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Application of Thin Spray-on Liners for Rock Surface Support in South African Mines – A Review

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Abstract - Statistical data on fatalities in the South African mining industry indicate that the conventional surface support methods, such as mesh and shotcrete, need to be replaced with an alternative method. This is in order to meet the safety target of zero harm. To realise this, the industry since 1996, has fronted Thin Spray-on Liner as the alternative surface support method. In this paper, Thin Spray-on Liners are defined and their support mechanisms and application in mines are reviewed. In addition, benefits accruing to the local industry from their use are also discussed. The paper concludes by identifying directions for future research required to advance their usage.

Keywords: Rock surface support, Thin spray-on liners, Shotcrete and mesh, Mining safety, Rockfalls

I. INTRODUCTION

The future of the South African (SA) mining industry is contingent on a safe working place, free from injuries. This is centred on the fact that the business aim of any mining operation is to provide the planned return on investment; within budget and safety (Stacey, 2009; 2001). However, statistics to date show that this has not been realised. Although there has been a reduction, of 24%, in the number of deaths over the years (Mining Safety in South Africa, 2010; Shabangu, 2010), the numbers are still greater than those in the competing mining industries of Australia, Canada and United States of America (USA) (Hermanus, 2007).

Potvin et al. (2004) state that rock surface support is used to provide adequate support for fragmented rocks. Therefore it has an impact on the provision of safety, both to the resources and workers in mines. The conventional methods used in S.A mines range from using no surface support to the installation of mesh, and shotcrete in poor ground conditions. However statistical rockfall sources, associated with these methods in some gold mines in Nevada, USA, over the years seem to suggest a steady increase in rockfall fatalities as shown in Figure 1 (Lacerda, 2004).

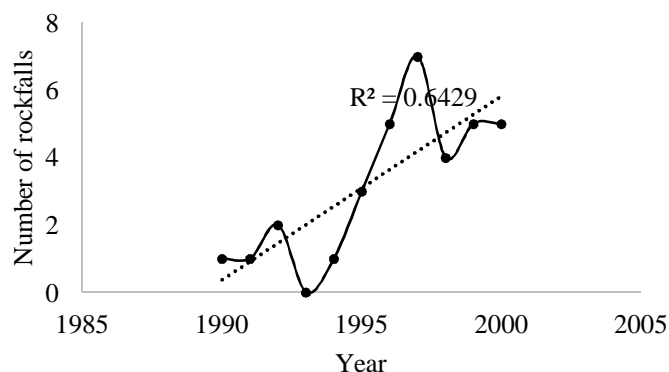


Fig. 1 Reported rockfalls related to mesh in Nevada gold mines (Lacerda, 2004)

Additionally, the conventional methods negatively impact the mining operations with regards to costs, logistics and mining cycle times due to large material volumes (Espley-Boudreau et al, 1999; Tannant, 2001; Ozturk & Tannant, 2010; Ferreira, 2012). Also, total elimination of rock related accidents in mines is not possible as human involvement in mining activity cannot be eliminated with current technology. Keeping in mind that the consequences of error in the industry are high, both in fatalities and costs involved (Marc, 2011), there is therefore a need to consider replacing traditional surface support methods with an alternative (Tannant, 2001).

Since 1996, the S.A mining industry has been fronting Thin Spray-on Liners (TSLs) as an alternative rock surface support method (Wojno & Kuijpers, 1997; Tannant, 2001; Yilmaz, 2011). Adams and Bakker (2002), although it may have been a coincidence, demonstrated that between 1998 and 2002 rockfall fatalities and injuries at active mine faces decreased with increased TSLs usage (Figure 2).

In addition, TSLs are employed using remote and rapid spraying techniques (Figure 3), which minimise interference with the mining cycle and reduce high costs due to lesser material volumes (Tannant, 2001; Lacerda, 2004; Yilmaz, 2011).

In this paper, based on previous studies, TSLs are defined and their support mechanisms and applications are reviewed in this paper. In addition, benefits accruing from their use in local mines are also discussed. The paper concludes by identifying directions for future research required to advance their usage.

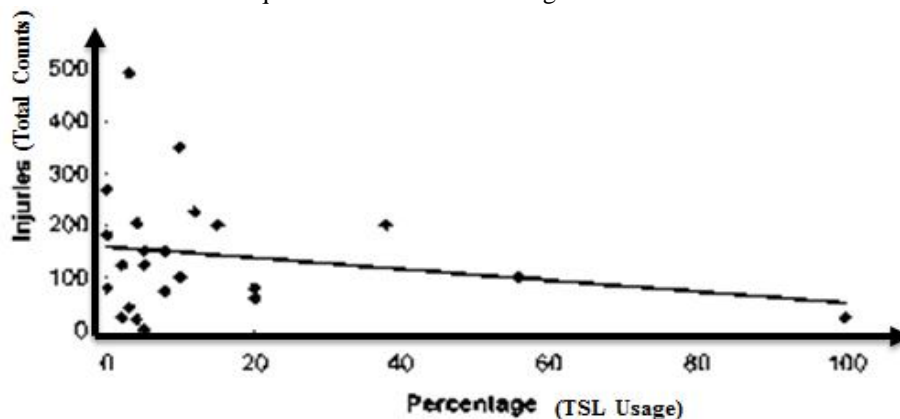


Fig. 2 Relation between injuries and TSLs % in South African Mines (1998 – 2002) (Adams & Bakker, 2002)



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



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

Fig. 3 Comparison between the application of TSLs and Shotcrete (Minova, RSA, 2012)

II. ROCK SURFACE SUPPORT

Underground rock excavations are commonly supported by two methods; rock mass support known as ‘retainment’ support and rock surface support referred to as ‘containment’ support (Stacey & Ortlepp, 1999; Stacey, 2001; Thompson, 2004). Retainment support consists of rock bolts, dowels, cables installed in boreholes. In contrast, containment support consists of wire mesh, shotcrete, wire mesh and shotcrete in combination and shotcrete reinforced with various types of fibres (Stacey, 2001). In severe conditions, such as highly weathered rocks, dynamic loading due to earthquakes and very high loads, wire rope lacing and various types of straps are additionally installed.

Rock surface support can be defined as the support placed onto the surface of a rock mass, classified into active and passive (Thompson, 2004).

Mesh and lacing provide passive support and protection from falling rocks as they dislodge from the roof (Nemcik, 2011). The rock mass is required to move or deform in some manner before the support system becomes active, therefore the rock mass integrity is not maintained. Shotcrete provides active support and protection where the integrity of the rock mass is maintained.

The principle of sprayed concrete started in the early 1900's (Lacerda, 2004) for civil engineering construction application (Spearing & Champa, 2000; Morton et al, 2008). It was adapted to tunneling applications in the mid 1950's and to mining applications in the early 1960's (Spearing & Champa, 2000; Lacerda, 2004; Morton et al., 2008). Shotcrete usage in mining applications has increased significantly in recent years due to significant technological advances associated with shotcrete materials and their placement (Morton et al, 2008). However, its application in mines has been associated with high costs and logistics, and interference with mining cycle times due to large material volumes (Tannant, 2001).

