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Shear strength testing of glass fibre reinforced thin spray-on liner

Abstract

Thin spray-on liners (TSLs) have been attracting increasing attention as an alternative to steel mesh in underground roadway support. In order to investigate the shear strength of glass fibre reinforced TSLs, an improved punch test was developed: the steel ring is replaced by TSL plates and four screws are used to tighten the TSL sample between the clamping plates to ensure stable and symmetrical loading. Four different glass fibre contents were tested to evaluate the effect of glass fibre reinforcement on the shear strength of TSLs. The effect of loading rate was studied. The results suggest that the steel punch can shear through the polymer sheet well and the failure mode can be easily identified. The results are consistent and easily calculated. The shear strength increases with glass fibre content. The TSL material samples showed good linear behaviour prior to reaching ultimate load and ductile behaviour that reflects the fibre reinforcement of failed resin during the yielding stage of the sample, which is beneficial to support in underground mines. Although there may be some impact of the shearing rate on the shear strength, the effect is negligible for the loading rates used.

Keywords

laboratory tests, mining, shear strength

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Shear strength testing of glass fibre reinforced thin spray-on liner

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Thin spray-on liners (TSLs) have been attracting increasing attention as an alternative to steel mesh in underground roadway support. In order to investigate the shear strength of glass fibre reinforced TSLs, an improved punch test was developed: the steel ring is replaced by TSL plates and four screws are used to tighten the TSL sample between the clamping plates to ensure stable and symmetrical loading. Four different glass fibre contents were tested to evaluate the effect of glass fibre reinforcement on the shear strength of TSLs. The effect of loading rate was studied. The results suggest that the steel punch can shear through the polymer sheet well and the failure mode can be easily identified. The results are consistent and easily calculated. The shear strength increases with glass fibre content. The TSL material samples showed good linear behaviour prior to reaching ultimate load and ductile behaviour that reflects the fibre reinforcement of failed resin during the yielding stage of the sample, which is beneficial to support in underground mines. Although there may be some impact of the shearing rate on the shear strength, the effect is negligible for the loading rates used.

KEYWORDS: laboratory tests; mining; shear strength

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NOTATION

A	contact area
d	diameter of steel punch
F	applied force
t	thickness of TSL material
σ_s	shear strength of TSL material

INTRODUCTION

Thin spray-on liners (TSLs) are a relatively new form of rock support in underground coal mines. As an active support technique, it is known that a TSL is able to take action even if only small rock movement occurs, which is desirable for rock support. As steel mesh is of a passive nature and does not contribute to roadway skin reinforcement, TSLs are currently being investigated as an effective technology. ToughSkin, a fibre glass reinforced polymeric material liner developed at the University of Wollongong, has properties that satisfy the specified requirements. Many experimental tests have been conducted at the University of Wollongong laboratory and a number of test results have been published (Nemcik *et al.*, 2008, 2009a, 2009b, 2011, 2012, 2013a, 2013b). As one of the most important TSL properties that contribute to the quality of reinforcement, the shear strength of ToughSkin needs to be evaluated. However, there are limited research studies on the shear strength of TSLs and there is no standard test method to determine the shear strength of TSL materials. When analysing the support capacity of TSLs, Hadjigeorgiou & Grenon (2002) assumed that the shear strength of a TSL is equal to its tensile strength. Tannant (2001) considered that the support capacity of a TSL depends on the adhesion loss and tensile or shear rupture. With this in mind, the development of a testing method to investigate the shear strength of TSLs is essential.

Yilmaz (2009) developed a punch test composed of a steel ring, a steel punch and a clamping fixture to determine the shear strength of TSLs. A 20 mm high and 10 mm thick steel ring with an inner diameter of 52 mm was used to house the TSL and the clamping fixture was used to clamp the steel ring with the TSL. A 29.6 mm diameter steel punch was used to shear through the polymer sheet. The test results indicated that the test method was effective and suitable for evaluation of the shear strength of TSLs. However, to determine the shear strength of glass fibre reinforced TSLs, the procedure is difficult and inconvenient. The test apparatus was thus modified to accommodate prepared samples. The new testing approach has the potential to simplify the sample preparation procedure and reduce testing costs by replacing the disposable steel ring with TSL plates. In addition, it can ensure stable and symmetrical loading, thereby improving the accuracy of the results. This paper describes the improved punch test and investigations of the shear strength of TSLs with four different glass fibre contents. The effect of loading rate on the shear strength of TSLs was also evaluated.

