International Journal of Rock Mechanics and Mining Sciences 104 (2018) 71–77

Contents lists available at ScienceDirect

International Journal of Rock Mechanics and Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

Mechanical performances of rock-concrete bi-material disks under diametrical compression

Xu Chang[a,b,*], Jianyou Lu[b], Shanyong Wang[c], Shuren Wang[b]

[a] Opening Laboratory for Deep Mine Construction, Henan Polytechnic University, Jiaozuo, China
[b] School of Civil Engineering, Henan Polytechnic University, Jiaozuo, China
[c] ARC Centre of Excellence for Geotechnical Science and Engineering, Civil, Surveying and Environmental Engineering, University of Newcastle, Callaghan, NSW 2308, Australia

ARTICLE INFO

Keywords:
Rock-concrete bi-material
Brazilian test
Fracture patterns
Interface fracture length

1. Introduction

The rock-concrete bi-materials are commonly used in civil engineering and mines,[1–4] for example, can be observed in concrete retaining structures (dams, retaining walls, etc.) built on rock foundations, underground geological repositories for nuclear waste storage and shotcrete structures installed as rock support in both tunnelling and underground mining.

In foundations of concrete retaining structures, loads create special stress states in which the magnitude of the shear stress along the rock-concrete interface is the most significant, and large shear displacement is the most dangerous for the stability of the structure. Sliding along the interface between the concrete and rock is one of the predominant failure patterns. Considerable experimentation, analytical studies and numerical modelling have been conducted to investigate the shear behaviour of rock-concrete interfaces. Johnston and Lam[5] carried out a series of shear tests on planar rock-concrete interfaces under constant normal stiffness conditions, and then regular triangular interfaces were created to investigate the influences of interface roughness.[6] Kodikara and Johnston[7] further provided an experimental study of the shear behaviour of rock-concrete joints with roughness in the form of regular and irregular triangles under conditions of constant normal load and constant normal stiffness. Their results indicated that shearing and crushing of the interface asperities led to sliding. The regular interface showed a relatively brittle response with a higher shear resistance while the irregular asperities appeared to behave more ductilely with a lower resistance. Andjelkovic et al.[8] also conducted direct shear tests on rock-concrete mass with various rock types, including compacted bedrock as well as weak, degraded and cracked rocks. Their results indicated that the shear deformation and failure were closely related to the properties of the rock foundations. However, shear tests do not account for the fracturing behaviour of a rock-concrete system. Many laboratory tests, field observations, and analytical studies demonstrated that failures occurred due to upstream rupture and downstream crushing of the foundation.

Many tests on the fracture behaviour of mortar-aggregate interfaces, which are intrinsic to rock-concrete interfaces, indicated that the failure of the bi-material interface depended on the mode mixity ratio. Fracture toughness of testing of the mortar-aggregate interface by Lee and Buyukozturk[9,10] indicated that there was clearly a greater increase in the fracture toughness with shear loading relative to tensile loading. Buyukozturk and Hearing[11] conducted bending tests on concrete-composite specimens, and their results indicated that the magnitude of the interface toughness was determined by the differences in the elastic moduli and fracture toughness between the aggregate and mortar. Yang et al.[12] tested the fracture toughness of a rock-concrete interface by using rock-concrete beams with a single notch. Their results indicated that the interface fracture toughness was closely related the mode mixity ratio, and a failure criterion for the rock-concrete interface was further proposed. Zhong et al.[13] recently investigated the fracture toughness of a rock-concrete interface by using a rock-concrete beam under four-point-shear loading. A wide range of mode mixity ratios was tested.

Shotcrete is commonly used as rock support in tunnels and other

* Corresponding author at: Opening Laboratory for Deep Mine Construction, Henan Polytechnic University, Jiaozuo, China.
E-mail address: changxu815@163.com (X. Chang).

https://doi.org/10.1016/j.ijrmms.2018.02.008
Received 11 July 2017; Received in revised form 22 November 2017; Accepted 3 February 2018
1365-1609/

underground excavations. The interface between shotcrete and rock plays a dominated role in this support method by effectively transferring the load between the rocks and shotcrete and retaining the integrity and durability of the shotcrete structures. Therefore, the accurate prediction and characterization of the behaviour of rock-concrete interfaces are also essential for the design of shotcrete structures. Barrett and McCreath[14] found that the failure pattern for the shotcrete liner was highly dependent on the rock-shotcrete strength. If this strength was sufficient, the shotcrete failed by a direct shear mode; otherwise, the shotcrete failed in a flexural manner. Sufficient interface strength can merge the rock mass and the shotcrete into a single body, increasing tunnel stability. Brennan[15] proposed a shotcrete bond test that used a core bit to drill the shotcrete and substrate, and then attached a rigid steel disk to the top of the core by using epoxy. Kuchta[16] studied the influences of surface roughness on the interface strength of shotcrete, and their results indicated that a treated surface can lead to an increased interface strength. Ozturk and Tannant[17,18] examined the influences of substrate parameters (tensile strength, roughness, and grain size) and contaminants (oil and dust) on the interface strength between shotcrete and a rock mass and noted that the interface contaminants can decrease the interface strength and that a larger grain size increase the interface strength. Saiang et al.[19] tested the interface strength by using various methods (direct and indirect). In addition, their results indicated that the interface strength was highly dependent on the test method. Therefore, these differences should be considered when analysing the stability or safety of shotcrete structures.

