Underground Mining Technology 2017 – M Hudyma & Y Potvin (eds)
© 2017 Australian Centre for Geomechanics, Perth, ISBN 978-0-9924810-7-0
doi:10.36487/ACG_rep/1710_05_Chang

Performance comparison between thin spray-on liners with different compositions

S-H Chang *Korea Institute of Civil Engineering and Building Technology, South Korea*

S-W Choi *Korea Institute of Civil Engineering and Building Technology, South Korea*

C Lee *Korea Institute of Civil Engineering and Building Technology, South Korea*

T-H Kang *Korea Institute of Civil Engineering and Building Technology, South Korea*

J Kim *Silkroad T&D Co., Ltd., South Korea*

M-S Choi *Silkroad T&D Co., Ltd., South Korea*

Abstract

Four thin spray-on liner (TSL) mixtures were produced and tested based on the performance requirements specified by EFNARC (2008). They generally showed good tensile and bond strengths; however, one powder-type TSL mixture was shown to be unsuitable as a permanent support member (a 'Class S' TSL), because its elongation at break was much lower than the EFNARC (2008) specification. Two-component TSLs consisting of a liquid polymer and a powder binding material were more ductile and generally performed better than the one-component powder mixtures. Their high ductility resulted in increased elongation at break, even though their tensile strengths were slightly lower than those of the one-component powder TSLs. One prototype two-component TSL produced here satisfied every criterion specified by EFNARC (2008). Notably, it increased the average compressive strength of mortar specimens by over 20% even when coated to a thickness of only 3 mm.

Keywords: *thin spray-on liner, one-component, two-component, rock, support*

1 Introduction

Thin spray-on liners (TSLs) have been developed to support and supplement or to replace entirely sprayed concrete and wire mesh. They can also be used as a non-structural coating to prevent rock masses from weathering (EFNARC 2008; Lau et al. 2008; Tannant 2001).

TSLs are polymer-based organic compounds and can comprise one or two components (Tannant 2001). One-component TSLs are easy and simple to handle, because they can mix with water at the spraying nozzle. However, their quality and dust generation are highly dependent upon the proficiency of the operator. Two-component TSLs are more expensive, but generally produce higher-quality support liners and much less dust and rebound. This is because the powder and an additional liquid component can be simply poured and mixed in the hopper of a spraying machine (Archibald 2004).

This study produced several TSL prototypes with different mixing conditions and assessed their performance based on the testing methods and performance criteria recommended by EFNARC (2008).

2 Production of TSL prototypes

The mixing conditions for the four kinds of TSL prototypes produced here are summarised in Table 1 (Chang et al. 2015, 2016). They were derived from a series of preliminary batch tests. Prototypes N1 and N2 are one-component powder-type TSLs that are mixed with water with a ratio of 1:2. They both contain a powder-type polymer at 65% by weight. Calcium sulf-aluminate (CSA) and anhydrous gypsum are added to increase their early strength. Ordinary Portland cement (OPC) is used as an inorganic binding hardener.

Samples MN1 and MN2 are two-component TSLs consisting of a liquid polymer (Vinnapas 547ED) and a powder material mixed at a weight ratio of 2:1.

Table 1 Mixing conditions for the four TSL prototypes

Prototypes	Liquid polymer	Powder (wt%)					Note
		Polymer	CSA	OPC	Gypsum	Others	
N1	None	65%	16%	9%	6%	4%	One-component
N2	None	65%	18%	8%	6%	3%	One-component
MN1	Vinnapas 547ED	None	30%	15%	45%	10%	Two-component
MN2	Vinnapas 547ED	None	30%	None	45%	25%	Two-component

3 Performance evaluation of TSL prototypes

A series of laboratory tests recommended by EFNARC (2008) were carried out on the four TSL prototypes. Their key performance parameters, such as tensile strength and bond strength, were measured by direct tensile tests and pull-off tests. The support capacities of the TSLs were also measured in bearing capacity tests as described by EFNARC (2008). Further coating core compression tests (Archibald 2004) were performed to investigate the confining effect of the TSLs on rock specimens. Every specimen was prepared in laboratory conditions for the purpose of their performance evaluation.

