Journal of Rock Mechanics and Geotechnical Engineering xxx (2018) 1–14

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Drag pick cutting tests: A comparison between experimental and theoretical results

Serdar Yasar*, Ali Osman Yilmaz

Department of Mining Engineering, Karadeniz Technical University, Trabzon, 61080, Turkey

ARTICLE INFO

Article history:
Received 15 November 2017
Received in revised form
19 December 2017
Accepted 4 February 2018
Available online xxx

Keywords:
Rock cutting mechanics
Rock cutting tests
Vertical rock cutting rig (VRCR)
Cutting force
Rock cutting theories

ABSTRACT

This paper aims at reporting the results of a number of drag pick cutting tests on selected igneous rock samples to compare the experimentally determined maximum cutting force (FC') values with theoretically estimated ones. First, a review on theoretical rock cutting models proposed for both chisel and conical picks was presented in detail. Experimental study consists of both chisel and conical pick cutting tests in unrelieved (single-pick) cutting mode with varying cutting depths. FC' values were determined from experimental results, and theoretical models were utilized to compute FC' for all cutting conditions. Computed and experimentally determined FC' data were then compared for a referenced cutting depth. It is shown that the theoretical models might overestimate or underestimate FC' and cannot give reliable results. Finally, explanations for these mismatches were presented.

1. Introduction

Partial-face tunneling machines (e.g. roadheaders) are versatile rock excavation machines used in both underground mining and civil excavations, and these machines are equipped with drag picks. Furthermore, the performance of these rock cutting machines relies vigorously upon forces that cutting tools can withstand (Mellor, 1975). The resultant force acting on a cutting tool has three orthogonal components, namely cutting force (*FC*), normal force (*FN*) and sideway force (*FS*). Among these components, *FC* has an exceptional effect on the performance of a cutting tool, especially on that of partial-face machines, since *FC* is in the direction of cutting action and regarded as the energy consuming component according to the principle of dynamics.

FC may be estimated/determined through a number of methods including direct cutting tests, and theoretical and empirical models. Rock cutting test can be found in very limited research centers. These tests, especially full-scale tests, require large blocks that are impossible to be acquired under certain conditions. Consequently, alternative testing arrangements (Roxborough and Philips, 1974; Detournay et al., 1997; Bilgin et al., 2010; Entacher et al., 2014; Kang et al., 2016; Yasar, 2018) have been proposed and other methods are not calibrated due to the absence of these tests. Empirical models derived from different rock mechanical properties were also utilized for cuttability assessment (Bilgin et al., 2006; Yasar et al., 2015). However, prediction accuracies of these models depend on the quality and the number of testing data. Generally, uniaxial compressive strength (UCS) was used as an input parameter in these models. Nevertheless, uniaxial compression test results are affected by many experimental conditions, and uniaxial testing cannot model the fracturing process of rock cutting (Fowell, 1993; Fowell et al., 1994).

Researchers utilized different methods to explain the cutting mechanism of a selected drag pick and suggested different analytical models for estimation of the maximum cutting force FC' based on strength and pick related parameters. These models can be categorized into the ones for chisel picks (Evans, 1958; Potts and Shuttleworth, 1958; Nishimatsu, 1972) and those for conical picks (Evans, 1984; Roxborough and Liu, 1995; Goktan, 1997; Goktan and Gunes, 2005). Even though several models were proposed for better understanding of rock breakage mechanism, it was found that some theoretical data did not match with the experimental results (Mellor, 1977; Bilgin et al., 2006; Spagnoli et al., 2017). Since there is still a limited work on the comparison of theoretical and experimental data, more rock cutting tests should be conducted and cutting theories should be improved according to the new experimental data obtained from rock cutting tests. In a standard experimental campaign concerning the comparison between

* Corresponding author. Fax: +90 462 325 74 05.
E-mail address: seyasar@ktu.edu.tr (S. Yasar).
Peer review under responsibility of Institute of Rock and Soil Mechanics, Chinese Academy of Sciences.

https://doi.org/10.1016/j.jrmge.2018.02.007

theoretical and experimental rock cutting data, a number of fundamental variables should be used, including cutting depth, rake angle and pick width for chisel type tools, and cutting depth, rake angle and cone angle for conical picks. However, in this paper, a referenced cutting depth was given and used as an independent variable. Additionally, sensitivity of the theoretical results to the changes in friction angle was investigated.

In this context, an experimental campaign was carried out on six different igneous rocks using a chisel and a conical pick. Pick specifications (cone angle, rake angle, clearance angle, and tool width) were kept constant, and cutting depth was used as an independent variable in rock cutting tests. Additionally, friction angle was selected arbitrarily to report the sensitivity of rock cutting theories to the changes in friction angle. Experimentally determined FC' values were then compared with theoretically estimated data. Possible explanations for the mismatches between the theoretical and experimental data were proposed.

