1ä^{h} International Mining Congress and Exhibition ot Turkey-IMCET 2003, @ 2003, ISBN 975-395-605-3

Emerging Support Concept: Thin Spray-on Liners

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ABSTRACT: Accidents resulting from rocktalls occur frequently in the vicinity of active mining faces where workers spend most of their time. Installation of conventional surface support methods has been successful in overcoming this problem. However, they are expensive, time consuming, and their thickness results in logistical problems due to large material volumes. "Thin Spray-on Liner (TSL)" is an emerging alternative surface support system with remote, rapid and easy spraying techniques. The support action of TSL is still not well understood. Currently, there is no standard test methodology for TSLs and it is not possible to evaluate the quality and performance capabilities of TSL products. Assessment of TSL performance would be possible once the design standards and requirements are determined. Only then, will more effective use of TSL be possible in any support design. This paper reviews the development of TSL as a support concept, current testing procedures and gives a brief description of the research work undertaken by the authors.

I INTRODUCTION

Rock related accidents are the major cause of injuries and fatalities in underground mines around the globe. The effect of rock related accidents on the fatality rates is up to 65% in South African gold mines (Erasmus 2000). More accidents occur in the vicinity of active faces, (production excavations or development ends), where workers spend most of their time. One of the major causes of instability is the lack of support coverage at these locations. Support tendons do not provide adequate rock reinforcement for fragmented rock and pieces of rock from the*excavation boundary can easily be separated due to gravity.

Increasing the use of surface support methods, such as mesh, shotcrete or fibrecrete, near the face would reduce the risk of rockfall injuries; however, these support components have disadvantages. Application of mesh is expensive and time consuming, while the required shotcrete thickness results in logistical problems due to large material volumes which need to be supplied.

Total elimination of rock related accidents is not possible by strict measures on ground support as human involvement in mining activity cannot be eliminated with current technology. An emerging alternative surface support system in the form of "Thin Spray-on Liners (TSLs)" has the potential to reduce accident levels and to increase productivity by minimising interference on the mining activities due to remote and rapid spraying techniques.

TSLs have been used in civil engineering for many years and is a recently growing support concept still lacking widespread application in the mining field. TSL can be applied easily and much faster after a new opening is excavated and their distance to face can easily be adjusted. Although the support action of TSL is not well understood, quick application with high areal coverage enables early reaction against ground movement. The initiation and propagation of fractures are prohibited and loose blocks are maintained in place at the early stages of face exposure. Rock strength and therefore excavation stability can be improved particularly for jointed rockmass. TSL design standards and requirements are not clearly available yet. Additionally, there is no standard test methodology for TSL support and it is not possible to evaluate the quality and performance capabilities of TSLs in the market. There is no reliable correlation between laboratory results and field results whether on surface or underground. Once rational procedures are developed and acceptable parameters are derived, more effective use of TSL will be possible in support design.

2 HISTORY AND BACKGROUND

TSL materials for ground support were initially intended to be used as an alternative to rock bolts and mesh or shotcrete. The first tests on TSL technology were initiated in Canada in the late 1980's (Archibald et al. 1992). The fact that TSL can be generally applied onto the rock to a thickness of 3 to 5 mm enabled the realisation of numerous advantages in terms of speed of application and minimizing transportation of materials in the 1990's.

Meanwhile, South African and Australian researchers have also been exploring the use of TSLs for rock support and have conducted various field and laboratory tests. By the mid to late 1990's news of TSLs being used in Canada's hard-rock underground mines reached many other interested manufacturers of a wide variety of spray-on products. Many products were tested and it was found that most did not possess adequate physical or chemical properties. The composition of some of the products has been dramatically changed to meet performance requirements. Newer products are continuously developed, introduced and tested. Recent developments on TSL support continue to receive increasing attention by the mining industry around the world due to considerable operational benefits, with the potential to greatly reduce mining costs. There are currently about 55 mines around the world that are considering the use of TSL for rock support and this number is increasing steadily. The greatest interest is in North America, Australia, and South Africa (Tannant 2001).

3 COMPOSITION, PROPERTIES AND TYPES OF TSL'S

Polymer based TSL's can either be non-reactive or reactive. Reactive TSLs are made from isocyanates (polyurethanes, polyureas) and acrylates. First versions of TSL were of single component "glue emulsion" type and were not suitable due to health & safety requirements. Later on, two and three component TSL systems were developed. Polymer based liners normally require physical combination of two liquid chemicals or a liquid and a powder phase to form liner material. Today, utilization of two-component, reactive TSL systems are increasing due to ease of application, longer shelf lives and fast curing times. Table 1 shows a list of TSL products, commercially available or under development, including some key characteristics describing each product (updated during workshop of 2^{nd} Int. TSL seminar-Johannesburg 2002).