3.1 Tensile strength

Tensile strengths of TSLs (thickness 3 mm) were measured by the ASTM D638 (ASTM International 2010) standard method. The tests showed that all the prototypes satisfied the minimum tensile strength of 2 MPa at seven days. However, the average tensile strengths of the two-component TSLs were lower than those of the one-component powder TSLs (Figure 1).

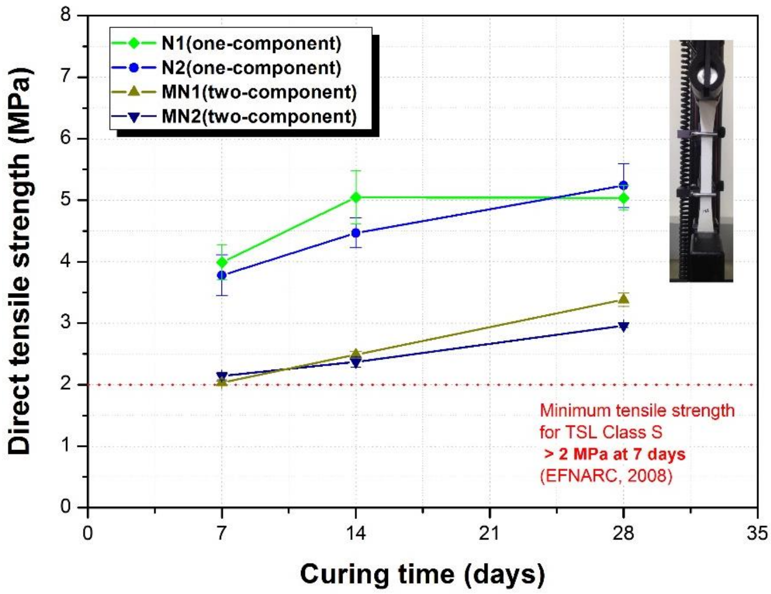

Figure 1 Average direct tensile strengths of TSLs at different curing ages

The elongation of the two-component TSLs at break was much higher than those of the one-component TSLs due to their greater ductility (Figure 2). The one-component N2 prototype did not satisfy the elongation criterion of over 10% at break (Figure 3).

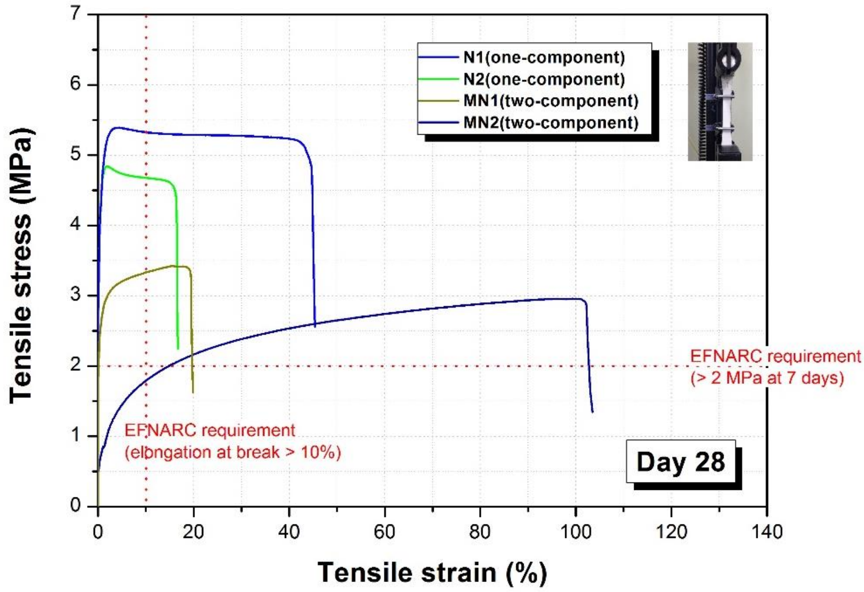

Figure 2 Tensile stress–strain curves from direct tensile tests of TSLs (day 28)

