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Procedia Earth and Planetary Science 11 (2015) 89 – 99

Procedia Earth and Planetary Science

Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources (GCPF2015)

Experimental Investigations on Penetration Rate of Percussive Drill

S. B. Kivade[a], Ch. S. N. Murthy[b], Harsha Vardhan[b]

[a]*Dept. of Mechanical Engg. BasavakalyanEnggCollege, Basavakalyan -585327India. Email: sbkivade@gmail.com*
[b]*Dept. of Mining Engg. NITK, Suratkal,-575025 IndiaEmail: chsn58@gmail.com*

Abstract

In this paper, detailed studies were carried out to determine the influence of rock properties on the penetration rate during pneumatic drilling. Further investigation was also carried out on the effect of thrust, air pressure, and compressive strength on penetration rate. Rock properties, like compressive strength and abrasivity of various samples collected from the field were determined in the laboratory. Drilling experiments were carried out on ten different rock samples for varying thrust, air pressure values and bit diameter. It was observed that very low thrust results in low penetration rate. Even very high thrust does not produce high penetration rate at higher operating air pressures. With increase in thrust beyond the optimum level the penetration rate starts decreasing and causes the drill bit to 'stall'. Results of the study show that penetration rate increases with increase in the thrust level. After reaching the maximum, they start decreasing despite the increase of thrust. The main purpose of the study is to develop a general prediction model and to investigate the relationships between penetration rate during drilling and physical properties such as uniaxial compressive strength and abrasivity of sedimentary rocks. The results were evaluated using the multiple regression analysis taking into account the interaction effects of predictor variables.

Peer-review under responsibility of organizing committee of the Global Challenges, Policy Framework & Sustainable Development for Mining of Mineral and Fossil Energy Resources.

*Keywords:*Pneumatic drill; thrust; penetration rate; air pressure; bit diameter; rock properties.

1. Introduction

Investigations on percussive drilling have been carried out analytically, numerically and experimentally over many years. In percussive drilling, an impact tool continuously rises and drops to generate short duration compressive loads to crush the rock material. In general, a piston driven by compressed air converts its kinetic energy to impact energy by colliding with a steel rod or drill bit. This impact energy is transferred to the steel in the form of a stress wave that travels to the bit rock interface. Part of the energy in the wave goes to the rock causing failure and part of the energy is reflected back. The effective stress in breaking rock acts in an axial direction and in a pulsating manner. Thrust is the external force applied to a drill to keep the bit in contact with the rock.

An accurate estimation of drilling rate helps in planning of the rock excavation projects more efficiently. Drilling is the most expensive process and the prediction of penetration rate is very important in mine planning [1]. Also, one could use the prediction equation to select drill rig type which

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doi:10.1016/j.proeps.2015.06.012

is best suited for given conditions. Variables used to predict penetration rate could be classified into three main categories such as drill bit characteristics, characteristics of rock and operational variables. However, rock properties such as compressive strength, porosity, density and geological conditions are uncontrollable parameters [2, and 3]. Penetration rate is the progression of the drilling bit into the rock in a certain period of time which is generally expressed as "mm/s". The phenomenon of percussive drilling is a complex process and is affected by many factors. Bit type and diameter, applied thrust and flushing of debris are some of the controllable parameters.

Percussive drills have been extensively used in quarries, open pit mines and construction sites all over the world. Many of the researchers carried out the experimental investigation on noise emitted by pneumatic drills and its control. Percussion drills are the source of the most serious noise problem in mining activities due to their extremely high noise levels of the order of 114 to 122 dB and their widespread use [4]. Percussion drills will continue to be widely used to drill small diameter holes in hard rock because no other method seems to be economically available to replace them [5]. Many studies were conducted to determine the major noise sources of percussion drills [6, 7, and 8].

The major noise source in pneumatic drill is the driving unit which emits high intensity low frequency noise due to compressed air[9]. Of the total noise energy of pneumatic drill, 87.5% is contributed by the exhaust and the next largest component is the impact between the piston and drill steel [10, 11, 12, 13, 14, and 15]. It was suggested by Miller (1963) that efforts should be made to attenuate the sound levels in the frequency range of 500 to 600 Hz and 1500 to 1700 Hz, as most of the sound power is concentrated in these frequency ranges [16].

Rock engineers widely use the uni-axial compressive strength (UCS) of rocks in designing surface and underground structures. The procedure for measuring this rock strength has been standardized by both the International Society for Rock Mechanics [17] and American Society for Testing and Materials [18]. Recent trend on estimating UCS from simple laboratory index tests have gained popularity. Various experimental methods and drillability models were developed to determine drillability or to predict penetration rate by various researchers [19, 20, 21, 22, and 23].

Further a number of attempts have been made by many researchers to indirectly define various rock properties using different approaches [24, 25, 26, 27 and 28]. Most of these studies have been dealt with simple models relating UCS to Schmidt hammer rebounds (SHR), UCS to sonic velocity (Vp,) UCS to porosity (n), UCS to point load (PL) and so on.

In view of the above, it is felt that investigation using percussive drilling machine which is widely used in the mining and mineral industries for estimating rock properties will be very much useful for the mining community. In this laboratory investigation, total three drill bits were used. Three integral steel chisel bits with 30, 34 and 40 mm diameter and 42, 43, and 62 cm length of chisel geometry were used. These bits were selected from among the available sizes. An attempt has been made in this investigation to determine the rock properties and developing various models for the prediction of UCS and abrasivity for rocks considered using penetration rate during percussive drilling and prediction of penetration rate for a given air pressure, thrust and bit-rock combination using multiple regression analysis. The developed models were checked using various prediction performance indices and compared with the traditional statistical model.

2. Laboratory investigation

In this investigation, different types of sedimentary (shale, dolomite, sandstone, limestone, and hematite), rocks were collected from different localities of India taking care of variety of strength. During sample collection, each block was inspected for macroscopic defects so that it provides test specimens free of fractures and joints. Penetration rate on pneumatic drill set up was carried out for 5 different rock samples. The size of the rock blocks was approximately 30 cm × 20 cm × 20 cm.

2.1. Equipment /Instrumentation

2.1.1. Drilling machine

In the laboratory, all the sound level measurements were conducted on a commercially used jackhammer drill machine (Atlas Copco, RH658L) operated by compressed air with suitable arrangement made to measure applied thrust and air pressure is shown in Fig. 1. It is extensively used in underground hard rock excavation (underground mine and opencast mine) and quarries. The important specifications of the jackhammer drill used were: