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A Review of Application and Benefits of Thin Spray-On Liners for Underground Rock Support in South African Mines

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Abstract

Thin Spray-on Liners (TSLs), an emerging alternative surface support system for underground rock support with performance characteristics in-between those of shotcrete and wire mesh, are receiving increasing attention from the South African mining industry. Previous rock support trials conducted at South African mines and laboratory sites to determine the reinforcement potential of TSLs, and to assess their effectiveness relative to existing traditional support techniques showed positive results. The purpose of this article is to review the reinforcement potential of TSLs surface support system critically in light of the traditional mining technologies. Both laboratory simulations of loose rock deformations and in-situ observation of falls of loose rock fragments, constrained solely by TSL layer strength and rock adhesion were reviewed. An overview of the technology and observed and measured support capabilities is provided and thereafter assessment of rock reinforcement potential done plus the benefits of the technology in the South African mining industry.

Keywords: *Rock support, Thin spray-on liners, Shotcrete, Mining, Rockfalls*

1 Introduction

Rock support is the basis of any underground mine and many open cut operations. Ground support methods have evolved over the years with the current trend to use bolts, mesh and shotcrete (Lau, 2008). There are two types of support in underground hard rock excavations; rock reinforcement and retainment (rock mass support) elements such as rock bolts and cable bolts and rock containment (surface support) such as wire mesh, shotcrete, Thin Spray-on Liners (TSLs), lacing and straps. Rock mass support are installed in boreholes while rock containment components are applied on the surface of the excavation (Thompson, 2004). Surface support provides areal coverage, while faceplates and straps or lacing provide point load and strip restraint respectively. Rock related accidents are the major cause of injuries and fatalities in South African underground mines and most of these accidents occur near active faces where workers spend most of their time, with lack of support coverage as the major cause (Klokow, 1999). Webber-Youngman & Van Wyk (2009), Figure 1, reported that rock fall fatalities represented 39% of total number of fatalities in underground mines between August 2006 and March 2009. Gold mines, with their great depth and seismicity, represented 52% of these fatalities. South African mining safety statistics between 1998 and 2002 show that about 67% of all fatalities and 64% of all injuries caused by rockfall occurred at the stope face (Adams, 2002) with drilling, mucking, installing support and barring down as the most common activities at the time of the accident.

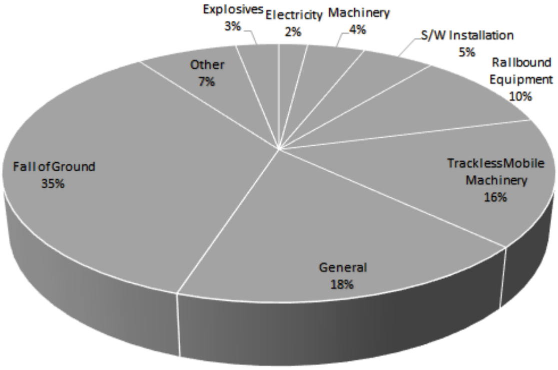

Figure 1. Main contributors to fatalities in South African mines (Webber-Youngman & Van Wyk 2009).

Rock surface support is simply the support placed onto the surface of a rock mass classified into active and passive (Thompson, 2004). Mesh and lacing fall into the passive category where the rock mass is required to move or deform in some manner before the support system becomes active. As a result, passive support does not fulfil the function of maintaining rock mass integrity since deformation has to occur first for support to take effect. In extreme cases contained rock fragments have to be bled out causing further disintegration of the rock mass surrounding excavation. Shotcrete and TSLs fall into the active category where the liner material maintains the initial rock mass integrity. Potvin (2002) stated that surface support is widely used in order to combat rockfalls and resulting injuries and fatalities in the vicinity of active faces where workers spend most of their time. Therefore, support coverage that can reduce weathering and unravelling of exposed rock surface has the potential to minimise rockfalls in South African Mines (Applegate, 1987).