In recent years, new types of surface support, in the form of Thin Spray-on Liners have been developed with the intention of providing alternatives for the conventional forms of containment support (Stacey, 2001; Tannant, 2001; Yilmaz, 2011). They have the advantages of low volume, rapid application and rapid curing. These are all properties that ease logistics, improve on cycle times, increase mechanization and improve safety (Adams, 2001; Stacey, 2001; Tannant, 2001; Yilmaz, 2011).

III. THIN SPRAY-ON LINERS

A. Definition of TSLs

A TSL, also referred to as a sealant, coating or membrane, is defined as a thin chemical based coating or layer that is applied to mining excavations at a thickness of 3-5 mm (Saydam & Docrat, 2007; Lau et al., 2008). They are generally applied by mixing and spraying a combination of liquid/liquid or liquid/powder components onto the rock face as quickly as possible. The TSL sets quickly and develops an intimate and strong bond with the rock. The bond between the TSL and rock is an important property controlling the design and performance of TSL rock support systems (Tannant, 2001; Ozturk & Tannant, 2010; Ozturk, 2012). The most common applications of TSLs are (Potvin et al., 2004):

- Support between rock anchors,
- Supporting areas with limited access and/or logistic constraints,
- Mesh replacement,
- As primary support immediately after blasting,
- Temporary support (before shotcrete),
- Temporary support in TBM tunnels (poor ground conditions),
- Reduce rockburst damage,
- Pillar reinforcement,
- Face support,
- Large machine borehole lining and stabilisation,
- Stabilisation of return air tunnel,
- Ore pass lining,
- Prevention of rockfalls,
- Rigid ventilation seals,
- Ground degradation (weathering, fretting, swelling and slaking), and
- Ground alteration (moisture, heat, humidity and chemical contamination).

The advantages of TSLs over the conventional systems include; fast application rates, rapid curing times ranging from seconds to hours, reduced material handling compared to mesh and shotcrete, high tensile strength with high areal coverage, high adhesion which enables early reduction against ground movement and ability to penetrate into joints (Finn, 2001; Tannant, 2001; Pappas, Barton & Eric, 2003; Kuijpers et al., 2004; Lacerda, 2004). TSLs are also more flexible with thickness of 3-5mm compared to shotcrete of typical thickness of 25-100mm (Tannant, 2001; Yilmaz, 2011). Improved cycle times, increased mechanization, reduced labour intensity and improved safety accrue from these advantages (Stacey & Yu, 2004). Notwithstanding the essential structural, operational and cost-effective benefits obtainable by usage of TSLs, there is still concern over environmental, occupational health and safety risks associated with the use of some TSL materials containing diphenylmethane diisocyanate (Ferreira, 2012). 5 to 20% of unprotected workers can become sensitized and may develop life-threatening asthmatic signs ensuing from recurrent exposures either by inhalation or skin contact (Pappas, Barton & Eric, 2003; Archibald & Dirige, 2005). However, Potvin et al. (2004) argue that if appropriate measures are taken, it is possible for TSLs to be applied in mines without adverse effects on humans.

B. History and Background of TSLs

According to Lacerda (2004), TSLs have been around since the invention of gunite in 1907. The first versions of TSL products were tested and did not possess adequate physical or chemical properties and did not meet the occupational health and safety requirements of the mining industry (Yilmaz et al, 2003). Therefore, their application in civil engineering and mining applications was delayed till the early 1990's with the development of non-hazardous products (Tannant, 2001; Archibald & Dirige, 2005; Yilmaz, 2011). On the contrary, Gunite application continued and eventually evolved into dry-mix and wet-mix shotcrete, in 1950, for use in underground mine and tunneling construction projects (Spearing & Champa, 2000; Lacerda, 2004).

Initial TSLs were mainly designed as rock sealants to limit the weathering of rocks (Spearing & Champa, 2000; Spearing et al, 2009), sealing of dams and other civil engineering applications (Borejszo & Bartlett, 2002; Kuijpers et al, 2004). The composition of these early sealants varied from gypsum based plasters through polymer modified cement mortars to latex and similar coatings (Steyn et al, 2008). Widespread application of thin skin liners (sealants) and chain link mesh prior to shotcrete application is reported in South Africa, specifically on diamond mines, in an attempt to preserve the integrity of Kimberlite (Bartlett, 2002; Steyn et al, 2008). Later on, the aim shifted to use as an alternative to mesh and shotcrete (Yilmaz, 2011).

Research into the application of TSLs in the mining industry was pioneered by Urylon Plastics Inc. from Canada and CSIR Miningtek from South Africa around 1990 (Spearing & Champa, 2000). In 1992, INCO Limited, the largest Nickel mining company in Canada, began research into the application of a TSL product called Mineguard in its mines (Espley et al, 1995, 1996; Espley-Boudreau, 1999; Tannant, 1997; Tannant et al, 1999; Tannant, 2001; Archibald & Dirige, 2005). Tannant (2001) points out that, in the late 1990's the research in Canada included a new product based on hybrid polyurethane/polyurea mixture called Rockguard. Meanwhile, in 1996, research into the application of TSLs in SA mines involved a latex-based thin liner product called Everbond currently used as a waterproofing membrane in the construction industry because it did not meet the mining industry requirements (Wojno & Kuijpers, 1997). Everbond evolved into another product called Evermine, an acrylic-based polymer membrane which was used as a TSL in the mining industry (Tannant, 2001; Leach, 2002; Yilmaz, 2011).

To meet the ever increasing demand, and occupational health and safety requirements of the mining industry, other new TSL materials have been developed since the 1990's. There are currently about 55 mines around the world considering the use of TSLs for rock support due to the numerous advantages of TSLs as stated above (Tannant, 2001; Belfield, 2006). The greatest interest is in Canada, Australia and South Africa (Belfield, 2006). Given that the technology is still in its early stages, other products are expected to arise for testing and evaluation (Tannant, 2001; Leach, 2002; Saydam et al, 2003). A list of TSLs either existing commercially or under research and development is provided in Table I reproduced after Yilmaz (2011).

TABLE I
TSL PRODUCTS COMMERCIALY AVAILABLE OR UNDER DEVELOPMENT AFTER YILMAZ (2011)

Manufacturer	Product-Trade Name	Mix Base-Chemistry
3M	3M Liner	Polyurethane
Ardex	Ardumin TMO 20	Hyd, cements, admixtures and graded fillers
BASF	Mayco Super lining; BASF white TSL	Cementitious Polymer
Carbontech	A-Seal; V-Seal	Cement Polymer; Sand-polypropylene fibre
Cementation Lining Products (CLP)	Superseal	Cementitious Polymer
CHC	CHC TSL	Acrylate Polymer
Chryso	Chryso TSL	Cementitious Polymer
CONCOR	021H; Concor Standard TSL	Cementitious Polymer
Engineered Coatings Ltd	Rockguard	Polyurethane/polyurea hybrid
Fosroc	Polyshield SS-100	Plural component polyurea elastomer
Fosroc Inc.	Tekflex	Cementitious Polymer
Geo-Mining	Geo-Mining TSL	Cementitious
Guyric Pipe Company	GPC TSL	Polyurethane
Hydroflex Pty Ltd	Diamondguard	Polyurethane
Kohlbergerer Enterprises Pty Ltd	Polyurethane TSL	Polyurethane
Master Builders Inc. (MBT)(Degussa)	MaterSeal 840R01A; 850C	Methacrylate resin and filler mixture
Master Builders Inc. (MBT)(Degussa)	Masterseal CS1251; 845A; CE1286; CT1266	Acrylate polymer
Minova	Capcem KT (grey, white); Raplok; Tekflex white	Cementitious Polymer
Mondi Mining Supplies	Rock Hold	Methacrylate mixed with water
Nico Du Rand Consultants (NDRC)	Super lining	Cementitious Polymer