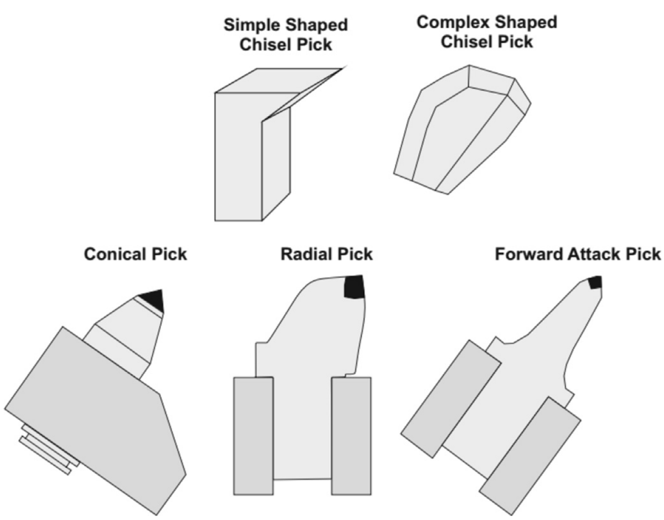

Fig. 1. Types of drag picks.

2. Rock cutting theories for drag picks

The cutting tools equipped on rock cutting machines can be grouped into two main types: drag picks and roller bits (indenters). Drag picks are used frequently on partial-face machines such as roadheaders, continuous miners, plows and shearers, and these picks are usually regarded as true shearing picks. Radial pick, conical pick, forward attack pick, and simple and complex shaped chisel picks are generally considered as drag picks, as shown in Fig. 1. On the other hand, roller bits are used on full-face machines such as tunnel boring machines, and the most frequently used roller bits are disc cutters.

Drag picks travel in parallel with the rock surface to be excavated and cut the rock by dragging the rock piece ahead of the pick face. Regardless of their types, drag picks present a similar phenomenological cutting action. They cause compressive, shear and tensile stresses in the rock samples changing with cutter configurations and other relevant parameters. Cutting cycle of a drag pick, based on physical observations, is given in Fig. 2 and detailed explanation is presented as follows.

At the first stage, pick is ready for traveling in parallel with the rock and is forced to tear off a large rock chip. Simultaneously, a crushed zone arises in the vicinity of the tool tip and small rock particles are generated in this region. However, at this point, a distinction should be made to avoid a misconception that this so-called indentation is different from that in a disc cutting or wedge/cone penetration. In both penetration and disc cutting tests, it has been found that 90% of the energy dissipated for creating a rock chip is consumed for generation of small rock particles rather than for generation of a large rock chip (Bao et al., 2011; Entacher et al., 2015). However, due to the fact that drag pick cutting is neither a disc cutting nor an indentation test, this phenomenon might be excluded. This does not mean that crushing does not

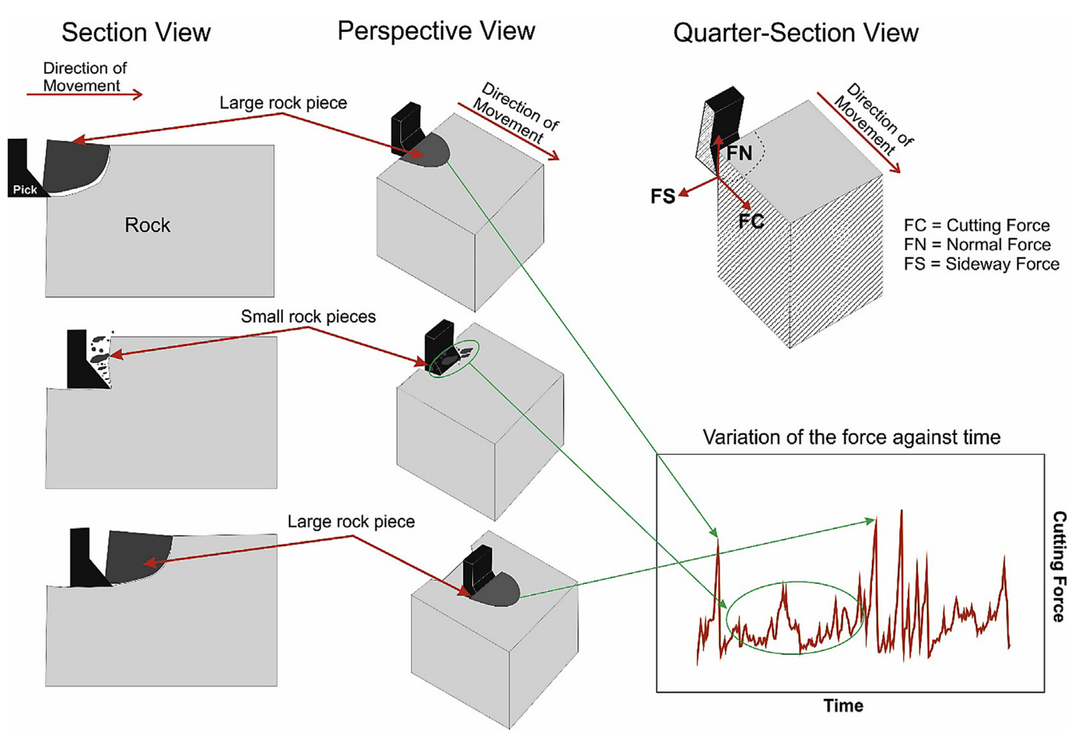

Fig. 2. Illustration of the simplified cutting cycle of a drag pick based on physical observations.

Please cite this article in press as: Yasar S, Yilmaz AO, Drag pick cutting tests: A comparison between experimental and theoretical results, Journal of Rock Mechanics and Geotechnical Engineering (2018), https://doi.org/10.1016/j.jrmge.2018.02.007