DESCRIPTION OF TESTING APPARATUS

The testing apparatus consists of two parts, a clamping fixture and a steel punch, as shown in Fig. 1. The cylindrical steel punch (29.9 mm in diameter) is used to puncture the TSL material. The clamping components are made up of two steel plates with threaded holes for four screws. The central diameter of the holes within both clamping plates is 30 mm in diameter to accommodate the steel punch. Both the top and bottom steel plates are 20 mm thick, providing sufficient clamping of the polymer sample for testing. The thickness of the bottom steel plate is also sufficient to accommodate the polymer residue produced in the test. Four screws are used to tighten the polymer sample between the clamping plates to ensure stable and symmetrical loading.

SAMPLE PREPARATION

The procedures for preparing the samples for material shear strength testing are shown in Fig. 2. Four types of

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Fig. 1. Material shear strength testing apparatus: (a) clamping fixture; (b) steel punch

polymer were prepared – without glass fibre and with one, two and three layers of glass fibre reinforcement sheet. The preparation procedure was as follows.

- (a) Using several plastic plates glued together, a mould 250 mm long, 85 mm wide and 5 mm thick was prepared. This geometry allows four tests and the boundary effect can be eliminated to improve the accuracy of evaluating the shear strength. The mould was placed onto a smooth glass plate and all components were lightly greased with Vaseline for ease of sample removal when cured.
- (b) The polymer components were mixed evenly according to the manufacturer's recommended ratio using a

plastic cup and wooden spatula. When the mixture changed colour, hardener was added and mixed evenly.

- (c) The TSL mixture was then poured into the plastic mould. The TSL viscosity was high, meaning it was difficult to pour directly; a wooden spatula was used to assist in the even placement of TSL into the mould.
- (d) Once the TSL was placed, it was left to cure for approximately 4 h. The sample was then removed from the plastic mould and left to cure at room temperature for a further 14 days.
- (e) In preparing the samples reinforced with one sheet of glass fibre, half of the mixture was poured into the

Fig. 2. Sample preparations for shear (punch) test: (a) mould; (b) sample in the mould; (c) prepared sample

Fig. 3. Material punch shear strength testing setup

mould. A glass fibre sheet was then placed on top and the remaining mixture was placed to complete the sample. Step (d) was then repeated.

- (f) To make the samples reinforced with two sheets of glass fibre, a third of the mixture was poured into the mould and a fibre sheet was then placed on top. The second third of the mix was then poured into the mould and the procedure repeated. The sample was then finished as described in steps (d) and (e). The aim was to ensure that the two fibre layers were evenly spaced within the sample.
- (g) The TSL samples with three glass fibre layers were prepared in a similar manner.

TEST SETUP AND EXECUTION

The tests were carried out after sample curing for the pre-determined period under laboratory conditions. Each type of polymer sheet requires a number of tests (four are suggested). Figure 3 demonstrates the material shear strength testing setup. The samples tested at the University of Wollongong laboratory were 250 mm long, 85 mm wide and 5 mm thick. Before commencing the TSL shear strength tests, the exact thickness of the material was measured at the test location, as listed in Table 1. A sample was placed in the test rig and clamped by two steel plates. In order to avoid sample bending or tilting, the test rig clamps the sample symmetrically by tightening four screws. A 29.9 mm diameter steel punch was used to shear through the polymer sheet. It is important to ensure that there is no gap or clearance between the two steel plates and the tested sample in order to prevent sample bending or other dislodgement. The shear test assembly was then placed in

an Instron compression machine. In the process of puncturing the TSL material, the TSL shearing rate used (punch displacement speed) was 1.5 mm/min. At this speed, the 5 mm thick TSL test is completed within 2 min as the peak strength is reached at displacements of approximately 1.4 mm while the residual load is obtained at displacements of 2–3 mm depending on the amount of fibre reinforcement. Load was applied to the steel punch until the polymer sheet was sheared through. The load and displacements were recorded during the test.

ANALYSIS OF TEST RESULTS

In the shear strength test, the failure mechanism of TSL material takes place along the TSL material thickness by punching through the TSL sheets. The punctured TSL samples shown in Fig. 4 indicate that the failure plane was regular and consistent.