NS Consultancy	Ultraskin	Polyurethane
Precrete	Rockliner A; F2; T1; 916; D50	Cementitious Polymer
Pumachem CC	Conseal	Cementitious Polymer
SA Mining and Engineering Supplies, Reynolds Soil Technologies	Tunnelguard (grey, yellow, white); TGNC; TGNT; TGC	Cement-polymer-sand-polypropylene fibre
Specialty Products Int. Pty. Ltd.	Polyurea TSL	Polyurea
SPI	SPI TSL	Polyurea
Spray-On Plastics	RockWeb	Polyurethane/polyurea hybrid
Stratabond SA Pty Ltd	Everbond; Evermine	Water-based polymer; cementitious filler
TAL	TAL TSL	Cementitious
Urylon Plastic Canada	Mineguard	Polyurethane

C. Composition, Properties and Types of TSLs

There are many different types of TSL products in the market. They differ by polymer base and mixture types based on their chemical compositions. The first versions of TSLs were of single component, 'glue emulsion' type, and were not suitable due to health and safety requirements.

Later on, 2 and 3, component TSL systems were developed (Yilmaz et al, 2003). Today, utilization of 2-component reactive TSLs are increasing due to ease of application, longer shelf lives and fast curing times.

Common TSLs are reactive or non-reactive (Yilmaz, 2011); (1) polymer based (Leach, 2002; Yilmaz, 2011), (2) water-based Portland cement latex products (Leach, 2002; Yilmaz, 2011; Ozturk, 2012) and (3) two part polyurethane/polyurea (Leach, 2002; Ozturk, 2012). Polymer based liners are two-component liquid chemical systems consisting of a polyisocyanate and resin mixture (Yilmaz, 2011). According to Potvin et al (2004) and Northcroft (2006), they can be divided into six distinct groups: acrylics, liquid latex, polyurethanes, polyureas, methacrylates, and hybrids (polyuria/polyurethane, cement/acrylic and cement/polyurethane).

Reactive TSLs are associated with a short curing time of less than ten minutes of application and gain most of its tensile strength within one hour of application (Tannant, 2001; Lacerda, 2004). They are made from isocyanates (polyurethanes, polyureas) and acrylates. Though non-reactive TSLs have a longer curing time (30 to 60 minutes) and build bond/tensile strength at a slower rate (Lacerda, 2004), they are deemed suitable to meet desirable cycle time conditions for most underground construction applications (Tannant, 2001; Lacerda, 2004).

Technical categorization of TSLs was done by Yilmaz (2011, 2013) in Figures 4, 5, 6 and 7, and Steyn et al (2008) in Table II. The purpose of the technical categorization was to assist the manufacturers and end users to easily establish the strength category of their TSL product (Yilmaz, 2013; Steyn et al, 2008), in conjunction with the geotechnical requirements for the specific loading conditions (Steyn et al, 2008).

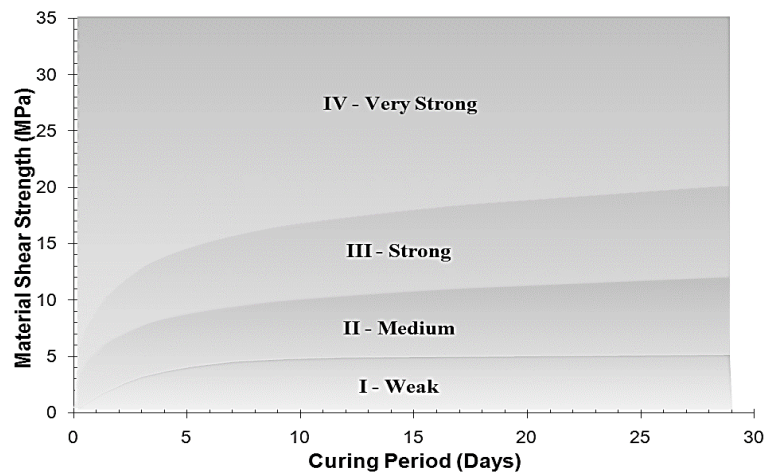


Fig. 4 Material shear strength categories (Yilmaz, 2011)

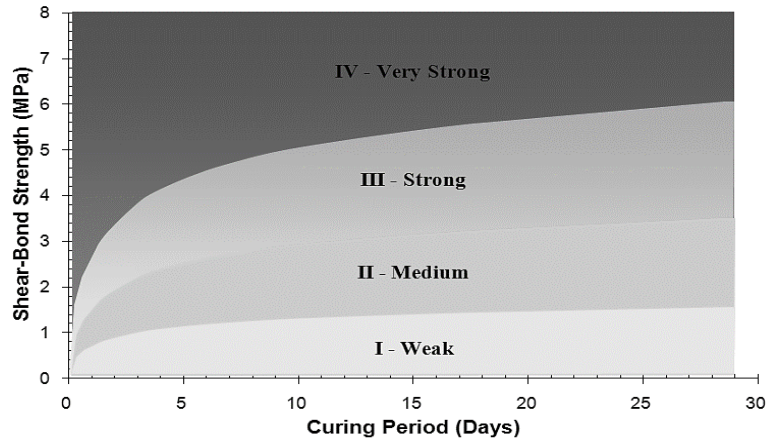


Fig. 5 Shear-bond strength categories (Yilmaz, 2011)

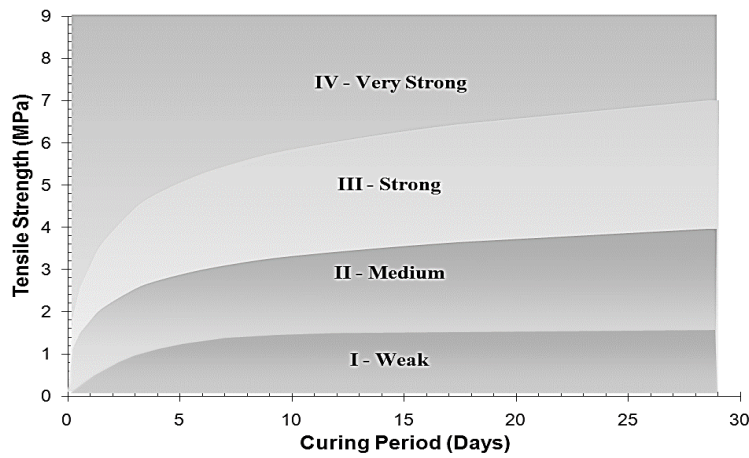


Fig. 6 Tensile strength categories (Yilmaz, 2011)

