International Journal of Rock Mechanics & Mining Sciences 91 (2017) 195–202

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

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

Effect of rock strength and surface roughness on adhesion strength of thin spray-on liners

Zecheng Li, Benjamin Nocelli, Serkan Saydam*

School of Mining Engineering, University of New South Wales, Sydney, NSW 2052, Australia

ARTICLE INFO

Keywords:
Thin spray-on liner
Adhesion strength
Rock strength
Surface roughness

ABSTRACT

This paper discusses the results of a series of tests developed to examine the link between substrate strength and surface roughness on the adhesion strength of thin spray-on liners (TSLs). Laboratory adhesion tests were conducted using grout substrates with different uniaxial compression strength (UCS) and surface roughness. Two different TSL materials were used for the tests. Steel dollies were glued onto the surface of the TSL with a strong epoxy and then pulled in tension to measure the adhesion strength. The results of the experiment suggest that both rock strength and surface roughness play a significant role in determining the adhesion strength of TSLs. As the rock strength increases, the adhesion strength also increases significantly for the lower strength substrates tested and then levelled out as the substrate strength further increased. Both TSLs exhibited large increases in adhesion strength when the substrate was changed from a flat to a rough surface. As the surface roughness for rough profile substrates increased, there was also slight increase in adhesion strength of TSLs.

1. Introduction

Thin spray-on liners (TSLs) are a relatively new form of rock support technique that has been gaining increasing interest as a supplement to traditional support methods such as mesh or shotcrete. A TSL is defined as a thin chemical coating or layer that is applied to a mining excavation at a thickness of between 3 and 5 mm.[1] They are usually comprised of two components: either a liquid/liquid mix, or a liquid/powder mix.[2] The components are combined immediately prior to or during application. Once applied, the TSL bonds to the rock surface, providing support to rock mass. Tannant[3] states that TSLs have performance characteristics lie between those of shotcrete and mesh support systems. Since the 1990 s, TSL support has been evaluated by various researchers because of its potential operational benefits, with the potential to reduce mining costs.[4]

One of the critical parameters that affect the capacity of a TSL to provide effective rock support is its ability to achieve a strong adhesion bond with the rock surface to which it is applied. The adhesion properties prevent loosening of the rock, which aids the self-supporting capacity of the rock mass. The adhesion properties are also crucial for transferring applied loads from failed areas to intact areas of the rock mass.[5] The adhesion strength of TSLs has been the topic of many studies,[1,5–12] which have identified several key elements that influence the adhesion strength. These factors include: substrate strength, substrate surface roughness, surface contamination prior to application, surface integrity, liner thickness and curing time.[7,9,12] Despite these investigations, insufficient testing has been conducted to provide a quantitative link between the strength and surface roughness of a substrate and adhesion strength of the TSL.

The purpose of this study was to quantify the effects of substrate strength and surface roughness on adhesion strength of TSLs. Laboratory adhesion tests were conducted on artificial rock substrates made of grout. Substrates with different UCS and surface roughness were prepared for the adhesion tests. Two types of TSL materials were used for the tests. The test method selected was a modified glued dolly test method which is an adaption of the American Society for Testing and Materials (ASTM) standard test method for pull-off strength of coatings.[13] This test procedure has been the most widely accepted and used method to investigate the bond strength of TSLs.[7] This testing method is consistent and easy to replicate, both in the laboratory and in the field.

2. Test preparation and execution

2.1. Substrate preparation

Epirez class A superstrength grout[14] was selected as the substrate for the adhesion testing. The properties that make grout the most suitable substrate include: (a) Grout provides a competent and consistent surface for adhesion testing. (b) Grout allows for a homogenous

* Corresponding author.
E-mail address: s.saydam@unsw.edu.au (S. Saydam).

http://dx.doi.org/10.1016/j.ijrmms.2016.11.011
Received 7 January 2016; Received in revised form 29 September 2016; Accepted 14 November 2016
Available online 01 December 2016
1365-1609/

Table 1
UCS of the grout with different water ratios and curing times.[14]

Curing Time (days)	2 L Water/20 kg	3 L Water/20 kg	4 L Water/20 kg
1	50 MPa	34 MPa	17 MPa
7	82 MPa	62 MPa	36 MPa
28	91 MPa	70 MPa	45 MPa

substrate to be prepared. (c) Grout is readily available and inexpensive allowing for multiple tests. (d) The UCS of the grout can be easily varied by altering the water content. Table 1 shows the UCS of the grout prepared with different water contents.

The substrates were prepared by vigorously mixing the grout with the pre-determined water ratio using a handheld electric mixer. The mixed grout was poured into the moulds (inner dimensions: 300 mm×300 mm×100 mm) and allowed to cure. A concrete vibrator was used to ensure the grout settles and no air bubbles are present. Any air bubbles on the grout can affect the strength of the substrate and influence the results. Once cured, part of each substrate was cored to determine the UCS of the substrates. The UCS test results are presented in Section 3.