A number of passive area support techniques have been applied by the mining industry to restrict the movement of loose and broken rock fragments that form as the result of convergence and failure of rock around excavations. The traditional approaches used in South Africa mines range from using no surface support to the installation of mesh (steel & fibre) and the installation of shotcrete in poor ground conditions (Yilmaz, 2011). However rockfalls still remain the major cause of injuries and fatalities in the modern underground mines of South Africa (Webber-Youngman & Van Wyk, 2009). While applying the current methodologies near the face would likely reduce the risks of rockfall injuries, it could negatively impact the operations with regards to cost, logistics and mining cycle times due to large material volumes. Statistical rockfall sources over the years also seem to suggest a steady increase in rockfall injury associated with traditional methods. This suggests that the current approaches in controlling the small pieces of exposed rocks near the active face where mineworkers are consistently exposed need to be replaced.

The installation of a surface support system using remote and rapid spraying techniques, Figure 2, has the potential to minimise interference with the mining cycle and reduce costs (Tannant, 2001). Thin Spray-on Liner (TSL) is an emerging alternative surface support system for underground rock support receiving increasing consideration from the mining industry in South Africa. Thin Spray-on Liners (TSLs) can be applied essentially on or at the face to keep the small key blocks in place and reduce the potential of gravity induced fallouts of small pieces of rock. New TSL materials are continuously being developed and tested in South Africa as replacements for traditional surface support methods. Since the 1990s, TSL support has become the focus of the mining industry in South Africa due to considerable operational benefits, with the potential to reduce mining costs (Ozturk, 2012). The performance characteristics of TSLs lie between those of shotcrete and wire mesh. In this review, a detailed and systematic survey was carried out on the use of TSLs for underground rock surface support in South African mines.

Source: TSL, P. H. Ferreira, Minova RSA, 2012

Source: Shotcrete, Dennis Van Heerden, Minova RSA, 2012

Figure 2. Comparison between the application of TSLs and Shotcrete (Minova, RSA)

2 Overview of Thin Spray-on Liners

Thin Spray-on Liners (TSLs) have been around since the invention of gunite in 1907. Gunite, a mortar containing fine aggregates and cement, eventually evolved into dry-mix shotcrete and in the past few decades into wet-mix shotcrete for use in underground mine & tunneling construction projects (Lacerda, 2004). The installation of traditional surface support is associated with many operational, logistical and cost disadvantages due to large material volumes. Unlike shotcrete, which has been around for almost a century and has been used since the 1950s in underground mines (Spearing & Champa, 2000), TSLs have only been used since the 1980s.

Common TSLs, also referred to as membranes, are reactive or non-reactive polymer or water-based materials formed from a combination of cement and sand, or cement only, that are sprayed onto the rock surface at a thickness between 3mm and 5mm, and form part of surface support system (Yilmaz, 2011). Reactive TSLs have a short curing time of less than ten minutes of application and gain most of its tensile strength within one hour of application. Non-reactive TSLs have a slower curing time (30 to 60 minutes) and build bond/tensile strengths at a slower rate (Lacerda, 2004). However, for most underground construction applications nonreactive TSLs are deemed adequate to meet desirable cycle time conditions. Polymer liners are two-component liquid chemical systems consisting of a polyisocyanate and resin mixture. The majority of current TSLs are two part polyurethane/polyurea or Portland cement based latex products that are mixed on site before spraying onto surfaces (Ozturk, 2012). TSLs are more flexible compared to shotcrete which has a typical thickness of 25mm to 100mm depending on the need. Though TSL structural capacity is negligible, its performance is almost always reported as being better than expected (Spearing & Champa, 2000; Stacey & Yu, 2004). Effective polymer support is created by a continuous membrane, which is firmly adhered to the rock.

TSLs have been used in civil engineering as sealants before being tried in the mining industry (Kuijpers et al., 2004). Liners often developed for applications such as the sealing of dam walls, construction and other civil engineering uses (Borejszo & Bartlett, 2002) represent materials that have been used as TSLs. Initial TSLs were mainly designed as rock sealants to limit the weathering of rock (Spearing & Champa, 2000; Spearing, Borejszo & Campoli, 2009) and later on were intended to be used as an alternative to mesh or shotcrete. In the early 1990s trials were initiated in Canada mines (Archibald & Dirige, 2005) to substantiate the concept that TSLs enhance the structural performance of the excavation. Recently, TSLs have been tailored to specific underground and rock-related applications, with many success stories (Borejszo & Bartlett, 2002). Since the 1990s, thin spray-on liner (TSL) support has become the focus of the mining industry due to considerable operational benefits, with the potential to reduce mining costs (Ozturk, 2012).