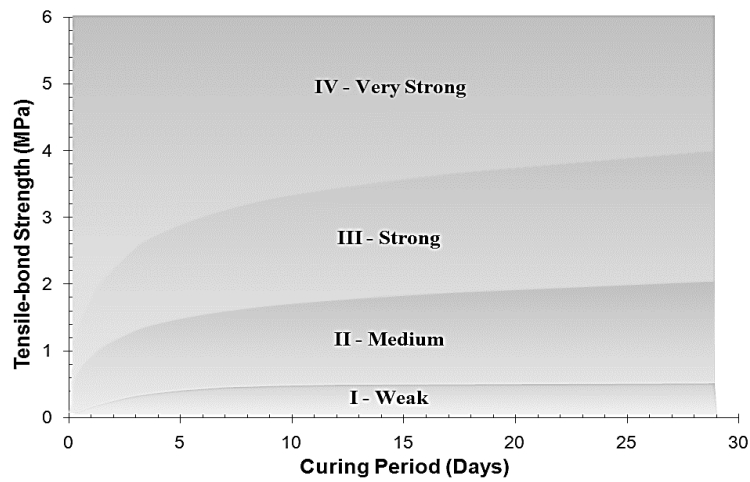


Fig. 7 Tensile-bond strength characteristics (Yilmaz, 2011, 2013)

TABLE II
TSL STRENGTH CATEGORIES (STEYN ET AL., 2008)

Uni-axial Compressive Strength (UCS)		
10 MPa	20 MPa	> 30 MPa
Weak TSL	Average TSL	Strong TSL
Tensile Strength		
1 MPa	3 MPa	5 MPa

Weak TSL	Average TSL	Strong TSL
Material Shear Strength		
5 MPa	10 MPa	15 MPa
Weak TSL	Average TSL	Strong TSL
Tensile Adhesive Strength		
1 MPa	2 MPa	4 MPa
Weak TSL	Average TSL	Strong TSL
Shear Bond Strength		
1 MPa	3 MPa	5 MPa
Weak TSL	Average TSL	Strong TSL

IV. SUPPORT MECHANISM OF TSLs

The ability of a sprayed TSL to firmly adhere to the rock surface generates a continuous membrane (Ozturk & Tannant, 2010). The continuous membrane builds-up an effective support in terms of increased areal coverage (Kuijpers et al., 2004; Ozturk & Tannant, 2010). Where open joints or fractures exist, the sprayed TSL penetrates into the loose rock.

In this situation, the TSL support depends on the depth of penetration of the joint or fracture and the shear-bond strength of the TSL (Tannant, 2001; Stacey, 2001; Mason & Stacey, 2008). Therefore, the potential of a TSL to resist displacements and fractures, to a greater extent, depends on a combination of shear-bond, tensile-bond and adhesive-bond between the liner and the rock as shown in Figure 8 (Kuijpers et al, 2004; Tannant, 2001; Ozturk & Tannant, 2010). Furthermore, since TSLs are airtight, they are able to prevent the entry of air into the joint restricting the dilation of the rock mass along the joints and fractures (Stacey, 2001). Henceforth, a significantly effective support mechanism in dynamic loading situations.

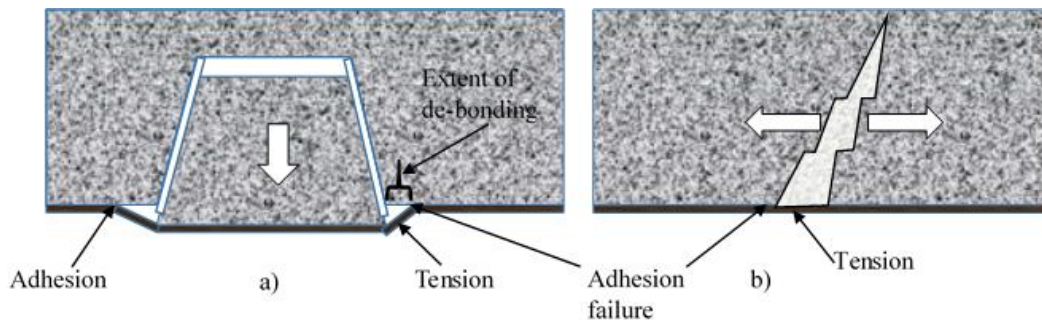


Fig. 8 Liner failure modes at small block displacements caused by either shear rupture (right) or diagonal tensile rupture (left) (Kuijpers et al, 2004)

Ozturk & Tannant (2011) identified environmental and rock conditions that may affect the adhesion of spray-on liners as; surface roughness, surface moisture, rock strength, weathering and contaminated surfaces. They concluded that contaminants reduce while large grain sizes increase the adhesive bond between a TSL and the rock substrate. However, roughness did not have an effect on the bond strength. Though the TSL structural capability is negligible, its performance is continuously reported as being better than expected (Spearing & Champa, 2000; Stacey & Yu, 2004; Yilmaz, 2011). The ability of liners to adhere to the rock helps prevent the raveling or loosening of discrete rock fragments (Ozturk & Tannant, 2010). The intimate contact between the liner and rocks surface reduces the magnitude of the stress and strain energy due to distortion, displacement and rotation in the rock at the interface (Tannant, 2001). This is important since it is difficult for a support system to hold up the dead weight of the rock once the rock mass has loosened (Hoek & Brown, 1980), particularly with liners associated with limited load capacity (Tannant, 2001).

Figure 9 shows load transfer mechanisms in a typical support system (Kuijpers et al, 2004). The interaction between the different components (rock mass, tendons and fabric) in a support system creates three load transfer paths; 1) directly through the rock mass, 2) into the tendons and 3) via the fabric into the tendons. Any grouping of these three resistances is possible. However, if the excavation wall is competent, non-fragmented skin, no forces are transmitted through the fabric and component 3 has zero values. Also, if the fragmented skin is completely detached from the “base rock”, component one will have zero values. In practice, support design is based on these two situations (Kuijpers et al, 2004).Kuijpers et al (2004) state that the load transmitted internally within the skin is controlled by its strength which can be enhanced by the surface support. The strength of the skin is negatively affected by deformations which is itself controlled by the fragment size, shape, orientation and distribution. Any load in excess of the skin strength is transmitted through the surface support. Therefore, the stronger the rock mass skin, the smaller the requirements for surface support (Tannant, 2001).

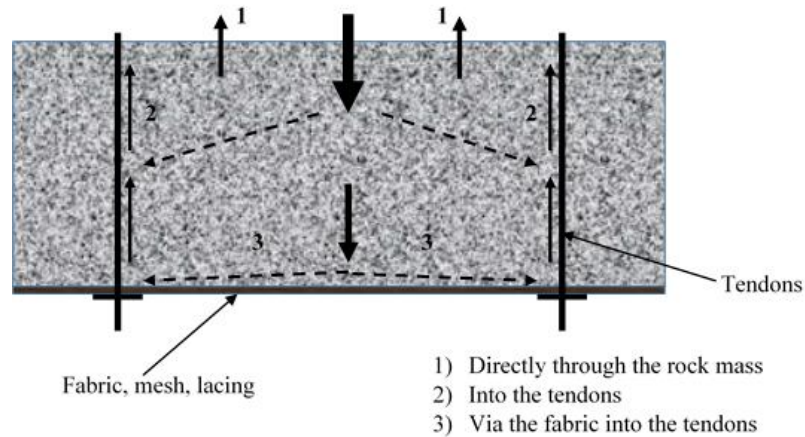


Fig. 9 Load transfer in a typical support system (Kuijpers et al, 2004)

The energy, due to relatively large rock mass deformations between the support units, is absorbed locally by the fabric support and within the unravelling rock mass. A stiff fabric support attracts large forces and small deformations but can easily be damaged, Figure 10 (Kuijpers et al, 2004).