The rock-concrete bi-material consists of three different parts, rock, concrete and the rock-concrete interface. The behaviour of the rock-concrete interface, which is traditionally regarded as the weak link of the rock-concrete structure, has been extensively investigated in the aforementioned studies. These investigations are fundamental and have contributed to a better understanding of the behaviour of rock-concrete structure, which has in turn led to higher quality designs, cost reductions and safety improvements. However, the stability of rock-concrete structure is related not only to the interface properties but also to overall behaviour of rock-concrete bi-materials. Few of the existing works pay attention to the overall behaviour of a rock-concrete bi-material, limiting the understanding of the fracturing behaviour of rock-concrete bi-materials and precluding the accurate prediction of the mechanical performances of rock-concrete structures. The authors therefore try to investigate the overall behaviour of rock-concrete bi-materials to provide a new view of evaluating the rock-concrete structure.

It should be noted that there is no standard method to determine the mechanical properties of a rock-concrete bi-material. The traditional test method is therefore adopted as an attempt to investigate the mechanical behaviour of a rock-concrete bi-material. The test results would be helpful to further develop a method to determine the mechanical properties of the bi-materials in future work. The Brazilian disk test is a popular indirect method of determining the tensile strength of rocks. The basal assumption is that the materials are homogeneous and linear elastic and the diametrical compression acts as a line load.[20] In recent years, this solution has been expanded to test tensile strength of anisotropic rocks.[21–24] In this study, the Brazilian disk test is also adopted to investigate behaviour of the rock-concrete bi-material disk.

2. Experimental setup

2.1. Specimen preparation

Marble plates with dimensions of 300 mm × 110 mm × 60 mm were used. The surfaces of the marble were roughened by introducing grooves with various dimensions by a water-jet cutter machine. This approach conforms to the standard practice in engineering in which the rock-concrete interface was treated to increase the interface shear

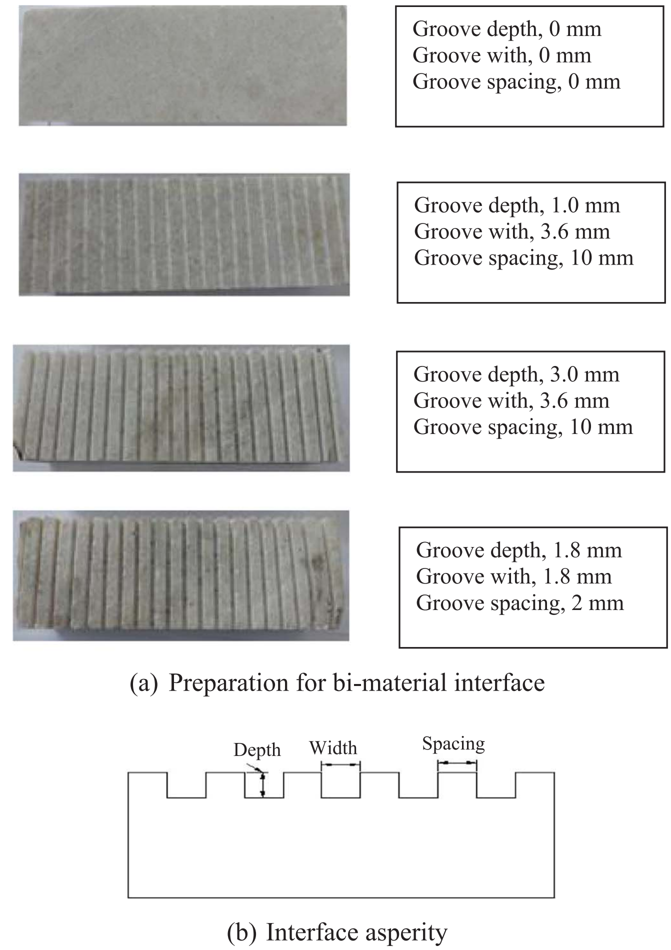

Fig. 1. Roughening of the rock interface.

performance. To investigate the influences of the interface roughness on the interface behaviour, different dimensions of the grooves by the water-cut machine were adopted, 0 mm × 0 mm (Interface I, no grooves), 1 mm × 3.6 mm (Interface II), 3 mm × 3.6 mm (Interface III), and 6 mm × 3.6 mm (Interface IV), as indicated in Fig. 1. Then, the marble plates were placed in a designed mould prior to casting the concrete. The specimens were taken out of the moulds two days after casting and allowed to cure in the same room temperature and humidity conditions for 28 days. At the same time, concrete prisms were prepared to test the material parameters of the concrete. The specimens were cored in the laboratory using a 50 mm diameter drill bit and machined to the desired sizes. The direction of coring was parallel to the rock-concrete interface. During this process, the disks were carefully machined to ensure that the rock-concrete interfaces were equal to the disk diameter. According to the ISRM suggested method[25] the diameter and height of these specimens were 50 mm and 25 mm, respectively (see Fig. 2), giving a thickness-to-diameter ratio (t/d) of 0.5. The errors in the specimen dimensions were within ± 0.5 mm, and the flatness of the specimen ends was within ± 0.1 mm after hand polishing. A total of eleven series of disks were tested (B series… to L series). In addition, all test specimens are summarized in Table 1.

2.2. Material properties

For the results of the experimental programme to be of practical use in the safety evaluation of rock-concrete structures, slag Portland cement, which is often adopted in practice, was used in this study. As mentioned above, three different types of concretes were adopted, and the mixes are listed in Table 2. In all the concrete mixes, the fine