Surface contamination such as oil and dust could greatly reduce the adhesion strength of TSLs.[9] To ensure no surface containments were present, the substrate was thoroughly wiped with a damp cloth and dried prior to application of the TSLs. The substrate was prepared using a wooden mould, with the smooth surface of the mould providing a flat and consistent surface for TSL application.

2.2. Application of TSL

After the substrates cured, TSLs were then applied to their surfaces. In a field application, TSLs are sprayed onto the rock surface under high pressure; this method of application is not practical for laboratory-based samples. Instead, the TSLs were hand poured onto the substrate surface. Hand pouring allowed for greater control of substrate thickness compared with field application. However, hand application does have the potential to slightly alter the characteristics of the TSL. It was noted by Yilmaz[10] that the application of TSLs applied in the field were structurally more compact than those hand applied in laboratory conditions. Yilmaz[10] theorised that this may be due to small air bubbles in the mix bursting on impact with the rock surface.

It is possible that results in the laboratory experiments may differ slightly from those achieved under in-situ conditions. However, as all specimens were prepared using the same method, the trends observed during testing can be translated to TSL applied in field.

2.2.1. TSL mixing

Two different polymer-based TSL materials were used for the testing. Due to the confidentiality agreement with the TSL producers, the product names are not disclosed in this paper. Instead, they are named as TSL-1 and TSL-2. TSL-1 consists of a single polymer powder product which was mixed with water using a ratio of 1.1 kg of powder to 0.9 kg of water. TSL-2 is a two-part cementitious powder and polymer liquid product, which is combined in a ratio of two parts liquid to one part powder.

The TSL mixtures were prepared using a small variable speed handheld mixer. It was discovered that using the mixer on low speeds was better, as faster speeds resulted in the formation of a vortex that drew air into the mixture creating bubbles. Slow speeds produced a uniform, well-mixed, sticky material. The TSL was immediately applied to the pre-prepared substrate, as the TSL became more difficult to handle with prolonged exposure to air.

2.2.2. Thickness control

Ozturk and Tannant[7] observed that the adhesion strength is inversely proportional to the liner thickness for the liner they tested. It is therefore crucial that the thickness is controlled in order to maintain a valid experiment. The thickness of the TSL was maintained at 5 mm throughout the experiment.

A wooden mould was used on the substrate surface to control the thickness of the TSLs. A 5 mm thick mould was used for TSL-2, which exhibited almost zero shrinkage during curing. TSL-1, however, displayed shrinkage of approximately 30%. Thus, a thicker 7 mm wooden mould was employed for TSL-1, which resulted in a uniform 5 mm thickness after curing.

2.2.3. Curing time

The adhesion strength of TSLs is dependent on the curing time allowed. With an increase of the curing time, the adhesion strength for both TSL-1 and TSL-2 firstly increased and then levelled out after four weeks.[11] However, due to the time constraints and the number of tests required, the curing time for this series of tests was set for seven days. In order to produce comparable results, the curing time was kept constant for all the experiments.

2.3. Test apparatus and execution

Ozturk and Tannant[7] stated that the glued dolly adhesion testing method has been the most suitable procedure for the TSL adhesion testing. This method was also adopted for this study. The simple, cheap, and quick nature of the testing procedure ensures that the results can be easily correlated with future research using the same method.

2.3.1. Test apparatus

The adhesion tests were conducted using a PAT GM01 Elcometer testing machine, which is a manual hydraulic tensile adhesion testing apparatus.[15] This apparatus is capable of applying a tensile force of up to 6.3 kN to the steel dolly. The maximum tensile stress applied to the liner depends on the size of the dolly used. Standard 28.2 mm dollies were used for the experiments, which correspond to a maximum tensile stress of 10 MPa. The apparatus has an accuracy of 0.1 MPa.

2.3.2. Test set-up and execution

After the TSL had cured for seven days, the steel dollies were glued to the surface of the TSL using PC-7 adhesive.[16] The dolly was then over-cored to isolate the testing area. A hand-held hole saw drill bit with diameter of 28.2 mm was utilised in the coring process (Fig. 1). In order to achieve an isolated area, the coring depth was controlled to ensure that the hole saw penetrated at least 1 mm into the grout substrate.

The testing head was connected to the supplied dollies as seen in Fig. 2. The hydraulic pump was then connected to the testing head using the supplied hydraulic hose. A smooth motion was used when operating the hydraulic pump in order to provide a gradual increase in force. The peak pressure required to pull the dolly away from the surface was recorded on the precision gauge (0.1 MPa) attached to the hydraulic pump.

2.3.3. Failure mode analysis

Four different failure locations are possible during the adhesion testing, and they are described as follows. (1) Epoxy failure: Failure takes place at the interface between TSL/epoxy or epoxy/steel dolly. A strong epoxy should be used to eliminate this problem. (2) Liner tensile failure: Failure occurs within the TSL materials, which means the tensile strength of the TSL is lower than its adhesion strength. (3) Substrate tensile failure: Failure occurs within the substrate due to the tensile failure of the substrate, this failure is common for rock substrates with low tensile strength. (4) Adhesion failure: Failure