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Experimental linear cutting tests of forces and temperature gradients in disc cutters

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Abstract. The disc cutter, part of the cutterhead of a tunnel boring machine, is a key tool for excavating rocks. The forces acting on a disc cutter depend on its type and shape as well the rock mass and cutting conditions. This study aims to evaluate the differences in the forces and stress acting on disc cutters for different ring shapes. The temperature variations and loads exerted on disc cutters are measured. Full-scale rock cutting tests show that the mean cutter forces and axial stress are proportional to the contact area of the disc cutter tips. In some cases, the loads exerted on the disc cutters are close to the load carrying capacity of the inner parts of the disc cutters. Therefore, it is essential to determine the adequate load carrying capacity of the inner parts of a disc cutter when cutting deeply through strong material. Heating during excavation can increase the wearing of disc cutter rings. The temperature gradient of a disc cutter is calculated in a laboratory setting.

Keywords: linear cutting test; disc cutter; cutter force; axial stress; temperature gradient

1. Introduction

Linear cutting testing is a well-established method of predicting the performance of tunnel boring machines (TBMs) (Ozdemir and Nilsen 1993). The tests can provide reliable results, because they employ a full-scale disc cutter and real cutting conditions; however, there are limitations to laboratory test conditions such as cutting length and linear cutting. Linear cutting tests are therefore often used to study cutterhead design and drilling performance (Bilgin et al. 1999, Chang et al. 2011, Choi et al. 2013, Rostami and Ozdemir 1993, Rostami 1997, Snowdon et al. 1982).

Disc cutters, part of the cutterhead of a TBM, are key tools for excavating rocks. The forces acting on the cutters depend on the rock properties and cutting conditions, and essentially determine the maximum capacity of a disc cutter and the design parameters of a TBM (e.g., thrust forces and torque) (Entacher et al. 2012).

The forces acting on a cutter are generally indicated as normal, rolling, and side. The normal force is the greatest among them, and determines the allowable load of the disc cutter. The sum of all the normal forces acting on each disc cutter on the cutterhead also dictates the required thrust of the TBM. The rolling force is useful in predicting the required torque of a TBM; it is influenced by the size of the disc cutter, the shape of the cutter ring, and the penetration depth of the disc cutter during each revolution (Balci and Tumac 2012, Rostami 2013). The forces acting on a disc cutter are generally proportional to its diameter.

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The forces acting on a disc cutter depend on its ring shape (Rostami 2013); however, except for a few studies of V-shaped disc cutters (Balci & Tumac 2012), most studies of cutter forces consider only ring shapes of constant cross section (CCS) (Chang et al. 2012, Cho et al. 2008, You et al. 2008).

The inner parts of a disc cutter during excavation have also not been well studied, but their load capacity has been shown to depend on the diameter of the disc cutter (Roby et al. 2008). Efficient disc cutter design requires the experimental evaluation of the load factors in each part of a disc cutter (e.g., the loads on the shaft and bearings, and the stiffness of the cutter ring).

This study presents three experimental results using a linear cutting machine on high-strength rock: variation in cutter forces for different cuter ring shapes, the axial loads on the shaft of a disc cutter, and the inner and surface temperature variations of a disc cutter. The cutter forces are derived from axial stress measured by strain gauges attached to the shaft of a disc cutter, and the inner and surface temperature are measured using thermocouples.

2. Experimental Setup

2.1 Linear cutting machine

The linear cutting machine (LCM) used here is illustrated in Fig. 1. It consists of a hydraulic unit, a controller, a steel specimen mold, a load cell, and a frame with actuators that can move in the X, Y, and Z directions. The load cell can measure the forces acting on the disc cutter in the directions of movement of the actuators.

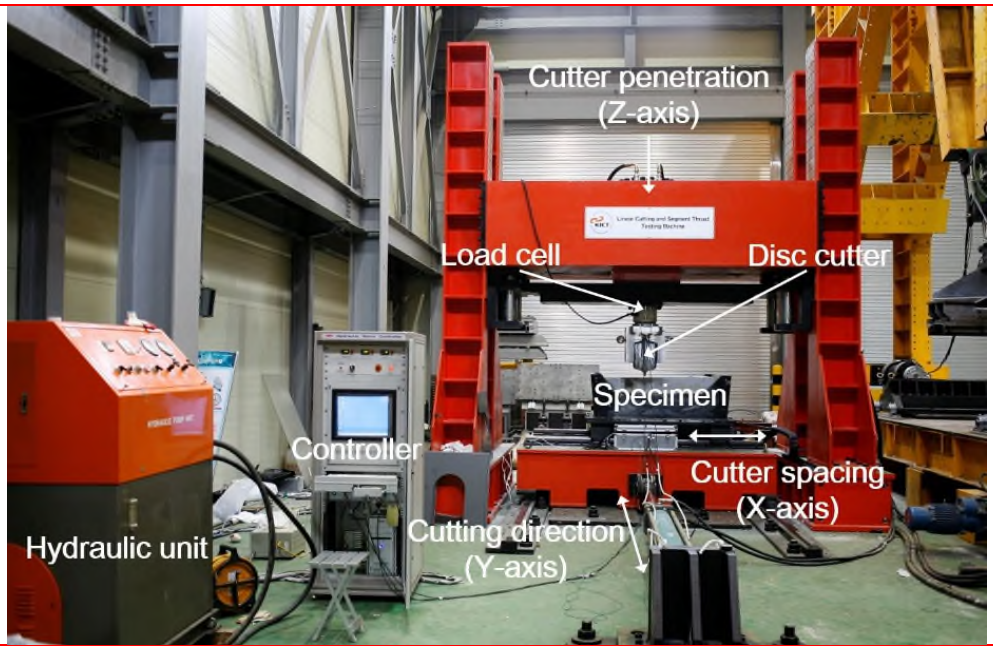

Fig. 1 Photograph of the linear cutting machine.

2.2 Disc cutter

The cross section of the cutter rings of disc cutters can either be uniform (i.e., CCS) or V-shaped. Although a V-shaped cutter is efficient for the excavation of soft rock, as its tip wears the forces acting on the cutter exponentially increase during use. Therefore, CCS disc cutters are commonly used, because

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