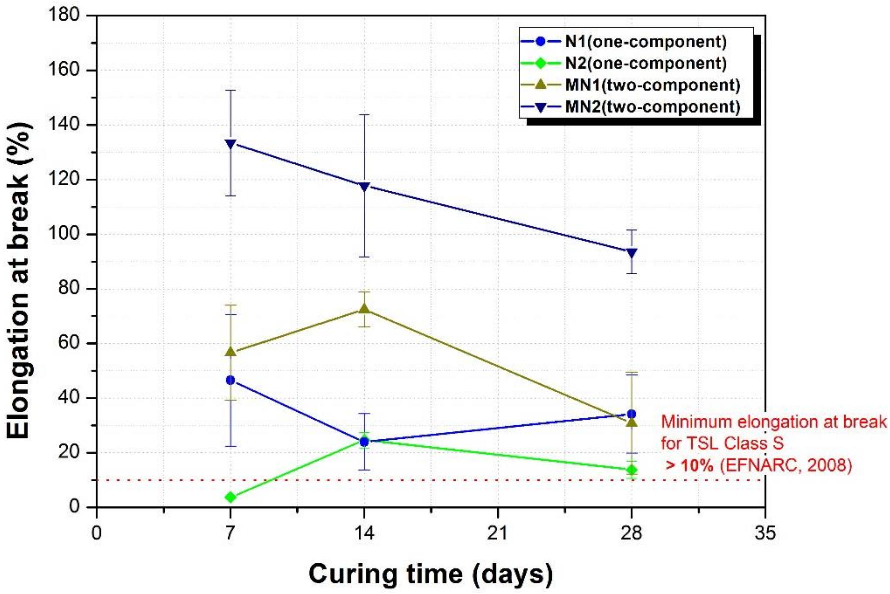

Figure 3 Average elongation at break of TSLs at different curing ages

3.2 Bond strength

Bond strengths of the TSLs were measured by the EFNARC (1996) method for sprayed concrete. The loading rate during pull-off tests was set to 1–3 MPa/min.

Among the four samples, prototype N1 showed the highest average bond strength, but they all satisfied the required minimum of 1 MPa at 28 days (Figure 4).

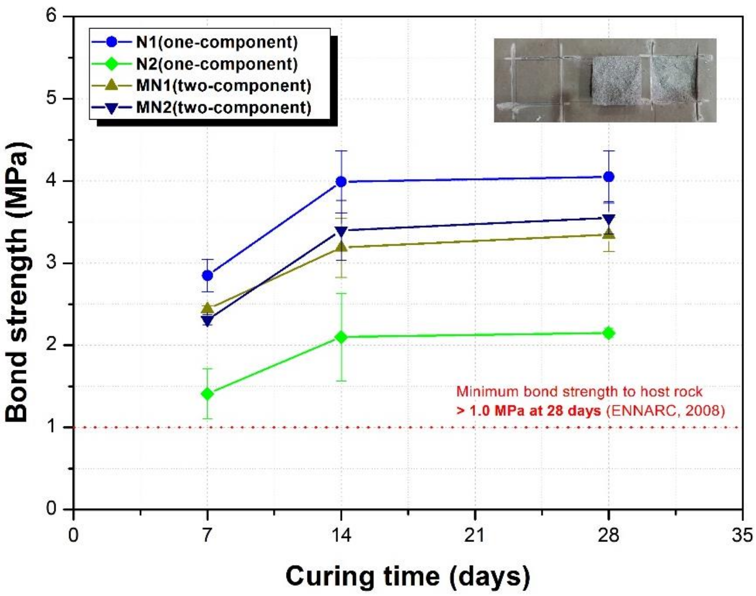

Figure 4 Average bond strengths of TSLs at different curing ages

3.3 Compressive strength of TSL-coated specimens

Compression tests using cylindrical mortar cores (70 MPa average compressive strength) coated with 3 mm TSL were carried out at different curing ages. Only the two-component TSL prototypes were applied here to verify their confining effect on rock or other material.