However, it is able to prevent mass unravelling as long as it does not fail (Tannant, 2001). On the other hand, a soft fabric will be subject to large deformations and smaller forces, Figure 10 (Kuijpers et al, 2004). They have a smaller capacity to prevent rock mass from raveling, but are associated with a relatively large elastic energy absorption capacity (Tannant, 2001). Therefore, a decision on the prevailing rock mass conditions and potential energy impulses to be absorbed in the various components of the support system is paramount in the design process (Kuijpers et al, 2004).

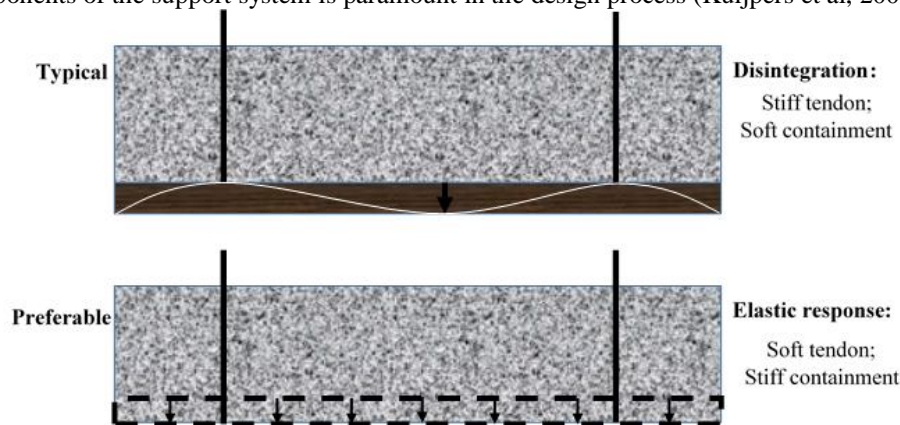


Fig. 10 Energy absorption through bulging (top) and into tendons (bottom) (Kuijpers et al, 2004)

The liner can 'lock' rock blocks together, keeping relative block displacements small (< 11 mm), thus functioning to stabilize the rock mass around excavations and prevent small rockfalls from happening (Tannant, 2001; Kuijpers et al, 2004). But when rock mass conditions, stress levels and excavation geometry combine to generate larger rock deformations or convergence, a thin liner may not be able to suppress relative displacements and a zone of unstable rock will develop. Under these conditions, the liner's function switches to retaining the loose rock in place between the rock bolts (Tannant, 2001; Lacerda, 2004; Kuijpers et al, 2004). Therefore, the support function required by a thin liner depends on the amount of the rock involved and magnitude of relative displacements between adjacent rock blocks (Tannant, 2001; Kuijpers et al, 2004). However, it is important to note that the overall objective is to have tight sound rock present before the liner is sprayed (Tannant, 2001; Lacerda, 2004). Otherwise, a sufficient portion of the rock mass self-supporting capability will already be compromised before the liner is applied.

V. APPLICATION OF TSLs IN MINES

The application of TSL technology in the mining industry is still in its infancy (Tannant, 2001; Yilmaz, 2011). Consequently, the design of TSLs as surface support systems is currently based on experience, assumptions, field observations and cost considerations (Tannant, 2001; Saydam, Yilmaz and Stacey, 2003; Yilmaz, 2011). This is due to the fact that the mechanisms by which TSLs act to provide support are not fully understood (Tannant, 2001; Leach, 2002; Saydam, Yilmaz and Stacey, 2003). However, since the first trials were initiated in Canada in the late 1980's (Archibald et al, 1992), some progress has been attained.

In Canada, from field observations, Espley et al (1999) developed some tentative application guidelines, Table III, for TSL application as a ground support and reinforcement tool. Additionally, in South Africa, Kuijpers et al (2004), formulated standard testing methodologies and developed testing equipment in order to quantify relevant TSL parameters on the basis of underground and laboratory work in conjunction with numerical modelling results. In July 2008, EFNARC, through its technical committee on TSLs formed in 2004, produced Specification and Guidelines dealing with TSLs used in the mining and tunneling industries for non-structural rock support and for sealing rock against gas and moisture transfer and weathering. However, it is worth noting that, to date, there is no universal agreed on documentation on the testing, design and application of TSLs as structural rock support systems in mines.

Despite all the limitations, TSL application in S.A mines is making a steady progress. Steyn et al. (2008) and Ferreira (2012) reported that TSL materials from Minova RSA, a S.A TSL manufacturing company, were being extensively used in the local Platinum and Chrome mines with relatively limited application in other hard rock and diamond mines. This is due to the fact that Diamond and Gold mines are too deep, and therefore, associated with high risks and consequences of seismic activity (Hermanus, 2007; Webber-Youngman & Van Wyk, 2009). Nordlund (2013) notes that mining at depth is associated with high stress magnitudes and often serious ground control problems in many cases exceeding the strength of the intact rock, geological structures and the rock mass. Design at these depths cannot be based on trial and error technology (Marc, 2011), yet TSL technology is still limited in depth of knowledge. On the contrary, Stacey (2005) reported that S.A local gold mines of Gold Fields and AngloGold Ashanti were using TSLs. The effective application in all the different cases stems from numerous TSL advantages.

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

VI. BENEFITS FROM USE OF TSLs IN S.A MINES

Research has proved that TSLs have the potential to benefit the SA mining industry by offering improved productivity, profitability and safety (Tannant, 2001; Steyn et al., 2008; Yilmaz, 2011; Ferreira, 2012). Though spray-on liners tend to have high material costs, they result in significantly increased productivity and reduced material handling efforts (Tannant, 2001; Lacerda, 2004).

An example of a generic temporary shaft sinking support option of mesh and bolts versus TSL, in Table IV reproduced after Lacerda (2004), shows that the apparent cost of TSL option is 50% more than conventional bolt and mesh support. However, the TSL option becomes more attractive if the additional two hours per shift for the TSL option can be utilized to increase the advance rate (Lacerda, 2004). Additionally, Table V reproduced after Ferreira (2012), shows product comparisons (cost, application and time) between shotcrete and different liners in SA platinum mines. It reveals that the economic benefits from using TSLs are realized by the higher productivity accruing from reduction of the time needed for support installation.

TABLE IV - TEMPORARY SHAFT SUPPORT EXAMPLE (LACERDA, 2004)

	Mesh and Bolts	Thin Support Liner
Description	6-gauge, 3" x 3" Welded wire mesh 39mm x 4' friction bolts on 5' x 5' pattern	Non-reactive TSL 4mm thickness
Temporary support cost per advance:		
Man-hours to complete task	10.5	4.5
Direct supplies x labour cost	1,203 \$	1,826 \$
Apparent GS cost to complete shaft	197,347 \$	299,403 \$
Cost difference		102,056 \$
Cycle time savings		2 hours
Project hours saved		328
Estimated project savings	n/a	196,800 \$
Actual cost	197,347 \$	102,603 \$
Net Difference		94,744 \$

TABLE V - PRODUCT COMPARISONS (COST, APPLICATION AND TIME) (FERREIRA, 2012)

Description	Shotcrete (± 25mm)	KT 2C (± 5mm) 3m ²	KT White (± 5mm) 3m ²	KT Grey (± 5mm) 3m ²	KT Fast (± 5mm) 3m ²
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 m ² 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.					