Belfield (2006) reported that more than 50 mines worldwide have used TSLs for rock support. TSL trials or applications were commonly implemented at locations with extremely poor ground conditions or ground control problems such as: friable and weathered ground with some water seepage, damaged concrete shaft lining, high stress environments (shaft pillar) and rock mass conditions with rockfall and rock burst hazards, burnt coal site, intensely spalled and shattered pillar corners, development ends with humid conditions, rapidly deteriorating shale band/green bar, running black dykes and old sites. In spite of the often un-favourable conditions, most of the applications were found to be successful for what they were planned for. TSL applications, in a few cases, resulted in poor bonding, falling of large slabs, peeling, tearing and damage due to blasting and moving machinery (Tannant, 2001). TSLs in these applications were principally used as temporary support for strata control and ground stabilisation purposes.

The application of TSL technology in the mining industry is still in its infancy and the mechanisms whereby a sprayed coating acts to provide support are not fully understood (Tannant, 2001; Leach, 2002). The design of TSLs as surface support systems is currently based on experience, assumptions, field observation and cost considerations. Kuijpers et al. (2004) state that it is in practice difficult to quantify the parameters that accurately reflect the combined effects of fracturing and induced stresses on rock mass stability; therefore the mechanisms by which the liners support the rock need to be reviewed, understood and incorporated into an engineering support design. Espley et al (1999) developed some tentative application guidelines, Table 1, for TSL as a ground support and reinforcement tool based on field investigations. Kuijpers et al (2004) formulated standard testing methodologies and developed testing equipment in order to quantify relevant TSL parameters, in South Africa, on the basis of underground and laboratory work in combination with numerical modelling results.

TSLs' advantages are fast application rates, rapid curing times ranging from seconds to hours, reduced materials handling compared to shotcrete, high tensile strength with high areal coverage, high adhesion which enables early reaction against ground movement, and ability to penetrate into joints (Kuijpers et al., 2004; Finn, 2001; Pappas, Barton & Eric, 2003). Stacey & Yu (2004) suggests that these advantages lead to improved cycle times, increased mechanization and improved safety. The use of flexible support membranes prevents rock degradation and structural failure of excavations by mobilizing and conserving the inherent strength of the rock mass immediately about the excavation surface (Tannant, 2001). Thus the opening of fractures is restricted and key blocks are maintained in place from an early stage, and the rock mass strength and excavation stability can be enhanced.

Despite the economic advantages offered by the membrane materials in terms of support, there is still concern over environmental, occupational health and safety risks associated with use of some TSL materials containing diphenylmethane diisocyanate (MDI). Archibald &

Dirige (2005) and Pappas, Barton & Eric (2003) found out that 5 to 20% of exposed workers can become sensitized, and may develop life-threatening asthmatic symptoms following repeated exposures either by inhalation or skin contact. Potvin et al. (2004) suggest that if proper procedures are used, it is possible for TSLs to be used without adverse effects on humans. It is suggested that, for a TSL to be considered a safe and efficient ground support system, it should be manufactured such that all issues affecting the health of people working it, and the environments containing TSLs, are understood and addressed.

Table 1. Tentative application guidelines for TSLs (Espley et al, 1999))

Description	Rock Mass Rating (%)	TSL Thickness (mm)	Bolting pattern[1]
Development drift (walls)	45 - 65	2 - 3	1.8 m x 1.5 m[2]
	>65		1.8 m x 1.5 m[3]
Development drift (roof or back)	45 - 65	3 - 4	1.8 m x 1.1 m[4]
	>65		1.8 m x 1.3 m[4]
Production headings (lower wall)	45 - 65	2 - 3	1.8 m x 1.5 m[5]
	>65		Boltless or spot bolting[5]
Production headings (roof and back)	45 - 65	3 - 4	1.8 m or 2.4 m x 1.1 m[4]
	>65		

Note:
[1] Mechanical bolts.
[2] Bolting after every two rounds of advance.
[3] Indefinitely delayed with bi-annual audits.
[4] Install before or immediately after liner.
[5] Installation can be delayed.