Both coated mortar specimens showed uniaxial compressive strengths over 110 MPa at 28 days; thus, they were approximately 50% stronger than the uncoated mortar (stress–strain curves, Figure 5). The TSLs possibly confined the samples, providing triaxial compression that greatly increased the strength and stiffness of the coated specimens.

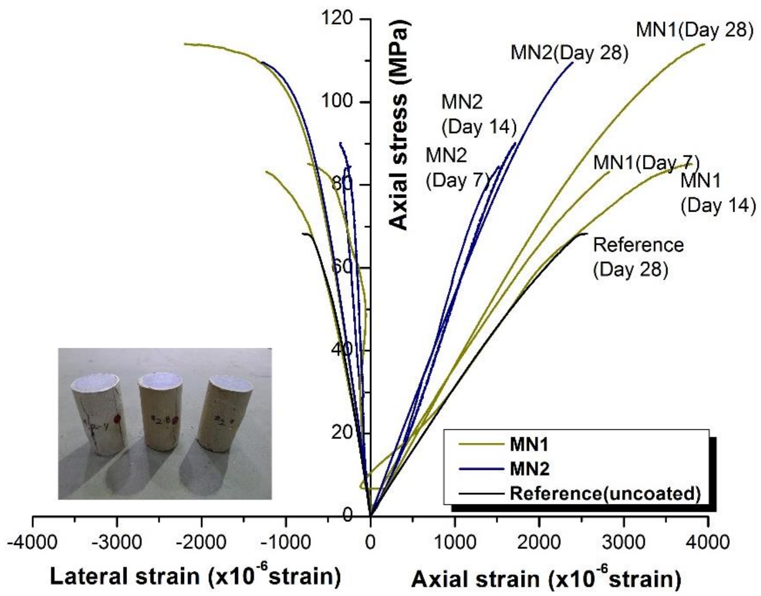

Figure 5 Compressive stress–strain curves for two-component TSL-coated specimens

Three-dimensional X-ray computed tomography (CT) scans of the coated specimens after failure showed that most of the cracks occurred intensively at the interface of the TSL and the mortar (Figure 6). This shows that bond failure at the interface of the TSL and the specimen might precede TSL surface and mortar specimen failures due to the high confinement by the coating.