Additionally, Figure 11 from the SA Mining and Engineering Supplies (SAM & ES) website indicates the total cost, including shaft time, tramming time and material cost, to apply 300 m² of Tunnel Guard versus the application of shotcrete. Tunnel Guard is a TSL product from SAM & ES Company. Figure 11 confirms that the cost of application of shotcrete is higher than that of Tunnel Guard. According to the SAM & ES website, a further benefit and cost saving of Tunnel Guard is the rebound factor ranging from 2% to between 10 and 15% for shotcrete.

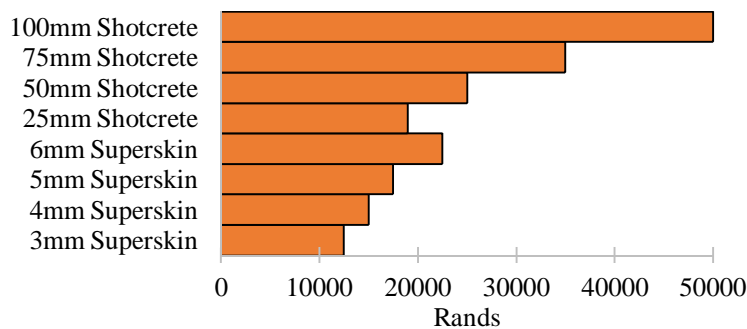


Fig. 11 Additional costs to apply 300m² of Tunnel Guard versus the application of Shotcrete at different thicknesses (http://www.samining.com/prod_tg_tg.htm)

TSLs are also associated with rapid curing times compared to shotcrete as shown in Table VI reproduced after Lacerda (2004). The rapid curing times enable early reaction against ground movement (Tannant, 2001; Lacerda, 2004). Mining and rock engineers have appreciated the requirement to support the rock as soon as possible after blasting most importantly in highly weathered and weak rocks (Lacerda, 2004). It is essential that rock surface support be installed timeously after the excavating process (Tannant, 2001; Lacerda, 2004; Ferreira, 2012), to ensure any movement that takes place in the rock mass is arrested while generating load on the support elements (Tannant, 2001).

TABLE VI - 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	

Furthermore, TSLs are more flexible and elastic, Figure 12 (Tannant, 2001), compared to shotcrete. Investigations by Tannant & Kaiser (1997) and Kaiser and Tannant (1997) showed that shotcrete panels attained peak strength and fractured after relative displacements of 5 to 10 mm. In contrast, concrete blocks coated by a polyurethane membrane tested in the same conditions did not attain peak load until 40 to 50mm of displacement and the load was maintained for up to 100 mm of displacement. These demonstrates the potential of TSLs to minimise violent eruptions in SA mines. Archibald and Dirige (2005) also report that TSLs provide more effective cover to rocks against weathering than shotcrete. In hard and soft rock mining, changes in humidity and temperature affect weak strata causing rockfalls and rib degradation (Ferreira, 2012). Effective surface support and protection against weathering of rock and strata are critical to the safety, efficiency and longevity of any mining operation (Tannant, 2001; Ferreira, 2012).

Finally, SA statistics between 1998 and 2002 suggest that fatalities and injuries at mine faces have a positive direct relationship to TSL usage, Figure 2 after Adams and Bakker (2002). TSLs are capable of reducing the number of fatalities in the SA mining industry leading to an improvement in its lost-time-injury frequency rate hence increased profit margins.

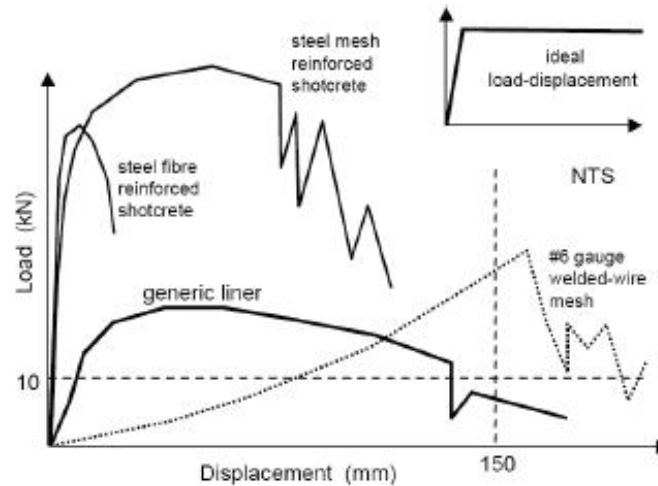


Fig. 12 Schematic load displacement curves of areal supports (Tannant, 2001)

VII. WAY FORWARD

A good grasp on material properties propels the successful integration of new support tools (Kuijpers et al., 2004). A new technology should have a relative advantage, compatible with existing technology, not too complex, tri-able and observable (Rogers, 2003). Preceding investigations have revealed that TSLs fulfil all these requirements. Rogers (2003), in addition, also analysed five stages of innovation process; 1) Knowledge, 2) Persuasion, 3) Decision, 4) Implementation and 5) Confirmation. A body of knowledge is used to persuade the end users to make a decision to implement and then confirm the new technology. Design methodologies for TSLs and evaluation of the insitu support performance requires a reliable databases (Nagel & Joughin, 2002; Hadjigeorgiou & Grenon, 2002; Leach, 2002; Yilmaz, 2011). Therefore, future research should be focused towards the formulation of design standards and requirements to buildup confidence among the hesitant end users to induce more effective and frequent use of TSLs. Large scale tests will be required to predict the potential behaviour of TSLs underground, and insitu trials as the final confirmation of the product performance.

VIII. CONCLUSION

Research into the TSL technology as a surface support system in mines since 1990's has evidenced that TSLs have the potential to benefit the SA mining industry. They have proven economic benefits such as reduced costs, logistics and shorter cycle times but its wide application is still on trial basis. In effect, majority of the end users, the mine operators, are still hesitant to effectively apply TSLs. Marc (2011) asserts that mine operators in South Africa are increasingly becoming leaner and more focused on their core business aim of maximizing profits. This includes the way in which they deploy technology since, with the significant speed and cost requirements of developing a mine, there is no longer any room for error. Therefore, deeper research focused on the field practical application of TSLs within SA mines is the way forward. This will encourage the mine operators and other users of TSLs to apply them based on their superior benefits.

