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Effect of polymer content on mechanical properties of thin spray-on liner

Jin-Tae Han, Gyu-Phil Lee & Soo-Ho Chang
Korea Institute of Construction Technology

Myung-Sik Choi
Silkroad C&T

ABSTRACT: The use of Thin Spray-on Liner (TSL) as an alternative to shotcrete has drastically increased since 1990s when it was first developed and introduced to mines. In this study, tensile strength test, bond strength test, compression test with specimens coated by TSL, and two kinds of bending tests proposed by EFNARC (2008) were performed with two kinds of TSLs with different material compositions in order to evaluate their support capacities. As a result, both TSLs were shown to be satisfactory for the minimum performance requirements for a structural rock support suggested by EFNARC (2008) and tensile strength of a TSL was shown to increase as its content of polymer was higher. In contrast, its bond strength was shown to increase proportional to the content of a cementitious component especially at the early age.

1 INTRODUCTION

Since the dry shotcrete was developed in 1910's, the capacities of the shotcrete were improved continuously (Clements, 2002). However, there are some shortcomings of the shotcrete which are increase of placing concrete in poor ground, rebound of about 10%, many-dusts, and relatively low bond strength. For these reasons, nowadays, "Thin Spray-on Liner" (below TSL) as a tunnel support member including water-proof capacity attracts attentions around the world. The TSL was agreed to describe the layer of surface support made from plastic, polymer or cement based compositions in the Workshop-Perth (2001). Material layer of about 3∼5 mm is generally agreed thickness that may range between 2 to 10 mm on field applications (Yilmaz, 2009). TSLs liners have applications in hard-rock mines as a replacement for either wire mesh or shotcrete. They function well as the areal support component in a support system that also incorporates rock bolts (Tannant, 2001).

TSLs are classified as reactive or non-reactive depending on their film formation or curing mechanism. Reactive TSLs cure rapidly by the immediate cross-linking of polymers after mixing. Non-reactive TSLs that consist of cement/water/polymer systems cure by loss of water, which is therefore a relatively slow process (Povin et al., 2004). However, the non-reactive liners are relatively cheap compared to the reactive liners.

As mentioned above, TSLs are many advantages. But, rock support design process by TSLs has not been established yet and, especially, general methods in which the support member was considered as arch structure cannot be applied in the design process by using TSLs whose thickness are very thin (Povin et al., 2004). In addition, the mechanical properties of TSLs have been rarely introduced, even though about 20 TSLs were developed and used around the world. Therefore, in this paper, the mechanical properties of two non-reactive TSLs which have different polymer contents were introduced. In order to evaluate the TSLs' support capacities, direct tensile tests, bond strength tests, compression test with specimens coated by TSL, and two kinds of bending tests proposed by EFNARC (2008) were performed with the two kinds of TSLs.

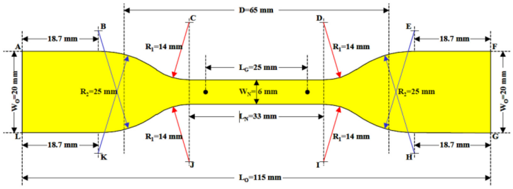
2 TEST METHODS

In this chapter, the methods of the four tests performed with two TSLs in Table 1 are introduced.

Table 1. Main characteristics of two TSL materials used in this study.

Material name	Application	Composition	Color	Polymer content (estimated)
T*	Support member	Liquid/Power	Beige	<30%
M**	Sprayable membrane	Powder (mixed with water)	light grey	approx. 30%

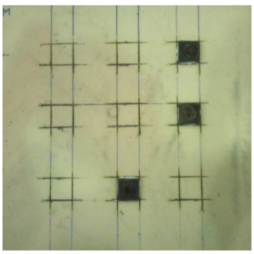
*Pot life: 30 minutes **Curing time: 4∼6 hours



Coordinates	A	B	C	D	E	F	G	H	I	J	K	L
X (mm)	0.0	18.7	41.0	74.0	96.3	115.0	115.0	96.3	74.0	41.0	18.7	0.0
Y (mm)	27.0	32.0	34.0	34.0	32.0	27.0	7.0	2.0	0.0	0.0	2.0	7.0

Where: **W_O**: Overall Width, **L_O**: Overall Length, **D**: Distance between grips, **L_N**: Length of Narrow section, **L_G**: Gage Length, **W_N**: Width of Narrow section, **R_1**: Inner Radius, **R_2**: Outer Radius

Figure 1. Dimensions of a tensile strength test specimen specified by ASTM D638 (Type 1).