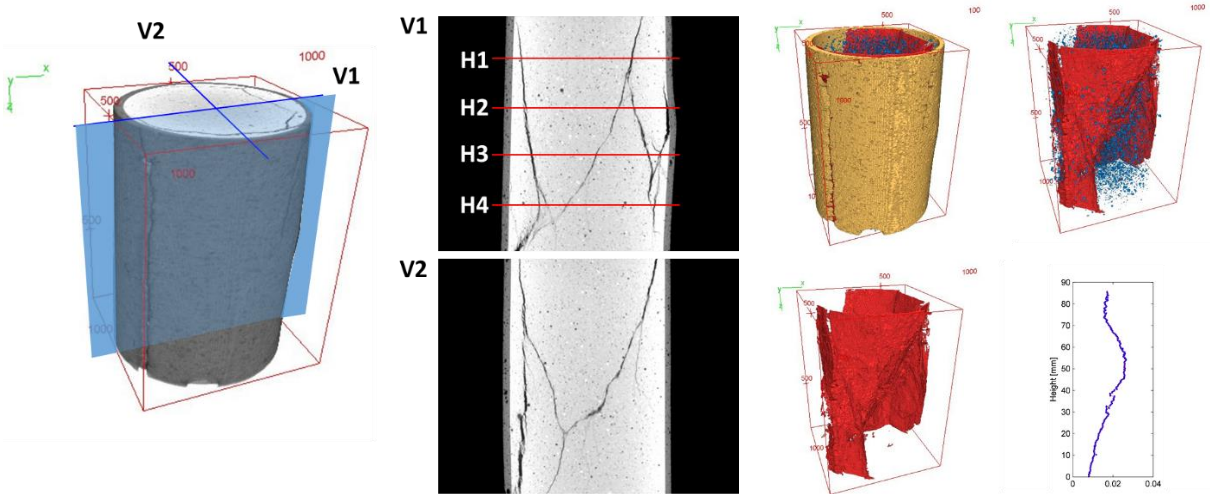

Figure 6 Three-dimensional X-ray CT images of a TSL-coated specimen after failure

3.4 Bearing capacity tests of TSLs

EFNARC (2008) proposes two kinds of test to evaluate the bearing capacities of TSLs. The linear block support test is intended to simulate rockfall between rockbolts and to estimate the bearing capacity of a TSL. The test simulates de-bonding between a TSL and a rock block by loading a rock block. The second test, the gap shear load test, evaluates the intrinsic bearing capacity of a TSL at the condition where the interface between it and a rock block does not fail by de-bonding, but by pure shear stress.

The linear block support tests showed every prototype (thickness 3 mm) to have a linear load resistance over the 5 kN/m minimum requirement for a Class S TSL. Here, a Class S TSL is defined as a permanent stabiliser of the integrity of rock structures (EFNARC 2008). The one-component TSL prototypes had higher resistance than the two-component TSLs (Figure 7).

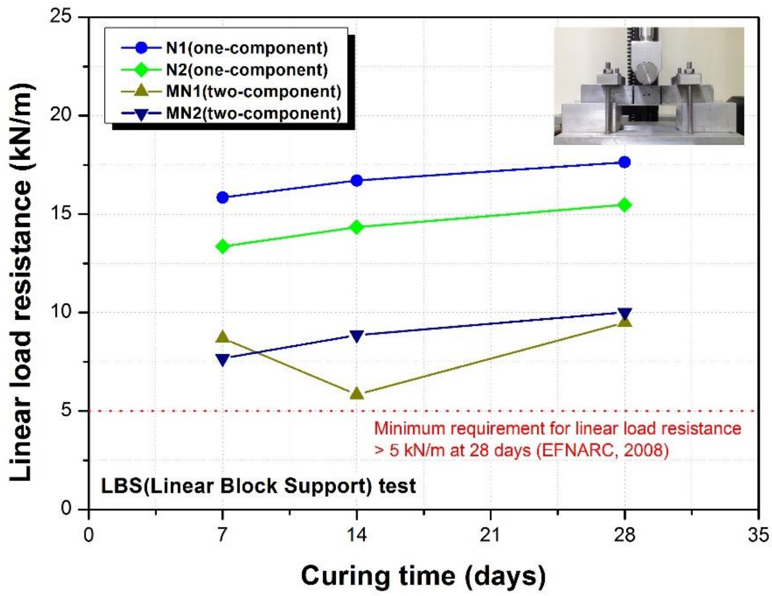

Figure 7 Linear load resistance of TSLs from linear block support tests

The ratio of the linear load capacity from gap shear load tests to that from linear block tests gives the safety factor of a TSL with a given thickness. The safety factors of the TSL prototypes (3 mm thick) estimated from the tests are summarised in Figure 8. All prototypes except MN1 showed average safety factors over one.