REFERENCES

- [1] Adams, D. and Bakker, D. An Assessment of the Use of Shotcrete and Thin Sprayed Linings in South African Mines from a Safety Point of View. *Proceedings of 2nd International Seminar on Surface Support Liners*, Johannesburg, South Africa, 2002.
- [2] Applegate, J.D. Review of current tunnel support practice in deep level South African gold mines. Design of Rock Reinforcing: Components and Systems. Johannesburg: ISRM South African National Group. 1, 1987.
- [3] Archibald, J.F, Mercer, R.A. and Lausch, P. The evaluation of thin polyurethane surface coatings as an effective means of ground control. *Proceedings of International Symposium on Rock Support in Mining and Underground Construction*, Balkema, Rotterdam, 105-115, 1992
- [4] Archibald, J., F. & Dirige, P., A. Spray-on lining innovation for support in burst-prone mine environments and tunnel coatings in civil engineering use. *Proceedings of 40th U. S. Rock Mechanics Symposium*. Fairbanks, Alaska, 2005.
- [5] Bartlett, P. Shotcrete at premier mine. *2nd Int. Seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, Mesh*. SAIMM, Sandton, RSA, Sect.9, 2002.
- [6] Belfield, S. Spray-on liners need goal posts. *Australia Mining Report*. 98(10):40, 2006.
- [7] Borejszo, R. & Bartlett, P. Tunnel guard in the mining industry. *Proceedings of 2nd Int. Seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, Mesh*. Sandton, RSA: SAIMM, 2002.
- [8] EFNARC. (2008) Specification and Guidelines on Thin Spray-on Liners for Mining and Tunnelling. http://www.efnarc.org/pdf/ENC%20250TSL%20v7.2%2025-07-08_r1.pdf. [Accessed on 15th May 2014].

- [9] Erasmus J. Assessment of the Applicability of Legislation, Pertaining to the Prevention of Rock Related Accidents Occurring at South African Metalliferous Mines. M.Sc. Research Report. University of the Witwatersrand. Johannesburg, 2000.
- [10] Espley-boudreau, S.J. Thin Spray-On Liner Support & Implementation in the Hard rock Mining Industry. Master of Applied Science, Laurentian University, Sudbury, Ontario, 1999.
- [11] Espley, S.J., Langille, C., McCreath, D.R. Innovative liner support trials in underground hard rock mines at INCO Limited. Canadian Institute of Mining and Metallurgy Bulletin 88(992), 66-74, 1995.
- [12] Espley, S.J., O'Donnell, J.D.P. Thibodeau, D., Paradis-Sokoloski, P. Investigation into the replacement of conventional support with spray-on liners. Canadian Institute of Mining and Metallurgy Bulletin, 89(1001), 135-143, 1996.
- [13] Espley, S.J., Tannant, D.D., Baiden, G., Kaiser, P.K. Design criteria for thin spray-on membrane support for underground hard rock mining. *Proceedings of Canadian Institute of Mining and Metallurgy Annual General Meeting, Calgary*, published on CD-ROM, 7 p, 1999.
- [14] Ferreira, P. A Perspective on Underground Support Technologies in Southern African Platinum Mines to Reduce Safety Risks and Enhance Productivity. *Proceedings of the Southern African Institute of Mining and Metallurgy Platinum Conference*, 2012.
- [15] Finn, D. Polymer Membrane Tests. *Proceedings of the International Conference on Surface Support Liners: Membranes, Shotcrete and Mesh*. Australia: Australian Centre for Geomechanics, 2001.
- [16] Fowkes, N., Freitas, J.A., Teixeira, A. & Stacey, R. *Crack repair using an elastic filler*. Journal of the Mechanics and Physics of Solids. 56(9):2749-2758, 2008.
- [17] Hadjigeorgiou, J. & Grenon, M. Towards a rational design methodology for thin sprayed on liners. *2nd Int. seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, Mesh*. Crowne Plaza Sandton, RSA, 2002.
- [18] Hermanus, M.A. *Occupational health and safety in mining - status, new developments, and concerns*. The Journal of the Southern African Institute of Mining and Metallurgy. 107: 531-538, 2007.
- [19] Hoek, E. & Brown, E.T. *Underground Excavations in Rock*. Institute on Mining and Metallurgy, London, England, 1980.
- [20] Kaiser, P.K. & Tannant, D.D. Use of shotcrete to control rock mass failure. *Proceedings of Symposium on Rock Support*, Lillehammer, 580-595, 1997.
- [21] Klokov, J. Evaluation of current recommended stope support design methodology as applied to deep level mining. *Proceedings of Successful Support Systems for Safe and Efficient Mining Conference*. SAIMM, 1999.
- [22] Kuijpers, J.S., Sellers, E.J., Toper, A.Z. & Rangasamy, T. Required technical specifications and standard testing methodology for Thin Sprayed Linings. (2004-0404). RSA: SIMRAC, 2004.
- [23] Lacerda, L. Shotcrete and Other Surface Support Liners. *Proceedings of SME Annual Meeting Feb. 23-25*, Denver, Colorado, 2004.
- [24] Lacerda, L., Rispin, M. Current ground support membrane applications in North American underground mines. *2nd Int. seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, Mesh*. Crowne Plaza Sandton, RSA, 2002.
- [25] Lau, V., Saydam, S., Cai, Y., Mitra, R. Laboratory Investigation of Support Mechanism for Thin Spray-on Liners. *Proceedings of the 12th International Conference of International Association for Computer Methods and Advances in Geomechanics*. Goa, India: IACMAG, 2008.
- [26] Leach, A.R. Comparison of support requirement performance characteristics of sprayed cementitious coatings. *Proceedings of the 2nd Int. seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, Mesh*. Crowne Plaza Sandton, RSA: 1, 2002.
- [27] Marc, G. (2011) Technology increasing efficiency in mines. Creamer Media's Mining Weekly. <http://www.miningweekly.com/article/technology-increasing-efficiency-in-mines-2011-07-08>. [Accessed on 4th May 2014].
- [28] Mason, D.P. & Stacey, T.R. *Support to rock excavations provided by sprayed liners*. International Journal of Rock Mechanics and Mining Sciences. 45(5):773-788, 2008.
- [29] Mining Safety in South Africa. (2010) <http://www.miningsafety.co.za/dynamiccontent/61/Mining-Safety-in-South-Africa>. [Accessed on 24th May 2014].
- [30] Morton, E. Thompson, A. & Villaescusa, E. Static Testing of Shotcrete and Membranes for Mining Applications. *In Proceedings of the 6th International Conference on Ground Support*, Cape Town, pp. 195-212, 2008.
- [31] Nagel, M. & Joughin, W.C. Thin sprayed liner trials at South Deep Mine. *2nd Int. seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, Mesh*. Crowne Plaza Sandton, RSA, 2002.
- [32] Nemcik, J.A. Porter, I. Baafi, E.Y. & Navin, J. 2011. Determining the ultimate strength of 'tough skin', a glass fibre reinforced polymer liner. 11th Underground Coal Operators' Conference, pp. 154 – 158. University of Wollongong & the Australian Institute of Mining and Metallurgy. <http://ro.uow.edu.au/engpapers/4286>. [Accessed on 4th June 2014].