3 Assessment of Rock Reinforcement Potential of TSLs

A principal objective of support is to assist the rock mass in supporting itself. It is difficult for a support system to hold up the dead weight of rock once the rock mass has loosened (Hoek & Brown 1980). This is particularly true when using thin liners, because they have a limited load capacity. In jointed or fractured rock masses, a thin liner prevents the rock mass from dilating, loosening and unraveling, thus forcing fragments of the rock mass to interact with each other creating a stable beam or arch of rock. To be effective at helping establish a stable zone of rock, a liner must be able to limit the kinematic movement of individual rock blocks. If conditions allow the rock mass to loosen excessively, then the liner's function can switch to retaining the loose rock in place between rock bolts (Tannant 2001). The support performance of a TSL is largely determined by the substrate onto which it is attached (Kuijpers et al 2004).

Various approaches are used to examine the load capacity of a liner. In situations where open joints or fractures exist it is possible for the sprayed polymer to penetrate into the loose rock, Figure 3. In this case the force required to remove the block from the competent rock depends on the depth that polymer penetrates the gap and the shear strength of the polymer (Tannant 2001). Using a combination of shear, adhesive and adhesive strength, TSLs can resist shear displacements of up to a few millimeters. This requires high liner stiffness.

At small rock displacements the liner functions to prevent unraveling of small rock fragments, lock small rock blocks or wedges in place (key blocks), prevent loosening of the rock mass, mobilize interactions between rock blocks, and establish a stable arch of self-supporting rock. The liner can fail in two modes as shown in Figure 3. It is assumed that failure of the adhesive bond does not occur. Given that a typical liner is only a few millimeters thick, direct shear failure or diagonal rupture of the membrane must occur within the first few millimeters of relative rock displacement. These two failure modes are most likely when the liner adhesive strength is similar to the tensile strength. This demonstrates that the membrane is able to deform and stretch before it fails. In order for significant stretching to occur, some adhesion loss must also occur, providing a debonded length of membrane for stretching. Therefore, adhesion loss followed by tensile rupture is an important process from a design point of view (Tannant 2001).

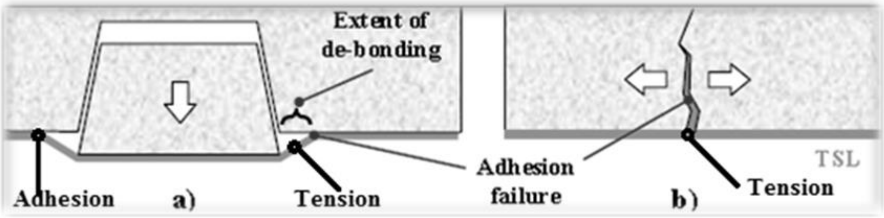

Figure 3. Liner failure modes at small block displacements caused by either shear rupture (right) or diagonal tensile rupture (left) (Kuijpers et al 2004)

According to Ferreira (2012), Minova RSA TSLs are being extensively used at present in South African platinum and chrome mines with relatively limited application in other hard rock and diamond mines. Local gold-mines Gold Fields and AngloGold Ashanti are using these thin spray-on liners (Stacey, 2005). The success of applications stems from ease of mixing and spraying and ultimately the cleaning of equipment after use leading to quick and cost effective spraying cycles. It is essential that rock surface support be installed timeously after the excavating process to ensure any movement that takes place in the rock mass is arrested while generating load on the support elements (Tannant 2001). Such installation has to be coupled with the liner curing time and the material properties as well as rock mass mechanisms of failure so that an effective support action can be achieved.

In hard and soft rock mining, changes in humidity and temperature affect weak strata, causing rock falls and rib degradation. Effective surface support and protection against weathering of rock and strata are critical to the safety, efficiency and longevity of any mining operation. TSLs provide an effective cover against weathering. In conclusion, TSLs offer a practical solution for limited ground support and if used in conjunction with appropriate webbing and followed in extreme cases by a layer of shotcrete, it offers a practical and mechanized solution to ground support in a sacrificial or permanent tunnel or excavation environment with the safest application method with very few people involved (Ferreira). All applications from the application of webbing to TSL to shotcrete can be done mechanized, remotely and fast.