(a) Brackets glued onto TSL surface

(b) Pull-out test

Figure 2. Specimen preparation and pull-out test to evaluate TSL bond strength.

2.1 *Tensile strength test*

EFNARC(2008) mentioned that the tensile strength tests of TSL should be performed with ASTM D638 or DIN 53504 Type S2. In this study, ASTM D638 as shown in Figure 1 was applied and the thickness of the specimen was 3 mm. In order to produce the specimen with 3 mm thickness, the acryl molds were made.

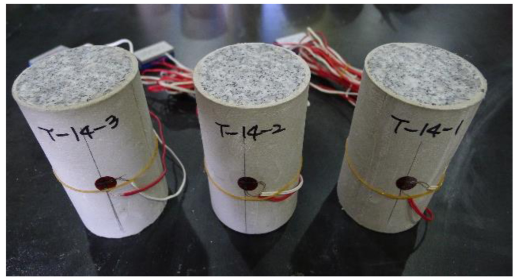
2.2 *Bond strength test*

In order to evaluate the adhesion properties of TSLs, pullout test in EFNARC (1996) which is used for shotcrete was applied. First of all, a mortar block with the size of 50 × 50 × 7 cm was prepared and then the TSL with the thickness of 3 mm was spread on the top of the mortar block (design strength: 40 MPa) and cured. During tests, a bracket for the bond strength test and the surface of the TSL were glued with epoxy by a square grid with 4 × 4 cm size, and tensile forces were applied as shown in Figure 2. The loading speed ranged from 1 to 3 MPa/min.

2.3 *Compression test*

A coated core uniaxial compression test in which a cylindrical rock specimen coated by TSL on the side can be used for evaluation of the capacity of TSL as a support member (Archibald, 2004; Povin et al., 2004). This test was proposed in order to obtain the support effect and optimal thickness of the TSL for rock pillars with different aspect ratios. In this study, rock specimens with the diameter of 54 mm and the length of 100 mm were prepared and TSLs with the thickness of 3 mm were coated using manufactured molds with the inner diameter 60 mm as shown in Figure 3. After 1 day curing, the coated specimens were taken out from the molds and used for the compression tests.

(a) Specimen preparation

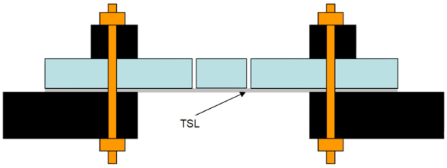


(b) TSL-coated specimen before compression tests

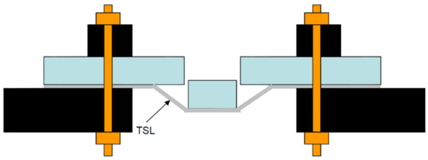
Figure 3. Specimen preparation for TSL-coated core compression tests.

2.4 *Linear block support test proposed by EFNARC (2008)*

Many tests are executed on TSLs to evaluate their mechanical characteristics such as tensile stress/strain, adherence to substrates or shear strength. They are typically defined by norms such as those recommended in the TSL Guidelines but they do not cover the question of how beneficial a TSL is in terms of bearing capacity. Each characteristic mentioned above can play a key role in the mechanism of rock support. EFNARC(2008) suggested another support tests such as Linear Block Support Test (below LBS test) and Gap Shear Load Test (below GSL test). LBS test is to evaluate support capacity of the TSL by simplifying falling block geometry and is to simulate the de-bonding between the TSL and rock block as shown in Figure 4. On the other hand, GSL test is to simulate the failure by only shear stress not by de-bonding as shown in Figure 5. For the specimen preparation, acryl molds with the size of 21 × 3.3 × 3 cm were made. Mortar blocks were placed in them and then TSLs with the thickness of 3 mm were spread on the top of the mortar blocks.