The material shear strength perpendicular to the TSL sheet can be calculated from equation (1). The strength can be obtained by dividing the force at failure by the area along which the TSL material shears

$$\sigma_s = \frac{F}{A} = \frac{F}{\pi dt} \quad (1)$$

where F is the applied force (in N), σ_s is the shear strength of the TSL material (in Pa), d is the diameter of steel punch (in m) and t is the thickness of the TSL material (in m).

To evaluate the effect of loading rate on the shear strength and to select an appropriate loading rate for the rest of the tests, four different loading rates (0.5, 1.0, 1.5 and 2.0 mm/min) were used. The curves of strength versus loading rate for different glass fibre contents are plotted in Fig. 5, and the results indicate that the effect of loading rate is negligible. Ozturk & Tannant (2010) investigated the effect of loading rate on tensile bond strength and similar results were obtained (i.e. the effect of loading is negligible).

A loading rate of 1.5 mm/min was thus used for the rest of the tests. Figure 6 shows the load–displacement graphs of samples containing different numbers of sheets of glass fibre reinforcement. Samples of around 5 mm thickness were prepared without any glass fibre reinforcement and with one, two and three sheets of glass fibre reinforcement. Figure 6 clearly shows that the peak load increased as glass fibre content increased. The polymer material samples showed good linear behaviour prior to reaching ultimate

Table 1. Summary of test results

Glass fibre content	Test ^a	Thickness: mm	Peak stress: MPa	Mean stress: MPa
None	0A	4.98	32.53	33.12
	0B	5.01	34.85	
	0C	4.99	33.70	
	0D	4.95	31.39	
One sheet	1A	5.02	38.72	40.76
	1B	4.97	38.00	
	1C	4.98	43.90	
	1D	5.01	42.41	
Two sheets	2A	4.96	48.22	51.76
	2B	4.93	50.45	
	2C	4.98	54.46	
	2D	4.96	53.89	
Three sheets	3A	5.03	65.98	67.24
	3B	4.97	66.96	
	3C	5.00	67.07	
	3D	4.99	68.95	

^a0, 1, 2 and 3 means the number of glass fibre sheets; A, B, C and D represent four tests for each glass fibre content

Fig. 4. TSL material sheets after testing

load and ductile behaviour that reflects the fibre reinforcement of failed resin during the yielding stage of the sample, which is beneficial for support in underground mines.

The main aim of these tests was to compare and determine the shear strength of material with different glass fibre contents. As expected, the shear strength of the polymer material increased significantly with an increase in glass fibre content. Without any glass fibre reinforcement, the mean shear strength of the polymer material was approximately 33.12 MPa and with one, two and three sheets of glass fibre reinforcement the mean shear strength was 40.76, 51.76 and 67.24 MPa, respectively (Table 1).

CONCLUSIONS AND DISCUSSIONS

The improved testing approach maintains sample consistency and thus improves testing accuracy by minimising errors caused by sample preparation. The results suggest that the steel punch can shear through the polymer sheet well and the failure mode can be easily identified. The results are consistent and easy to calculate.

The results from the shear tests (punch tests) consistently showed a distinct increase in TSL material strength with an increase in glass fibre reinforcement. The post-failure behaviour of samples loaded to failure indicated that the material does not fail in a brittle manner. The results reveal good ductile behaviour of the TSL samples and indicate that the effect of loading rate on shear strength is negligible.

Fig. 5. Effect of loading rate on the shear strength of TSL with different sheets of glass fibre reinforcement

Fig. 6. Stress-displacement plot of TSL with different amounts of glass fibre reinforcement

The test results might have been affected by parameters such as curing time, glass fibre distribution within the TSL material, quality of the glass fibre, chosen thickness of the TSL and other surrounding conditions. In order to minimise the factors affecting the tests, the geometry and sample quality variations must be kept to a minimum. In this study, the curing time and the thickness of the TSL material of all the samples was kept the same (14 days and 5 mm, respectively). In the future, different TSL thicknesses should be tested and the effect of curing time on the shear strength of the TSL material should also be investigated. Any test method should be kept simple and relevant to the material tested: the choice of the punch test to measure TSL shear loads satisfies these requirements for the testing of TSL materials. The advantages of the punch method are that sample preparation is simple, easy and quick; the test can be repeated quickly many times because each polymer sheet can be of any length to accommodate numerous tests; the test setup is small and easy to use; the complication of many variables is reduced because a substrate is not involved; it is cost effective.

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