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Evaluation and experimental study on the sealant behaviour of double gaskets for shield tunnel lining

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ABSTRACT

As waterproof joints are essential for shield tunnel segmental lining, double gaskets have been adopted for certain tunnel segments with high ground water pressure to prevent water leakage. To investigate the leakage behaviour of double gaskets in shield tunnel lining with joint opening and offset combination, mechanical and leakage tests were conducted on double gaskets subjected to water pressure. The linings are made of bolted and precast concrete with double gaskets, and the two gaskets are different sizes, but both have open bases. The mechanical test results revealed that three distinct phases are observable in the gasket load deformation curve, due to the process of gasket compression. Inappropriate design parameters for the gasket can result in the segment spalling around the gasket groove in field. In this study, improved parameters, including the diameter of circle hole inside the gasket and the hardness of the gasket, are presented with the goal of preventing segment damage. The experimental sealant test results demonstrated that the joint opening has a significant effect on the gasket leakage capacity: with increasing joint opening, the gasket sealant capacity decreases. The leakage mechanism of the double gaskets is also elucidated.

1. Introduction

The waterproofing of tunnel lining is a notable challenge facing metro shield TBM tunnels constructed in soft or sandy strata below the water table. A common structural problem, water leakage can be observed in joints, in cracks in the segment and in the hand hole or grouting hole, as shown in Fig. 1. These leakages cause deterioration of the shield tunnel, ageing of the installations in the tunnels, discomfort for the users of the tunnels and adverse environmental impacts (Yan et al., 2012; Sugimoto, 2006; Zuxi, 2016). In addition, leakage also leads to shield tunnel deformation, resulting in further leakage and other hazards. Therefore, the control of water leakage of the lining under high water pressure is one of the most critical issues to be considered in lining design (Koyama, 2003; Mair, 2008; ITA WG, 2000). The leakage at segmental joints accounted for 85% of the total water ingress based on field monitoring data and leakage phenomena observed at the Shanghai Metro Line 1 (Shen et al., 2014). Hence, the main leakage channel is thought to be the segmental joints, which has been verified by field experience and case studies (Wu et al., 2014; Tuo et al., 2013; Liu et al., 2016; Yoo, 2017). Leakage at the joints is induced by accidental surcharge (Huang et al, 2017), large-scale excavation at adjacent sites (Chen et al., 2016), differential settlements of the tunnel or construction error due to the construction and operation stage (Teachavorasinskun and Chub-uppakarn, 2010). One of the solutions to this problem is to install a waterproof gasket between segmental linings (ITA WG, 2000). Since the gasket is essential to prevent the ground water from leaking into the tunnel, especially for tunnels below rivers or the sea, its design is a key component for waterproof tunnels.

Many studies have been conducted concerning the leakage behaviour of gaskets in tunnel lining, including on the shape, materials, and configuration for the gasket (ITA WG, 2000), the contact pressure between the gaskets and the gasket-gasket groove (Shalabi et al., 2009, 2012, 2016), and the long-term gasket sealant behaviour (Tan et al., 2008; Zhong et al., 2011; Păunescu, 2006). Materials commonly used in the manufacture of gaskets are butyl non-sulfide rubber, deformation butyl rubber, solid rubber, special synthesis rubber, and water-expansive material (ITA WG, 2000). The most common choice for sealing the joints is Ethylene-Propylene-Diene Monomer (EPDM) elastomeric rubber, with the gaskets being arranged circumferentially on the segment (Shen et al., 2014; Wu et al., 2014). Based on the steel picture frame device, Paul and Kurihara et al. noted that when the ratio of the gasket volume to the gasket groove volume increases, the gasket sealant capacity increases (Shalabi et al., 2009, 2012, 2016). The sealant

