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Technical Note

A new approach for determination of the shear bond strength of thin spray-on liners

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1. Introduction

As a new type of strata skin support component, thin spray-on liners (TSLs) are becoming increasingly popular around the world. As a fast setting support system, TSLs can immediately support the excavations once applied onto the rock substrate. The first TSL trials were initiated in Canada in the late 1980s [1]. The main purpose of strata reinforcement in underground excavations is to make the rock mass support itself. In a non-reinforced system, it will be difficult to sustain the dead weight of the rock if the rock mass is loosened. TSL strength and ability to bond to various substrates enable formation of a composite skin layer that significantly improves the reinforcing capabilities of an immediate strata surface. The formation of the composite layer between a TSL and a rock skin is one of the most desirable properties that enables a stiff and a durable rock skin reinforcement. The adhesion between a polymer liner and a rock surface can confine the rock movement immediately after sprayed. In addition, penetration of TSL into fractures and joints during application can bond the fractured rock pieces together and keep the fragments in place increasing the self-supporting capacity of severely fractured strata [2]. Without bond strength, TSL performance is reduced. Therefore, the bond strength of a TSL is a very important property in supporting underground excavations. The bond strength comprises of shear-bond strength and tensile-bond strength adhesion. The tensile-bond strength test using steel dolly pull-off test [3–10] has received the common acceptance by the researchers and manufacturers. However, research on shear-bond strength is limited and there is currently no standard testing method exists for investigating the shear-bond strength of TSLs. Saydam et al. [11] developed a double-sided shear strength test to investigate the pure shear strength of a TSL material. In their test, the specimen is prepared from three rock cubes of 40 mm length side bonded together with 5 mm thick TSL. The testing procedure involved clamping the two outer blocks while the load was applied onto the central block. If not secured properly, the bending or rotation will be induced. Thus, the failure will be caused by tension rather than shear. To eliminate the effect of bending experienced in double shear test, Yilmaz [12] developed a testing method using a 20 mm thick steel ring and fill the gap between the steel ring and the rock core with the TSL. Finally, the rock core was sheared off the TSL. However, this method of specimen preparation could cause normal stress induced by shrinkage around the rock surface, affecting the shear-bond strength between the interface of the rock core and the TSL. The TSL shrinkage is highly desirable as it will introduce compression in the rock skin making a more durable composite layer of TSL bonded to substrate that provides resistance to fracture formation and propagation.

In this paper, a new testing method for determination of shear-bond strength for TSL materials was proposed by comparing two previous test methods [11,12]. The new approach can minimize the shrinkage problem and eliminate the bending problem.

2. Mechanism of shear bond strength

In underground coal mines, joints or fractures are ubiquitous. When a TSL is sprayed onto the rock surface, it is possible for sprayed liner to penetrate into the fractures and cracks within the rock. Stacey [2] described a series of mechanisms of loading behaviour and surface support behaviour of TSLs and proposed the theory of "promotion of block interlock" which is related to shear-bond strength between a TSL and a rock surface. The aim of this mechanism is mainly to keep the rock mass in a stable and unloosened condition. Based on the support mechanism described by Stacey [2], Yilmaz [12] tested the in situ loading mechanism of TSL relevant to shear-bond strength as shown in Fig. 1. The shear-bond strength between a TSL and a rock surface can promote the block interlock, which can keep the broken blocks in place and

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minimise the block rotation caused by the shear. Subsequently, Stacey and Yu [13] determined the effect of various factors on the support capacity of TSL using the method of finite element stress analysis and demonstrated that the support mechanism of TSL penetrating into the joints and fractures within the rock mass plays an important role in the support mechanism of TSLs.

3. Double-sided shear test and TSLring shear bond test

3.1. Double-sided shear test

3.1.1. Sample preparation and test procedure

The testing samples were prepared from three rock cubes of 40 mm length side bonded together with 5 mm thick TSL. The testing procedure involved clamping the two outer blocks while the load was applied onto the central block, as demonstrated in Fig. 2. The TSL material was applied to the dry rock and coal cube surfaces. The loading rate for the test is 1 mm/min. During the tests, the load and displacements were recorded.

3.1.2. Analysis of test results

Eighteen tests were done for the double-sided shear test. The results did not give the TSL bonding shear strength but only indicated the bonding values to be higher than the shear strength of the intact rock. The sample did not fail along the TSL-rock interface, as shown in Fig. 3. Closer examination showed that the bolts within the steel assembly were bending in response to the loads during testing.

The shear bond strength can be obtained by dividing the force at failure by the area along which the TSL material fails by shear:

$$\sigma_{sb} = \frac{F}{2A} = \frac{F}{2d^2} \tag{1}$$

where F is the applied force in N, σ_{sb} is the shear bond strength of the TSL material in MPa, d is the length of rock/coal cube length (measured before the test) in m, and A is the area of one contacted side in m^2.