(a) Fixed test sample before load is applied



(b) Loaded sample with de-bond as the major failure mechanism

Figure 4. Setup for TSL LBS Test (EFNARC, 2008).

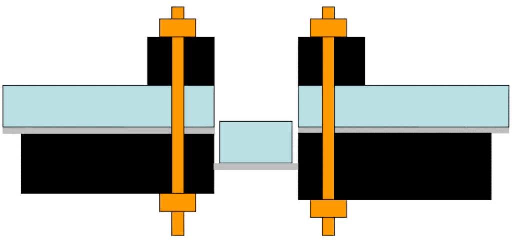


Figure 5. TSL GSL Test (EFNARC, 2008).

3 TEST RESULTS AND DISCUSSIONS

3.1 *Tensile strength*

Average tensile strengths of TSLs from 3 tests were shown in Figure 6. Average tensile strength of TSL M was greater than that of TSL T. When curing day was 7, the difference between two TSLs was around 10% and it increased by 50% after 14 days. This is because the polymer content in TSL M, which has great effect on the tensile strength, was higher than that in TSL T. However, the tensile strengths of both TSLs were over 2 Mpa which is minimum tensile strength on 7 curing days in EFNARC (2008).

In addition, average elongations at break of two TSLs were much higher than 10% which is criteria of elongation at break in EFNARC (2008).

3.2 *Bond strength*

Figure 7 shows bond strength of TSLs according to curing day. Average bond strength of TSL T was greater than that of TSL M. Especially, when the curing day was 7, average bond strength was 1.25 MPa. This value is greater than 1.0 MPa which is a bond strength criteria on 28 curing days for shotcrete in EFNARC (1996) and a bond strength criteria on 28 curing days for TSL in EFNARC (2008). Therefore, the results showed high bond strength from initial curing stage.

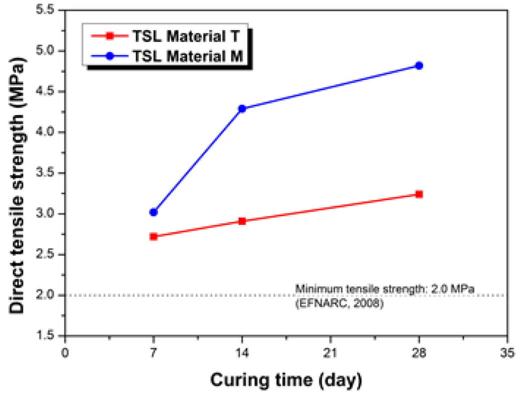


Figure 6. Average tensile strengths of TSLs at different curing ages.

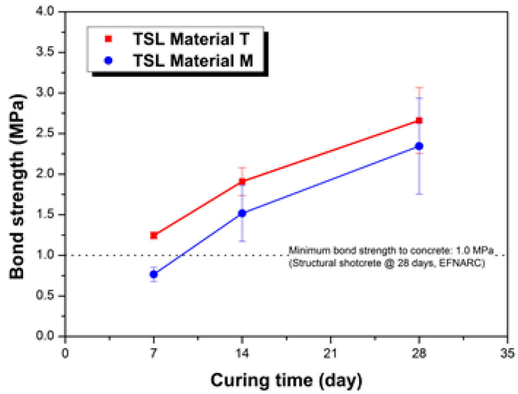


Figure 7. Bond strength of TSLs to a mortar substrate at different curing ages.

Average bond strengths of TSL T on 14 and 28 curing days were also greater than those of TSL M up to 13∼26%.

