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Experimental study on wear behaviors of TBM disc cutter ring under drying, water and seawater conditions

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ABSTRACT

To study the wear behaviors of the tunnel boring machine (TBM) disc cutter ring under drying, water and seawater conditions, a series of cutter-rock wear tests were conducted based on the self-designed TBM cutter performance test bench. The results indicate that the wear behaviors of the cutter ring are affected significantly by wear conditions. The largest mass loss of the cutter ring is under the drying condition, followed by the seawater condition, and the smallest is under the water condition. The differences in mass loss were explained by the cutter force, wear mechanism, and wear debris etc of the cutter ring. These results can provide some references for the wear resistance design and service life prediction of the TBM cutter ring.

1. Introduction

Tunnel boring machines (TBMs), as dedicated engineering machines, are widely employed in tunnel constructions due to their high excavation efficiency and excellent safety [1,2]. TBMs are applicable for various grounds including the rock, soil and soil-rock mixed grounds [3]. When tunneling in rock ground, the disc cutters installed on the TBM cutterhead are the most efficient and popular cutting tools to cut the hard rock [4,5]. During the tunneling process, the disc cutter ring interacts with and cuts rock directly through the rotation of the TBM cutterhead [6,7], and thus the cutter ring suffers from heavy contact stress and serious wear [8,9]. Undoubtedly, the severe cutting condition and serious wear of the cutter ring will cause high consumption of the disc cutter and high economic loss. A large volume of engineering data shows that the economic loss caused by cutter ring wear accounts for twenty percent of the total cost [10]. Thus, the wear problem of the cutter ring has attracted increasing attention both in the academic field and in the engineering field.

The wear mechanisms of the cutter ring have been investigated by many researchers. Lislerud [11] concluded that there are four basic wear mechanisms of the TBM cutter wear, including tribochemical reaction, surface fatigue, adhesive wear and abrasive wear. Barzegari et al. [12] found there are three types of wear mechanisms, i.e. impact, adhesive wear and abrasive wear. Zhao et al. [13] discovered that the wear mechanism of the cutter ring is abrasive wear. The abrasive wear including ploughing, micro cutting, micro fatigue and micro cracking is caused by hard particles sliding against the wearing surface [14,15]. Espallargas et al. [16] proposed that abrasion is the commonest wear mechanism for the disc cutter ring.

Generally, the wear behavior of the cutter ring depends on various factors including rock properties, cutter ring properties, and TBM working conditions [17,18]. For rock properties, Al-Ameen and Waller [19], West [20], Plinninger et al. [21], Yaralı et al. [22], Ko et al. [23], Er and Er [24], and Capik et al. [25] investigated the effect of rock strength and abrasive mineral content on Cerchar Abrasivity Index (CAI) value. Macias et al. [26], Majeed and Abu [27], and Petrica et al. [14,15] studied the influences of rock types on rock abrasivity. It should be pointed out that the above-mentioned researches are mainly focused on rock abrasivity rather than the wear behaviors of the cutter ring. For cutter ring properties, Lin et al. [18] studied the specific matching characteristics between cutter ring hardness and rock. Michalakopoulos [28] investigated the influence of hardness on CAI based on the wear testing device. All of the aforementioned studies are helpful in understanding the effects of rock properties and cutter ring properties on the wear characteristics of the cutter ring.

During the tunneling process, the TBM may encounter different working conditions such as dry rock grounds, or moist rock grounds which are soaked in water or seawater due to the complexity of rock grounds [29–31]. When the disc cutter ring cuts rock under different cutting conditions, the wear behavior may show difference. For example, when the cutter ring cuts rock under the seawater condition, its surface may be corroded by seawater during the cutting process [16].

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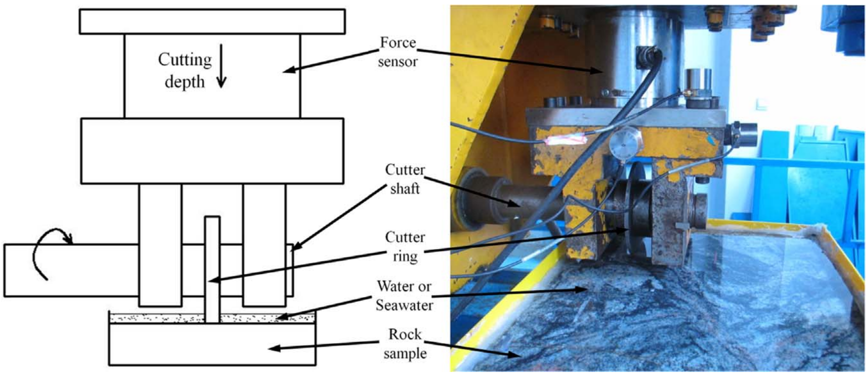

Fig. 1. Cutter-rock wear test device.

