International Journal of Rock Mechanics & Mining Sciences 91 (2017) 18–28

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

Numerical and experimental investigation of the impact fragmentation of bluestone using multi-type bits

Songyong Liu[a,b,*], Huanhuan Chang[a,b], Hongsheng Li[a,b], Gang Cheng[a,b]

[a] School of Mechatronic Engineering, China University of Mining and Technology, Xuzhou 221116, China
[b] Jiangsu Key Laboratory of Mine Mechanical and Electrical Equipment, China University of Mining and Technology, Xuzhou 221116, China

ARTICLE INFO

Keywords:
Impact fragmentation, Drilling velocity
Orthogonal experiment
Drill bit
Rock-breaking efficiency

ABSTRACT

In this work, a numerical model of impact fragmentation was established based on the finite element method to investigate the problem of low efficiency and high power consumption associated with an impact fragmentation apparatus. First, the main parts of the impact fragmentation apparatus were simplified and a numerical model of the piston-bit-rock system was constructed. The orthogonal experimental design method was used, and the results were analyzed using range and variance analyses. Finally, the numerical model was verified and an optimal combination of the working parameters was obtained from experimentation. The results show that the order of factors influencing the impact fragmentation apparatus's working parameters are impact energy, rotational speed, feed pressure, impact frequency and bit type. Moreover, impact energy has a significant effect on the drilling velocity, rotational speed and feed pressure has a moderate effect on the drilling velocity; the influence of the impact frequency and bit type on the drilling velocity is not obvious. Furthermore, the optimal combination of working parameters for the impact fragmentation apparatus in this study includes an impact energy, impact frequency, rotation speed, feed pressure and bit type of 100 J, 50 Hz, 270 rpm, 3500 N and 7-button bit, respectively. It is effective to increase the impact frequency and rotary torque to improve the rock-breaking efficiency of the impact fragmentation apparatus.

1. Introduction

Impact drilling fracturing is a universal method for rock breaking in engineering, such as railway and highway tunneling, underground roadway excavating, quarries, coal mining, and so on. According to statistics, the excavating length of a hard rock roadway is more than 2000 km every year in China. The annual increasing length of highway tunneling is 1000 km, and the planning length for railway tunneling has been over 10000 km since 2011. Drilling and blast tunneling is an important method of excavating rock tunnels and channels because of its excellent applicability. This method is divided into three steps: drilling holes, filling explosives, blasting and excavation of rock. The time required for drilling occupies a large proportion of the overall time required for hard rock roadway excavating processes. A poor drilling efficiency results in even longer drilling times. Therefore, it is valuable to study ways to reduce drilling time and improve drilling efficiency.

Numerous studies have been carried out on impact fragmentation. Akihiko Kumano et al.[1] studied the impact fragmentation mechanism for coarse granular rocks and indicated that there were three crushed zones: the crater, damage zone and crack growth zone. The work by Schormair et al. [2] examined the influence of rock anisotropy on drilling and tunnel blasting using percussive drilling experiment. They found that the texture angle controlled the mean size of the produced rock fragments. Kivadeet et al. [3] investigated the influence of the rock properties, feed pressure and inlet pressure on noise and the drilling velocity using pneumatic drill experiment. Shcherbakovet et al. [4] found that the acoustic-emission (AE) was in accordance with the power law rule for crack propagation, but did not apply to the fractoluminescence (FL) generated by the interatomic bond breaking on the specimen surface. To determine the influence of the piston shape and impact energy on rock impact fragmentation, Chiang et al. [5] constructed a 3D FEM methodology to simulate impacts associated with rock-drilling hammers. Lundberg et al. [6] established a 3D elastic FEM model and concluded that the elastic response of the rock had a significant effect on the drilling efficiency under good conditions. Cavanough et al. [7] examined the maximum drilling velocity and minimum deviation as well as the relationship between the pressure/feed pressure and determined the penetration rate, feed pressure and pressure parameters required to optimally control the drilling system. Kwon et al. [8] designed a drill bit with a new button arrangement to improve the

* Corresponding author at: School of Mechatronic Engineering, China University of Mining and Technology, Xuzhou 221116, China.
E-mail address: lsycumt@163.com (S. Liu).

http://dx.doi.org/10.1016/j.ijrmms.2016.11.006
Received 21 January 2016; Received in revised form 7 November 2016; Accepted 10 November 2016
Available online 15 November 2016
1365-1609/

drilling efficiency based on a drop-type piston impact test system. Keskinen et al. [9] conducted FEM modeling of a percussive drilling system to analyze the propagation process of a stress wave to predict the drilling effect of a cutter. Saksala et al. [10,11] constructed a 3D numerical model of a bit/rock system and proposed that side cracks were caused by tensile stresses associated with a quick unload, and there was significant shear and tensile damage underneath the hemispherical button. One year later, experiments using an equilateral triangle bit were used to determine the influence of the impact velocity on side cracks between buttons during percussive drilling. Zhou et al. [12] discussed the impact fragmentation mechanism for low power conditions via impact fragmentation experiments using a single-indenter and found that the shape of the impact crater was generally consistent with the Sikarskie shear fracture theory. Yasar et al. [13] utilized concrete to replace rock and examined the influence of the working parameters and material properties on the drilling velocity and energy consumption for drilling. The influence of pre-existing and structural cracks on granite rock fragmentation was studied via experiment by Saadati et al. [14]. Zhu et al. [15] examined the application effect by using numerical modeling to simulate using an air rotary-percussive drill based on the H-J-C (Holmquist-Johnson-Cook) material model.