4 Benefits of TSLs as Rock Surface Support in South African Mines

Typical areal support techniques currently used by the South African mining industry are bolts and mesh and shotcrete (Yilmaz, 2011). According to Tannant (2001), the installation of conventional rock bolts and wire mesh is labour intensive and time consuming. In addition, underground personnel are frequently injured during their installation. While the installation of rock bolts or other tendon support elements can be mechanized, mesh installation still requires manual labour. One method for overcoming some shortcomings of mesh is the use of shotcrete, in particular, steel fibre reinforced shotcrete. Application of shotcrete still has problems associated with the logistics of transporting large quantities of shotcrete materials to active headings far underground. In addition, it was noticed that deeper drifts in many Canadian mines underwent substantial deformations. These deformations exceeded the displacement capacity of the shotcrete rendering the shotcrete itself a hazard.

According to Archibald & Dirige (2005), bolt and screen support is relatively inexpensive but is not as productive as either shotcrete or polymer linings and is not readily automated. Shotcrete is significantly more productive than using screen and bolts, but is considerably more expensive and requires substantially more material handling. Spray-on liners tend to have high material costs associated with them, but they result in significantly increased productivity and reduced material handling efforts. Table 2 by Ferreira (2012) shows product comparisons (cost, application and time) between shotcrete and different liners in South African platinum mines. All the liners outperform shotcrete in all the comparisons.

Table 2. Product Comparisons (Cost, Application and Time) (Ferreira, 2012)

Description	**Shotcrete (± 25mm)**	**KT 2C (± 5mm) 3m²**	**KT White (± 5mm) 3m²**	**KT Grey (± 5mm) 3m²**	**KT Fast (± 5mm) 3m²**
Approximate ex factory product cost per m²	R85	R95	R85	R65	R85
Approximate dedicated labour cost per m²	R125	R55	R55	R55	R55
[*]**Approximate Total cost per m²**	**R210**	**R150**	**R140**	**R120**	**R140**
Rebound	Poor (lots of material)	Hardly any	Hardly any	Hardly any	Hardly any
Bags per m²	3.5	0.33	0.33	0.33	0.33
Kg per m²	88	8.35	8.35	8.35	8.35
Ease of Application	Cumbersome	Easy	Easy	Easy	Easy
[**]Time to cover 45 m² (conventional application)	150 Minutes	55 Minutes	55 Minutes	55 Minutes	55 Minutes
Equipment	Large	Small	Small	Small	Small
Interference with development cycle	High	Minimal	Minimal	Minimal	Minimal

[*] Product cost may vary slightly per m² from operation to operation due to surface areas. Labour cost for application could be very different from the numbers quoted above especially if the application crew is not part of the development crew.

[**] With continuous mixing arrangement of the TSL products, the application time can be limited to 30 minutes per application cycle followed by washing out the equipment before the next use. Minova RSA will ensure appropriate pump and mixing arrangements to allow for continuous mixing and spraying with the development cycle and equipment selection for development.

The economic benefits from using TSLs are realized by the higher productivity created by reduction of the time needed for support installation. Further gains are possible when material transportation and handling cost are considered. Compared to shotcrete, a lot less material needs to be moved underground to the working face when using thin polymer liners (Tannant, 2001). Furthermore, miners have realized the need to support the rock as soon as possible after blasting and before too much rock relaxation or “airslack” has taken place (Lacerda, 2004). It is essential that rock surface support be installed timeously after the excavating process to ensure any movement that takes place in the rock mass is arrested while generating load on the support elements (Tannant, 2001). TSLs have rapid curing times ranging from seconds to hours, Table 3.