However, considering deviation of the test results, the bond strengths on 14 and 28 curing days were similar each other. It is thought that bonding failure between TSL and a mortar block didn't occur completely and the epoxy between TSL and a bracket was separated on 14 and 28 curing days. In other words, most bond strength came from adhesion of epoxy. Therefore, it is judged that the bond strengths on 14 and 28 curing days were overestimated and pull-out test after inserting steel plates to the mortar block should be executed.

3.3 *Compression strength*

As shown in Figure 8, peak strengths of TSL-coated cores definitely increased compared with 135.7 MPa, average uniaxial compression strength of Pocheon granite, which was used as rock specimen. Additionally, peak strengths of TSL-coated cores increased as curing days passed. On the day 7, the rate of increase compared with the rock specimen was 9∼17%.

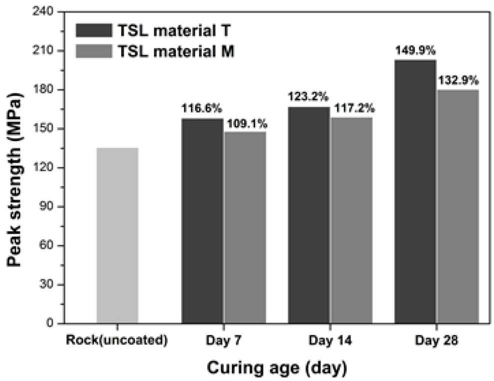


Figure 8. Peak strengths of TSL-coated cores at different curing ages.

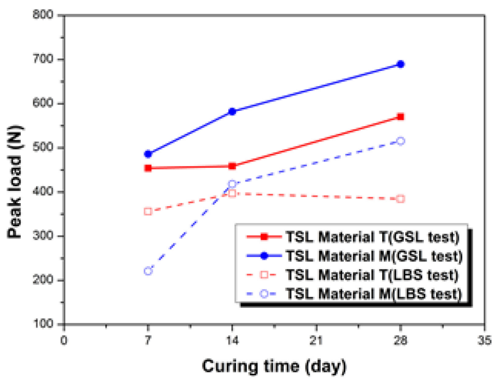


Figure 9. Average peak loads obtained from GSL and LBS tests at different curing ages.

However, on the day 28, the rateincreased up to 33∼50%. Especially, the rates in TSL T were relatively larger than those in TSL M. It is thought that high confinement was applied in TSL T-coated core because the bond strength of TSL T is greater than that of TSL M explained in chapter 3.2.

3.4 *LBS and GSL tests results*

Figure 9 shows the LBS and GSL test results according to curing days. In the case of the GSL tests, average peak loads of TSL M were greater than those of TSL T. This is because GSL test in which shear stress only leads to failure is much affected by tensile strength. Therefore, average peak loads of TSL M which has relatively more polymer affecting tensile strength were about 21% larger than those of TSL T on day 28.

In the case of LBS tests which simulate de-bonding failure between TSL and rock, average peak loads of TSL M which showed low bond strength were about 38% smaller than those of TSL T on day 7. But, on day 14, the results were similar and on day 28, results in the case of TSL T were greater. This is because of the characteristics of polymer that strength increases slowly as curing days passed and water came out from the specimens. Therefore, the peak loads of TSL M which has more polymer showed reversed results in the long-term curing ages.

4 CONCLUSIONS

In this study, tensile strength test, bond strength test, compression test with specimens coated by TSL, and two kinds of bending tests proposed by EFNARC (2008) were performed with two kinds of TSLs with different material compositions in order to evaluate their support capacities. As a result, both TSLs were shown to be satisfactory for the minimum performance requirements for a structural rock support suggested by EFNARC (2008) and tensile strength of a TSL was shown to increase as its content of polymer was higher. In contrast, its bond strength was shown to increase proportional to the content of a cementitious component especially at the early age. Considering the above characteristics according to the components ratio in TSL, optimum TSL as a tunnel support member should be developed. In addition, TSLs consisted of only powder with high percentage of polymer can generate relatively lots of dusts and can be affected by water condition of the sprayed surface. Therefore, the workability using TSL in a tunnel should be also considered when TSL as a tunnel support member is developed.

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