Fig. 4 shows a typical stress–displacement graph of the double-sided shear tests. There were several peak strength points and the test results were inconclusive and difficult to interpret.

3.2. TSL ring shear test

To eliminate the effect of bending experienced in double-sided shear test, the TSL ring shear test method was developed by modifying the test performed by Yilmaz [11].

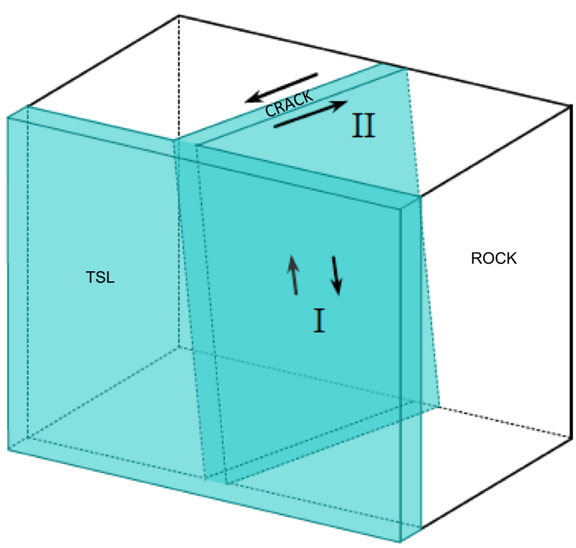

Fig. 1. In situ mechanism of TSL crack penetration relevant to shear bond strength testing , after [11].

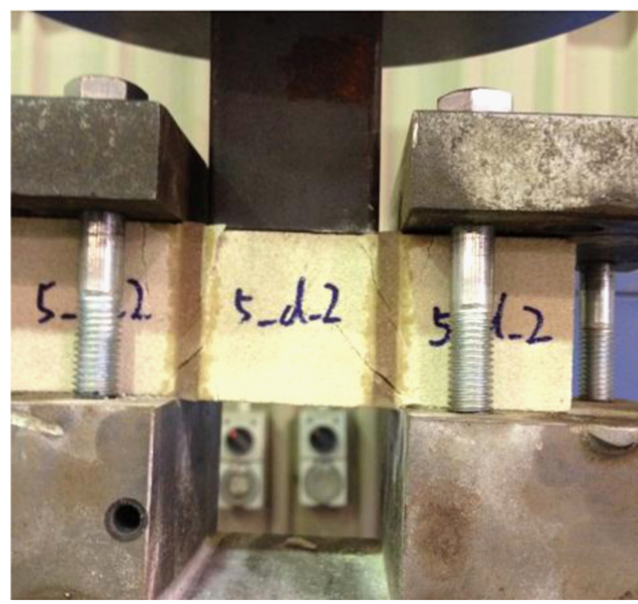

Fig. 3. A typical sample after failure.

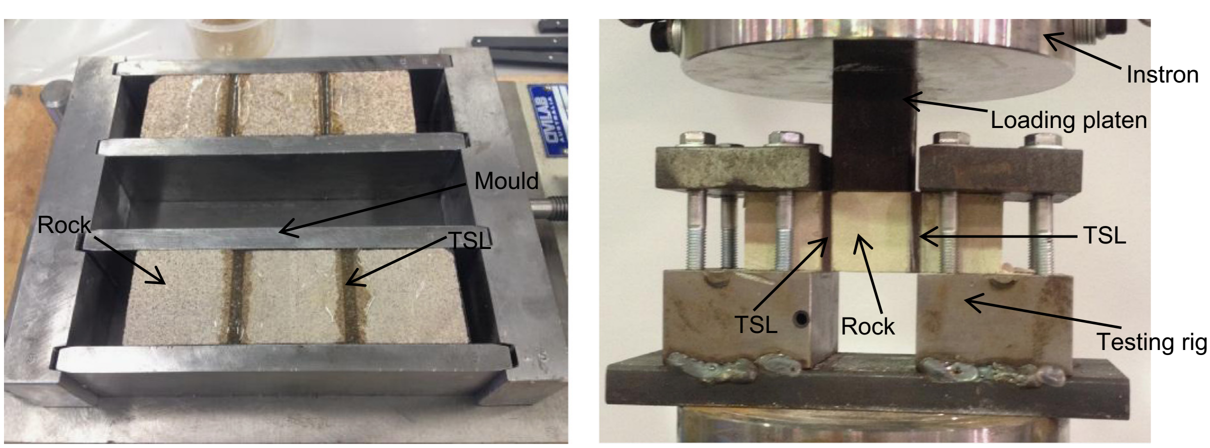

Fig. 2. Sample preparation and test setup.