Table 3. Surface Liner Early Age Properties Comparison (Lacerda, 2004)

Elapsed Time	**Non-Reactive TSL**		**Fiber Reinforced Shotcrete**		**6-gauge Welded Wire**	
	MPa	**PSI**	**MPa**	**PSI**	**MPa**	**PSI**
Bond Strength						
1 : 15 hr : min	0.30	44				
2 : 30 hr : min	0.40	58				
3 : 45 hr : min	0.50	73				
5 : 00 hr : min	0.55	80				
6 : 00 hr : min	0.60	87				
8 : 00 hr : min			0.2	29		
12 : 00 hr : min			0.3	42		
24 : 00 hr : min			0.5	71		
25 : 00 hr : min	1.20	174				
40 : 00 hr : min	1.50	218				
7 days	2.00	290				
28 days			1.7	239		
Note:	To concrete		From Stoble Study		n/a	
Tensile Strength						
5 hours	1.5	218				
8 hours			1.0	145		
24 hours	2.0	290	1.7	247		
7 days			2.2	312		
28 days			2.3	328		
6 weeks	4.0	580				
Note:	To concrete		From Stoble study		n/a	
Elongation						
5 hours	300%					
24 hours	60%					
6 weeks	20%					
Note:	At tear		Much lower than TSL		n/a	
Weld Break Strength						
Not Applicable					10.0	1450
Note:	Not applicable		Not applicable		Typical	

Most support design focuses on the load capacity of the support. It is equally important to consider the support's displacement capacity, Figure 4, especially in situations where large ground convergence and significant relative displacements or shear displacements between adjacent rock blocks are expected. Only through knowledge of the displacement capacity of various support types can proper design and selection of support be made for a given application (Tannant, 2001). Shotcrete, especially reinforced shotcrete, can generate much higher support resistance than thin polymer liners. However, in situations where large ground convergence occurs, the more flexible thin liners may provide superior support over the full range of rock deformations. In a study by Tannant and Kaiser (1997) and Kaiser and Tannant (1997), shotcrete panels attained peak strength and fractured after relative displacements of 5 to 10mm. In comparison, concrete blocks coated by a polyurethane membrane tested in similar conditions did not reach peak load until 40 to 50mm of displacement and the load was maintained for up to 100mm of displacement.

Furthermore, 1998 – 2002 South Africa statistics suggest that fatalities and injuries at mine faces have a direct relationship to TSL usage, Figure 5 (after Adams, 2002). TSLs have the potential to reduce the number of fatalities in the South African mining industry leading to an improvement in its lost-time-injury frequency rate hence increased profit margin.

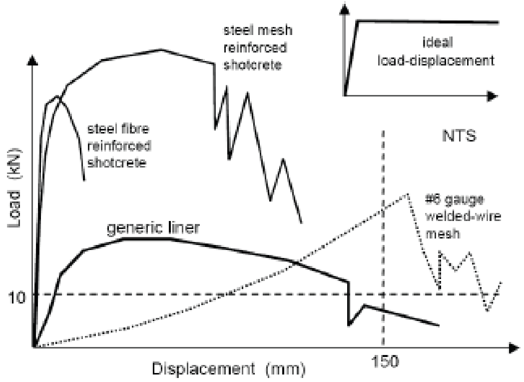

Figure 4. Schematic load displacement curves of areal supports (Tannant, 2001)

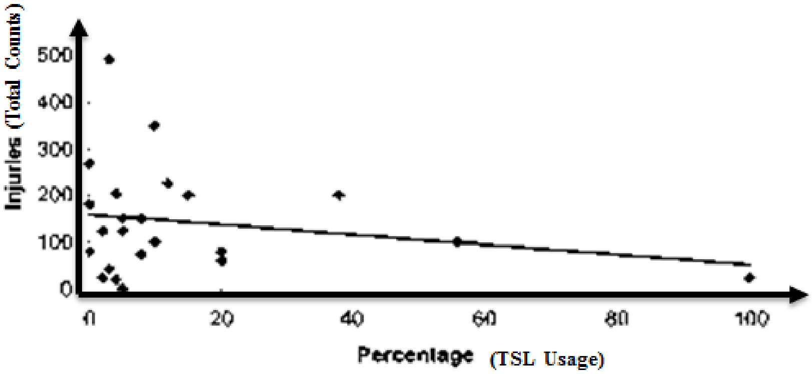

Figure 5. Relation between injuries and TSLs % in South African Mines (1998 – 2002).

5 Conclusion

TSLs have the potential to benefit the South African mining industry by offering improved productivity, profitability and safety. They have proven economic benefits such as reduced cost, logistics and shorter cycle times but its wide application use is still on trial basis. Therefore, there is a need to formulate design standards and requirements to build up confidence among the hesitant end users to induce more effective and frequent use of TSLs.

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