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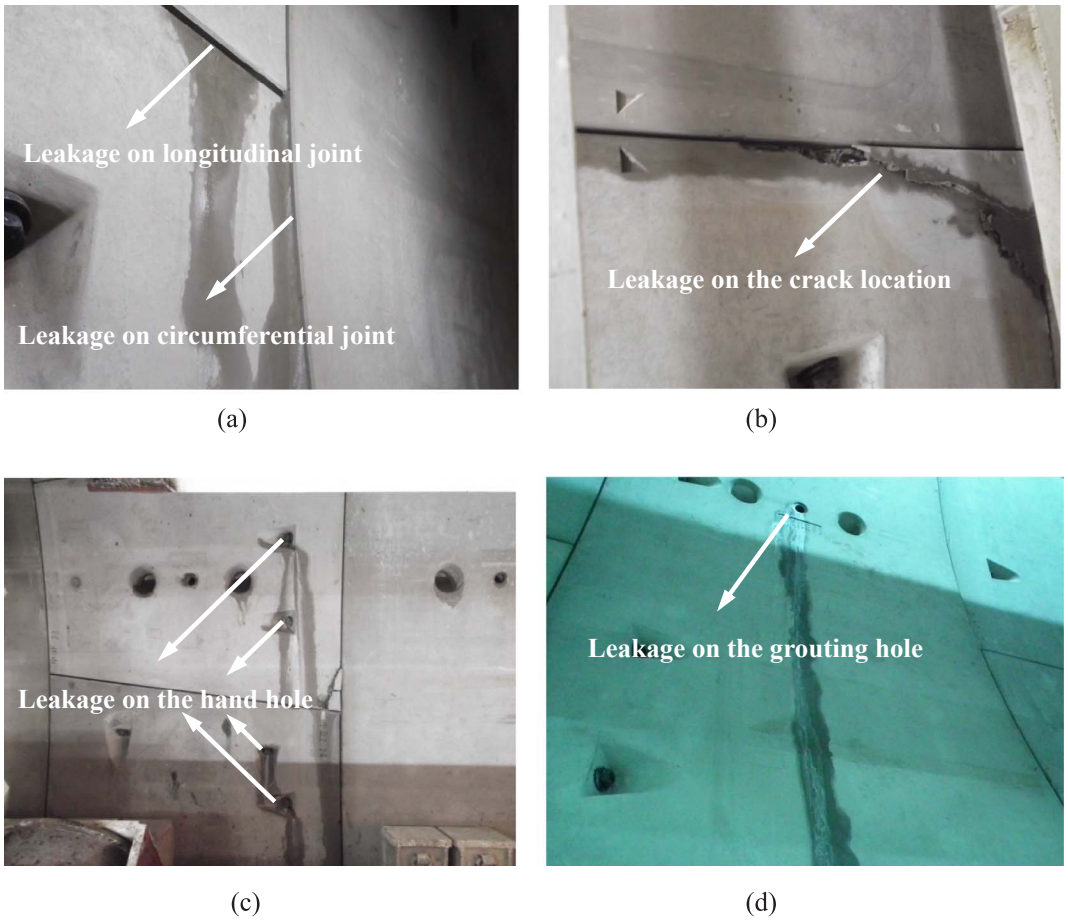

Fig. 1. Leakage in the practical tunnel: (a) joint leakage; (b) leakage at the crack location; (c) leakage at the hand hole; and (d) leakage at the grouting hole.

potential capacity of the gasket depends sensitively on the gasket shape and configuration (Shalabi et al., 2009). It was also observed that leakage at the gasket-gasket interface was closely related to the contact pressure between the gaskets. An integrated sealant test apparatus for single gaskets was developed and the leakage behaviour of the sealing gaskets was probed via waterproof experimental tests for different types of segmental joints (i.e., longitudinal and circumferential joints) (Ding et al., 2017; Zhao et al., 2013). From the tests, it was determined that gasket-gasket interfaces, gasket-concrete gasket groove interfaces, damaged zones, and frame corners were potential sources of leakage in segmental joints with a single gasket. Shalabi et al.(2012) investigated the two types of base conditions, fingers base and closed base, on the gasket sealant and observed a progressive reduction in the normal stress between the gasket and gasket groove interface for the fingers base gasket. Shalabi et al. (2016) reported that gasket contact pressure was found to be a key factor in water tightness. Many water leakage tests were conducted on rubber gaskets in segmental lining joints to determine the gasket sealant capacity. Water leakage tests of the picture frame steel device showed that the water pressure at leakage decreases as the size of the joint gap increases (Dong et al., 2017; Liu, 2009; Gao et al., 2014). Other factors influencing leakage include depth below groundwater level, differential settlement of the tunnel, and initial gaps and offsets between segments. The sealant gasket must be watertight against the groundwater for various combinations of joint openings and offsets in the construction and operation stages (DAUB, 2013). Therefore, the sealant performance will be not valid for certain gaps and offsets between segments.

The phenomena of ageing and gasket material degradation affect the performance life of gasket segment tunnel linings. The waterproofing performance of gaskets degrades with time and exerts a great influence on the water resistance of tunnel segment joints. Stress relaxation at the gasket-gasket interface reduces the long-term waterproof performance of the seal gasket. To ensure the shield tunnel segments water tightness in long term, the two conditions must be met: material stability of the sealing profile and maintaining the minimum required compression. Zhong et al. (2011) studied the effect of ageing time on the performance and durability of rubber gaskets in different service environments and predicted the variations in mechanical properties of the rubber material with time. Gac et al. (2012, 2013) conducted the research about the effect of aging time on the performance of and durability of gaskets in different service environments. And they pointed out the variations of mechanical properties of rubber material with time. Based on the service environment of metro tunnel segment joints, an accelerated aging test was designed and carried out on EPDM rubber gaskets in a groundwater environment to their performance degradation. A time-dependent model of EPDM rubber gasket for segmental joints was proposed according to the change rule of the mechanical properties of materials after ageing (Shi et al., 2015).

Nevertheless, only a small number of experimental studies on the waterproof capacity of double gaskets, on the failure effect mechanism for double gaskets and on double gasket with different sizes, especially for large-diameter slurry tunnel linings, have been documented. The purpose of this work is to investigate and evaluate the sealant behaviour of double gaskets under water pressure for various offsets and joint openings. This work presents results from load-deformation and sealant behaviour experimental tests for double gaskets used in shield tunnel segments.