches into the dynamic strength and hardness of the rock. Particle Drilling Technology Inc. had undertaken the laboratory and field tests and testified that particle impact drilling (PID) had higher efficiency than conventional drilling methods. Though granite exhibits variation of characteristics as those other types of rocks, nevertheless it has less properties variation than the rest [8]. In addition, rock fracture is defined as the formation of planes of separation within the rock as the cohesion between particles is broken and new surfaces are formed. Shear stress failure is considered as the most common and important type of failure where one face of surface slips from another [9]. The failure via shear faulting is addressed to be the most fundamental in rock damage [10]. And the importance of tensile

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fracturing was also emphasized in the development of shear zone [11].

The purpose of this article is to obtain the optimal parameters based on the impact experiments and simulations and demonstrate the new technique of FE simulation. The following works were carried out. Firstly, we conducted the single particle impact experiments in laboratory. Secondly, to determinate the parameters of HJC model, the SHPB tests, uniaxial compressive experiment, uniaxial tensile experiment and tri-axial compressive experiment were conducted. In order to simplify the article, only the SHPB test was described and the obtained HJC parameters were presented in this article. Thirdly, the simulation of single particle impact target was developed. And the values of the broken volume and penetration depth onto the rock were compared with the results of single particle impact rock experiments. Finally, the simulation of double particles impact granite were carried out, and the optimal parameters in PID were obtained.

2. Experiments

2.1. Single particle impact rock experiment

2.1.1. Materials

In the experiment, the projectiles were four kind of steel particles with the diameter 3 mm, 5.5 mm, 7 mm and 9.5 mm (shown in Fig. 1). The selected granite sample (shown in Fig. 2) was taken from Sichuan. The rock shape is cuboid with the size of $500 \times 500 \times 200$ mm. The temperature and pressure were 20 °C and normal pressure, respectively.

2.1.2. Experimental procedures

Four kind of steel particles with different initial velocity, ranging 100 m/s from 300 m/s, shot to the granite by air gun. And the specific parameters of initial velocity and diameters are shown in Table 1. Phantom V12.0 digital high-speed camera recorded the experimental progress (Fig. 3), whose highest amplitude frequency exceeds 500,000 per second. According to the grid paper and the ruler, incident velocity, rebound velocity and the flying velocity can be measured conveniently. The granite with craters is shown in Fig. 2.

In order to obtain the broken volume and the maximal penetration depth, 3D CaMega scanner and Cloudpoint software were used in the impact process. Firstly, the point-cloud data was obtained using 3D CaMega scanner (Fig. 3). Then, the maximal penetration depth and broken volume were calculated by Cloudpoint software.

Fig. 1. Different types of steel particles.

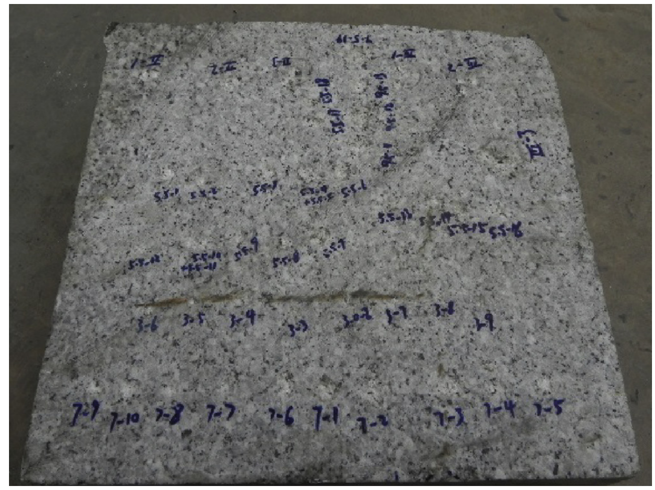

Fig. 2. The granite sample with craters.

Table 1
The Diameter and initial velocity of impact particles.

Diameter (mm)	3	3.5	7	9.5
Impact velocity (m/s)	91	137	100	97
	116	165	102.3	109
	146	180	130	171
	154	230	168	175
	202	253	263.4	202
	264.5	256	264	251
	276	273	267	269

3. Simulation

3.1. Finite modeling description

3.1.1. Particle specification

The steel particles have been used in FE simulation. The elastic material behavior has been chosen. The constitutive model [12] is described as follows:

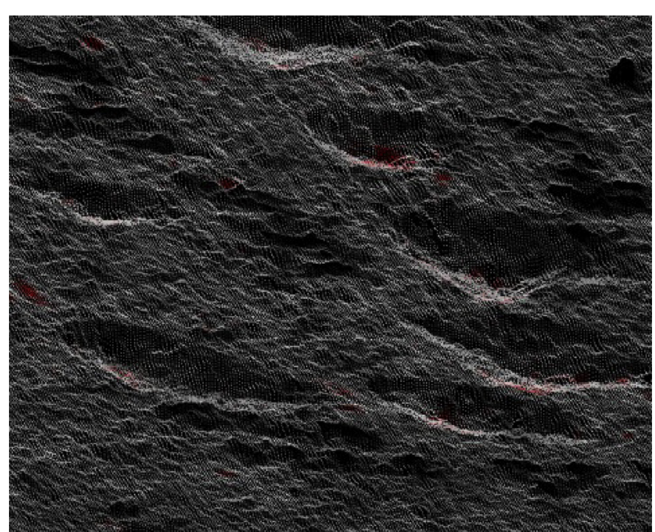

Fig. 3. The scan figure of impacted granite.