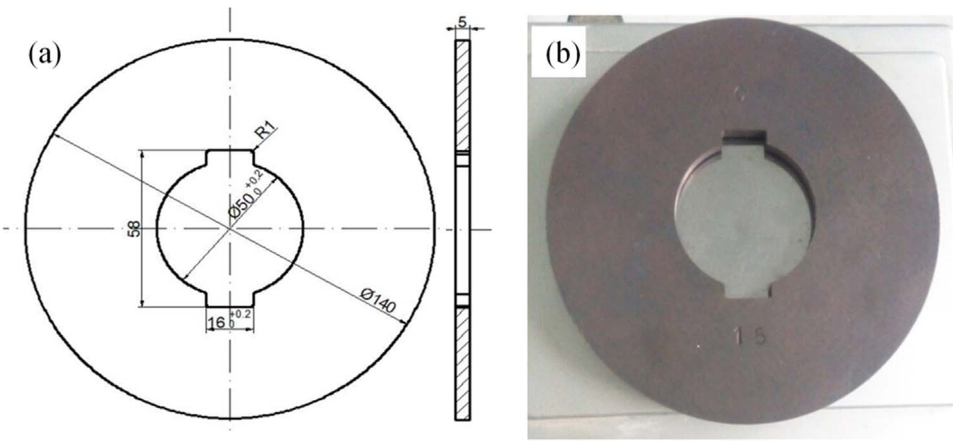

Fig. 2. Disc cutter ring: (a) structure of cutter ring; (b) sample of cutter ring.

Table 1
Chemical composition of H13 steel (%).

C	Si	Mn	Cr	Mo	V	Fe
0.52	0.96	0.30	5.03	1.23	0.92	balance

Table 2
Rock sample properties.

Density(g/cm3)	2.52
Elastic modulus (GPa)	62.5
Uniaxial compressive strength (MPa)	145.2
Brazilian tensile strength (MPa)	6.72
Equivalent quartz Content (%)	41.39

As a result, the abrasion of the cutter ring will be influenced by the corrosion. In this sense, the wear behaviors of the cutter ring are influenced by the mutual interaction of abrasion and corrosion. According to Madsen [32], the interaction of abrasion and corrosion involving the mining tool can be expressed by Eq. (1).

$$T = W + C + S \tag{1}$$

Where T denotes the total wear induced by both abrasion and corrosion, W denotes the wear induced only by abrasion, C denotes the wear induced only by corrosion and S denotes the synergistic wear. According to Eq. (1), the synergy of abrasion and corrosion can enhance the mass loss and influence the wear behaviors of the TBM cutter ring. Thus, the cutting conditions play an important role in wear behaviors of the cutter ring. Unfortunately, the cutting conditions such as water and seawater are usually ignored when the wear behaviors of the TBM disc cutter ring are investigated. Meanwhile, the cutting conditions are

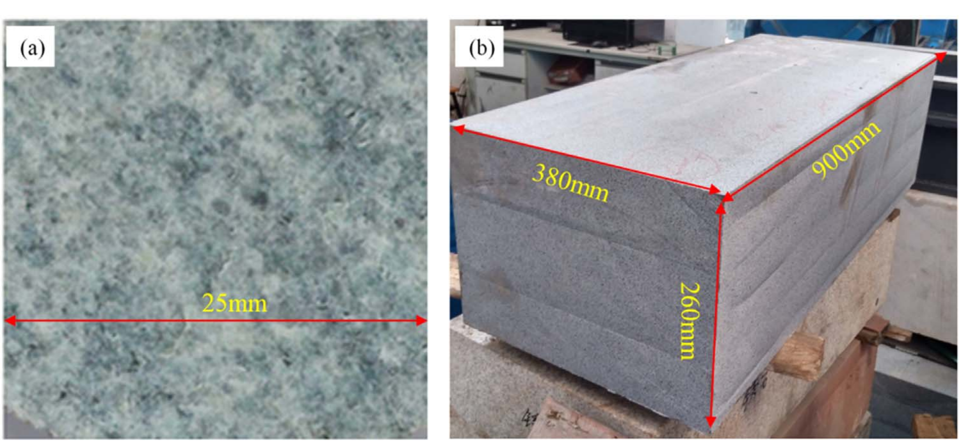

Fig. 3. Rock sample: (a) rock morphology; (b) rock shape.