4 TESTING OF TSL

A number of laboratory and field tests have been developed over the last few years, aiming at better understanding the properties of TSLs as well as characterising its interaction with rock. According to Naismith & Steward (2002) the following requirements should be satisfied from a well-designed TSL testing procedure:

- Simple (Easily prepared sample)
- Cost effective
- Repeatable
- Practical
- Representative of relevant properties and behaviour
- Relate to in-situ performance
- Statistically valid data should be generated.

Testing could be performed to address TSL material itself or could consider both the TSL material and the substrate in order to understand both the physical behaviour and the interaction of TSL with the substrate. It should be noted that most of the tests developed for rocks cannot be applied directly for TSL testing. Firstly, stresses imposed on TSLs are a few orders of magnitude smaller than rocks. Secondly, TSLs undergo much higher deformations than rocks. In addition, the effect of environmental factors such as temperature, humidity and chemical interaction could be more significant in altering TSL properties.

Table 1 Existing TSL Products (2^{nd} Int. TSL seminar 2002)

Product	Manufacturer	Mix Base	Material Type	Curing Speed
ArduimnTM020	Ardex	Hydraulic Cement	n.a.	Fast
E\et mine	Mead Mining	Cement/Acrylic	Liquid/Powder	Slow
GSM CS 1251	M BT	Polyurethane -Polyurea/Acrylic	u.a.	Fast
Masterseal	M BT	Methacrylate	Liquid/Liquid	Fast
Mineguard	Mineguard Canada	Polyurethane	Liquid/Liquid	Fast
Rock Hold	Mondı Mining Supplies	Methacrylate	Liquid/Powder	Slow
Rock Weh	Spray On Plastic	Polyurea	Liquid/Liquid	Fast
Rocks; uaid	Engineered Coatings	Polyurea/Polyurethane	liquid/Liquid	Fast
Tekilcx	Fosioc Inc	Cement Latex	Liquid/Powder	Slow
Tunnels: uaid	Reynolds Soil Tech	Cement Latex	Liquid/Powder/Fibre	Slow

The following mechanical properties are relevant and could be tested in defining TSL properties i.e.:

- Tensile Strength (Elongation)
- Adhesion (Bond) Strength
- Tear Strength
- Shear Strength
- Creep Behaviour
- Impact Strength (Abrasion)

Specimen preparation, speed of testing and environmental factors may change the test results. No matter which testing method is developed, the two most important factors, temperature and humidity, need to be recorded for the test duration. Another shortcoming will exist if the test does not consider any interaction between the TSL material and the applied surface.

5 PREVIOUS TESTS OF TSLs

Despite the significant variety of testing procedures developed, only two tests have met with the acceptance of the delegates who attended the P^{l} Int. Seminar on Surface Support Liners in Australia (2001). They were the tensile and the direct adhesion tests. Large-scale tests were found to provide interesting results but were also found to be difficult to interpret in terms of TSL properties and behavior. TSL's tensile strength, adhesive strength and elongation capacity are properties that are important to the liner's ability to hold loose rock in place and therefore are the key factors in the determination of TSL performance. The scope and results of selected tests are reviewed and presented in the following sections.

5. / *Adhesion tests*

The adhesion test measures the adhesion or bonding strength of a TSL attached to a rock substrate. Two types of bond strength needs to be considered: tensile and shear. Tensile bond strength is a measure of the ability of TSL to remain in contact with the rock when a tensile stress is applied normal to the rock-TSL interface. Shear bond strength is concerned with the ability to resist stresses that act parallel to the rock-TSL interface (Fig. 1). Practically, there is some combination of these stresses acting on the TSL-rock interface.

Failure may occur due to the low tensile adhesion strength between TSL and rock surface. Adhesion strength on different rock types and the factors influencing the adhesion are important test considerations

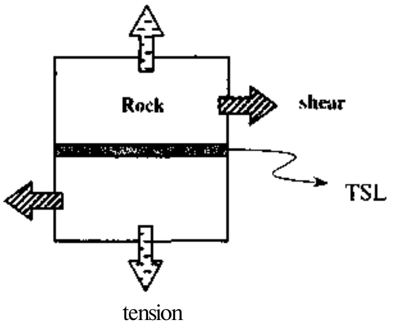


Figure 1 Debonding mechanism of TSL

5.2 *Core adhesion test*

The direct adhesion test consists of two pieces of core bonded together by TSL as shown in Figure 2. The top and bottom halves are subjected to a uniaxial pull until failure takes place at the TSL rock interface. The core adhesion test has the potential to become the main testing method in determining the bonding strength of TSL due to its simplicity. Sample preparation is an important issue in that both halves should lie along the same axis and in the direction of pull to prevent eccentric loading and premature failure.