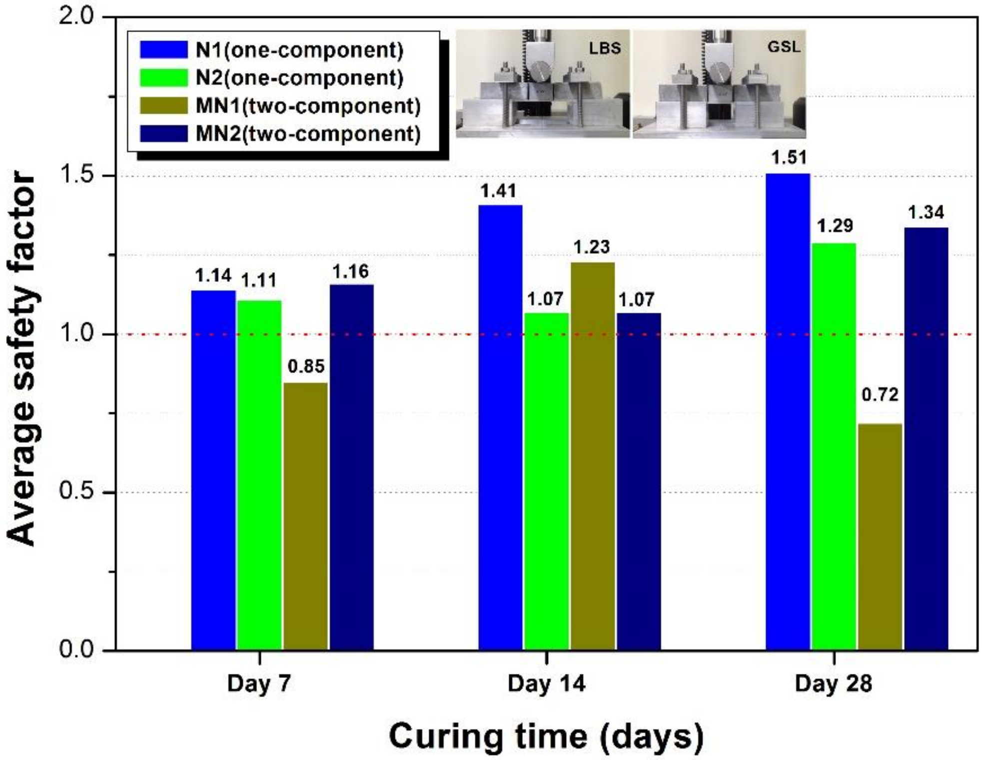

Figure 8 Safety factors of TSLs at different curing ages

3.5 Summary

EFNARC (2008) divides TSLs into two classes depending on their end use. Class B TSLs can be principally used as anti-weathering coating, and Class S TSLs are for permanently stabilising the integrity of rock structures while accommodating the stresses associated with strata movement.

Table 2 summarises the results of all the tests conducted here and compares them with the minimum performance requirements of EFNARC (2008). The two-component MN2 and one-component N1 prototypes are satisfactory as Class S TSLs, while prototypes MN1 and N2 should be used only as anti-weathering coatings.

Table 2 Classification of TSL prototypes based on EFNARC (2008) criteria – acceptable (A) versus unacceptable (U)

Performance categories	Class S TSL requirements	TSL prototype			
		N1	N2	MN1	MN2
Tensile strength	> 2 MPa (at seven days)	A	A	A	A
Elongation at break	> 10% (at 28 days)	A	U	A	A
Bond strength	> 1 MPa (at 28 days)	A	A	A	A
Linear load capacity	5 kN/m (at 28 days)	A	A	A	A
Safety factor	> 1	A	A	U	A

4 Conclusion

Tensile and bond strengths of the four prototypes meet the minimum requirements suggested by EFNARC (2008). The two-component TSLs showed higher elongation at break, but their tensile strengths and linear load resistances were slightly lower than those of the one-component TSLs.

The two-component MN2 and one-component N1 prototypes are satisfactory as Class S TSLs, while prototypes MN1 and N2 can be used only as anti-weathering coatings.

TSLs can increase the uniaxial compressive strength and stiffness of a specimen due to their high confinement effect, which creates similar conditions to triaxial compression.

Further study on the selection of suitable nozzles and spraying machines for the application of the TSL prototypes produced here is necessary. Their applicability in the field should be also verified.

Acknowledgement

This study was supported by a grant from the Strategic Research Project (Development of Underground Excavation and Stabilization Technologies for the Expansion of Underground Space in Use) funded by the Korea Institute of Civil Engineering and Building Technology.

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