Despite the fact that a significant amount of research has been carried out on the shape of the piston, impact energy, properties of rock and acoustics, which provide many references for studying impact fragmentation, in actual production, the rock properties are not optional, except the working parameters for the equipment (impact energy, impact frequency, rotational speed, feed pressure and bit type). To determine the influence of the working parameters on the drilling velocity as well as optimal combination of working parameters, this paper uses numerical simulations and experiments to research impact fragmentation.

2. Process of impact fragmentation

The working process of impact fragmentation apparatus is shown in Fig. 1. The impact fragmentation apparatus mainly consists of a piston, shank adapter, drill rod and drilling bit. The working process of impact fragmentation is divided into impact, feed, rotation and flushing. Rock fragments are generated by the impact. The drill bit presses into the rock surface to maintain contact or withdraw from the completed hole to prepare to drill a new hole at a different position. Rotation causes the drill bit to rotate to a new position for a rock break after completion of the impact. Simultaneously, some rock surfaces with cracks are peeled off. The purpose of flushing is to remove debris from the hole and prevent excessive wear of the drill bit [16].

Fig. 2 shows the fragmentation mechanism for wedged and button bits. There is a compacted body underneath the wedged bit (cross bit), as shown in Fig. 2(a). Opening cracks are generated under the compacted zone and become deeper with the load. Radial cracks are generated on both sides of the compacted zone, with parts extending to

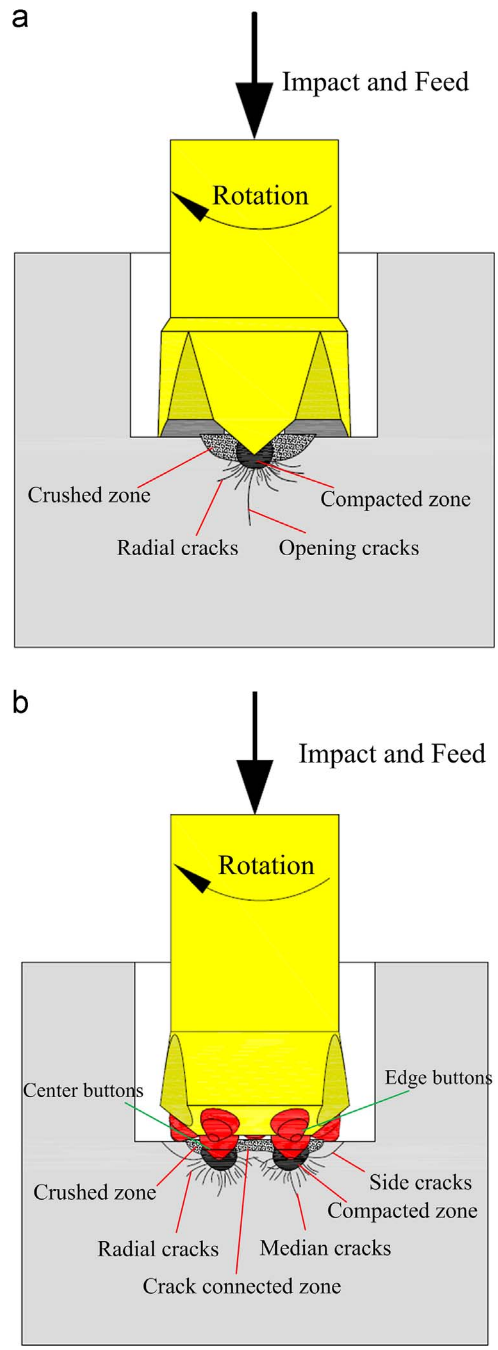

Fig. 2. Fragmentation mechanism of the wedged and button bit. (a) Wedged bit. (b) Button bit.

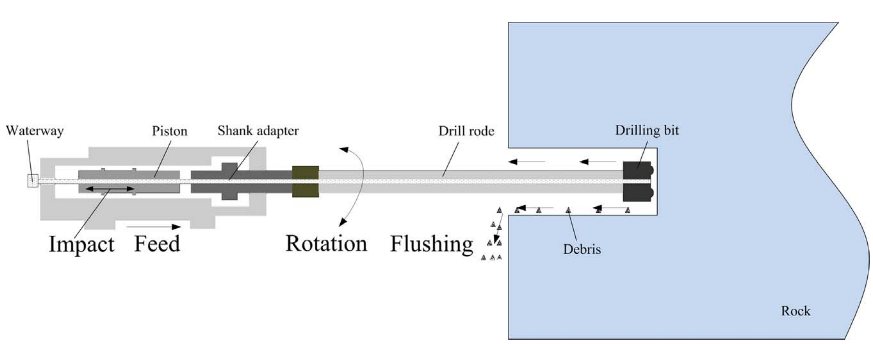

Fig. 1. Working process of the impact fragmentation apparatus..