- [33] Ozturk, H. *Fracture mechanics interpretation of thin spray-on liner adhesion tests*. International Journal of Adhesion and Adhesives. 34(0):17-23, 2012.
- [34] Ozturk, H. & Tannant, D.D. *Thin spray-on liner adhesive strength test method and effect of liner thickness on adhesion*. International Journal of Rock Mechanics and Mining Sciences. 47(5):808-815, 2010.
- [35] Pappas, D.M., Barton, T.M. & Eric, S.W. The Long-Term Performance of Surface Support Liners for Ground Control in a Underground Limestone Mine. *Proceedings of 3rd International Seminar on Surface Support Liners: Thin Spray-On Liners, Shotcrete and Mesh*. Quebec City, Canada, 2003.
- [36] Potvin, Y., Nedin, P., Sandy, M., Rosengren, K., Rosengren, M. Towards the Elimination of Rockfall Fatalities in Australian Mines. Australian Centre for Geomechanics, Perth, Australia. MERIWA Project No. M341, Technical Representative, 2001.
- [37] Potvin, Y. Towards a common understanding of TSL applications in mines. *Proceedings of 2nd International Seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, Mesh*. Sandton, RSA: SAIMM. 1, 2002.
- [38] Potvin, Y., Nedin, P. Rockfalls and Surface Support in Australian Underground Hard Rock Mines. *Proceedings of the 3rd Int. Seminar on Surface Support Liners: Thin Spray-On Liners, Shotcrete and Mesh*, Quebec City, Canada. Sect.1, 2003.
- [39] Potvin, Y., Stacey, T.R., Hadjigeorgiou, J. & Yilmaz, H. Thin spray-on liners (TSLs) – a quick reference guide, Part 1 in Surface Support in Mining. Potvin, Stacey and Hadjigeorgiou, Ed. Perth, Australia: Australian Centre for Geomechanics. 3, 2004.
- [40] Pritchard, C., Swan, G., Henderson, A., Tannant, D., Degville, D. TekFlexasa spray-on screen replacement in an underground hard rock mine. *Canadian Institute of Mining and Metallurgy- Annual General Meeting*, Calgary, published on CD-ROM, 6 p, 1999.
- [41] Pritchard, C., Swan, G., Hill, R., Amick, M. TekFlexasa spray-on screen replacement in an underground hard rock mine. Mining Engineering, SME in press, 4p, 2001.
- [42] Rispin, M., Garshol, K. Reactive vs. Non-Reactive TSLs: A Comparison Illustrated with Two Prototype Technologies. *Proceedings of 3rd International Seminar on Surface Support Liners*, Quebec City, Canada, 2003.
- [43] Rogers, E. The Diffusion of Innovations. 5th edition New York: The Free Press, 2003.
- [44] South African Mining and Engineering Supplies website. http://www.samining.com/prod_tg_tg.htm. . [Accessed on 4th May 2014]
- [45] Saydam, S. & Docrat, Y.S. Evaluating the Adhesion Strength of Different Sealants on Kimberlite. *In 11th ISRM Congress*. International Society for Rock Mechanics, 2007.
- [46] Saydam, S., Yilmaz, H. and Stacey, T.R. A new testing approach for thin spray-on liners: double-sided shear strength (DSS) test. *International Workshop and Seminar Surface Support Liners: Thin Spray-On Liners, Shotcrete and Mesh*. Quebec City, Canada, 2003.
- [47] Shabangu, S. (2010) Mining Health and Safety in South Africa. http://www.tabj.co.za/southern_africa/mining_health_and_safety_in_south_africa.html. [Accessed on 24th May 2014].
- [48] Spearing, A.J., Borejszo, G. & Campoli, A. The application of a structural thin support liner (TSL) on mines. *Proceedings of 43rd U.S. Rock Mechanics Symposium and 4th U.S.-Canada Rock Mechanics Symposium.*, 2009.
- [49] Spearing, A.J. & Champa, J. The design, testing and application of ground support membranes for use in underground mines. MASSMIN. AusIMM, 2000.
- [50] Stacey, D. (2005) Rock-slope research under way at university. Creamer Media's Mining Weekly. <http://www.miningweekly.com/article/rockslope-research-under-way-at-university-2005-09>. [Accessed on 4th May 2014].
- [51] Stacey, T.R. *Review of membrane support mechanisms, loading mechanisms, desired membrane performance, and appropriate test methods*. Journal of South African Institute of Mining and Metallurgy, 101(7), 343-352, 2001.
- [52] Stacey, T.R. The Importance of Engineering Design with Regard to Safety in Mining. *Proceedings of the Southern African Institute of Mining and Metallurgy Hard Rock Safe Safety Conference 2009*. Page 291, 2009.
- [53] Stacey, T.R. & Ortlepp, W.D. Retainment support for dynamic events in mines. *In Proceedings of the International Symposium on Rock Support and Reinforcement Practice in Mining*, pp. 329-333, 1999.
- [54] Stacey, T.R. & Yu, X. Investigations into mechanisms of rock support provided by sprayed liners. *Proceedings of 5th International Symposium on Ground Support*. E. Villaescusa & Y. Potvin, Eds. Australia: A A Balkema. 209, 2004.
- [55] Steyn, J., Gerber, R.J., Harrison, A.T., Ferreira, P.H. Investigation of the Characteristics of Thin Sprayed Liners (TSL) and their use as an additional Support Medium in Block Cave Mining. *Proceedings of the 6th International Symposium on Ground Support in Mining and Civil Engineering Construction*. SAIMM, SANIRE and ISRM, South Africa, pp 125-143, 2008.
- [56] Tannant, D.D. Large-Scale Pull Tests on Mineguard™ Spray-on Liner. Report to INCO Limited, Copper Cliff, 1997.

- [57] Tannant, D.D. Thin spray-on liners for underground rock support testing and design issues. *Proceedings of International Conference on Surface Support Liners: Membranes, Shotcrete and Mesh*. Perth: Australian Centre for Geomechanics, 2001.
- [58] Tannant, D.D. & Kaiser, P.K. Evaluation of shotcrete and mesh behaviour under large imposed deformations. *Proceeding of Symposium on Rock Support*, Norway, 782-792, 1997.
- [59] Tannant, D.D., Espley, S., Barclay R., Diederichs, M. Field trials of a thin sprayed-on membrane for drift support. *Proceedings of 4th ISRM Congress on Rock Mechanics*, Balkema, 1471-1474, 1999.
- [60] Thompson, A.G. Rock Support Action of Mesh Quantified by Testing and Analysis. *Proceeding of International Conference on Surface Support in Mining*. Y. Potvin, R. Stacey & J. Hadjigeorgiou, Eds. Australia: Australian Centre for Geomechanics. 391, 2004.
- [61] Webber-Youngman, R.C. & Van Wyk, E. Improving health and safety related education through virtual mining interactive simulations. *Proceeding of Hard Rock Safe Safety Conference*. South Africa: SAIMM. 323, 2009.
- [62] Wojno, L. & Kuijper, J.S. Spray-on, user friendly and flexible support for mine excavations. *Proceedings of International Symposium on Rock Support*, Lillehammer, 671-683, 1997.
- [63] Yilmaz, H. Development of Testing Methods for Comparative Assessment of Thin Spray-on Liner Shear and Tensile Properties. Ph. D. Johannesburg, RSA: University of the Witwatersrand, 2011.
- [64] Yilmaz, H. *Comparison of tensile-bond strength of thin spray-on liners*, International Journal of Mining, Reclamation and Environment, 27:1, 56-71, 2013.
- [65] Yilmaz, H. Saydam, S. & Topper, A.Z. Emerging Support Concept: Thin Spray-on Liners. *In 18th International Mining Congress and Exhibition of Turkey-IMCET*, ISBN 975-395-605-3, pp. 65-72, 2003.