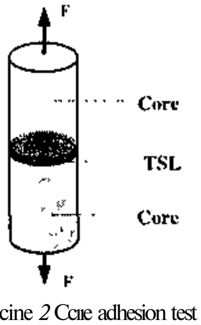
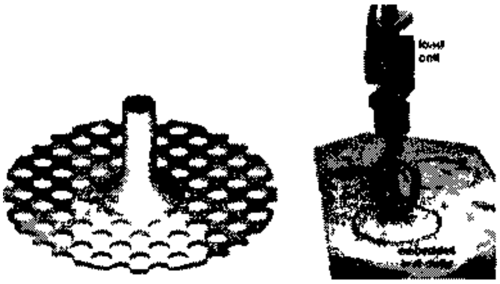


Figure *2* Core adhesion test

5.3 Plate-pull testing

This test consists of pulling on a test dolly embedded within TSL. A test dolly can be made from varying diameters and thicknesses of perforated steel discs that are applied to thin rock slabs (Fig. 3). Tannant et al. (1999) showed that high humidity or wet rock surfaces may significantly degrade the adhesive bond between the TSL and the rock. The TSLs bond to the rock normally increases with time, provided that the rock is firm, clean and dry. Adhesion to smooth, wet and soft rock is generally poor.

Difficulty persists in being able to produce consistently repeatable results between tests using rock slab bonding surlaces Archibald (1992) showed that bond adhesion vanes on irregular rock surfaces due to ditteiences in substrate strength, surface loughness, porosity and degree ol alteration characteristics Theretoie, he used a paving stone pioduct that exhibits uniform stiength and suitace propei ties



Figuie 1 Genenc view ot a test dolly and typical lest setup in the laboiatoiy (Tannant et ai 1999)

Specimen preparation and testing procedures can be summarised as following (see Fig 4 and 5),

- A test product is sprayed onto a flat suitace ot a cut concrete or rock surface
- A test dolly is immediately placed on the tiesh, uncuted coating TSL is still in its initial liquid state and peimitted to seep thiough the numerous peitoration holes of the test dolly
- immediately following the initial cunng, TSL forms an adhesion bond with the test surface and pioduces an embedment bond about the pull plate
- A second coating is spiayed ovei the test dolly to fully embed it within the TSL
- After the test product has cuied, the embedded test dolly and coating aie overcored to isolate the test aiea from the iest ot the TSL (Oveicoring ot the pull plate is conducted to insuie that only the bond adhesion associated with the area immediately beneath the pull plate is actually measured during pull testing)
- After 2 days ot cunng toi the last layer ot TSL, the test dolly is pulled normal to the substiate sut face
- Test is continued until lull ielease or loss ot adhesion contact between the pull plate assembly and the substrate
- The adhesive strength is determined from the peak stiess

The manner in which material adhesion loss occurs was shown to vary between mateiials assessed as can be seen by dltterent failuie modes in Figure 6 (Archibald 2001)

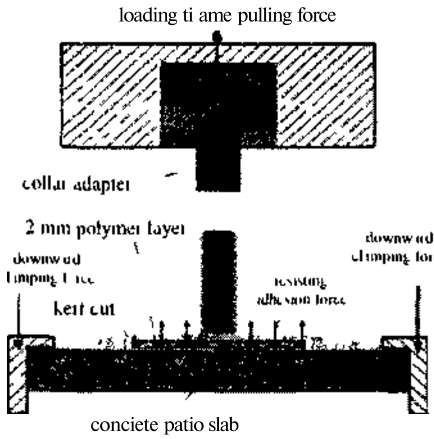


Figure 4 Adhesion pull ttst assembly schematic (Aichibald 21)01)

Figuie 5 Specimen assembly piioi to oveicoung and at finish ot adhesion bond stiength lest (Aichibald 2001)

The test piocess is designed to be earned to ultimate bond lailuie theietore no residual adhesion bond stiength is quantifiable The location ot the failure should be determined and, if it is in the bond plane, the amount ot the applied material remaining should be assessed

Undergiound adhesion testing ot TSLs, similar to laboiatory plate-pull testing, on iock and shotcrete was also performed with a range of cure times and lor various moisture levels (Espley et al 2001)

Figuie 6 Typical views showing adhesion bond suitaces alter completion of tailuic tests (Aichibald 2001)

The surface substrates were cleaned pnor to linet application and pull plates were embedded in the liner for the testing. After the liner had cured, each test dolly was overcored and pulled as the loads were measured. The results indicate a correlation between surface moisture and adhesive strength - that is, the adhesion strength is decreased as the surface moisture increases.

5.4 Baggage capacity test

The baggage capacity test measures loose rock supporting capacity of a deformable TSL (Swan & Henderson, 1999). An open-ended steel frame, of dimension 1.1m x 1.1m x 0.3m, is used and loaded with actual slabs of unwashed -100mm rock debris. A liner is sprayed on the "loose" rock debris surface (Fig. 7). Since the surface is discontinuous some penetration occurs between the rock fragments. After curing for the required time the frame is inverted and placed in a loading machine. A distributed compressive load is applied to the "loose" rock, thereby deforming the liner, which eventually ruptures. Repeatability of this test is questionable since the distribution of rock debris varies for each test. Preparation for a test appears to be difficult and time consuming due to the size involved.

Figure 7 Baggage load test frame & set-up (Swan & Henderson. 1999).

5.5 Tensile strength and elongation tests

Standard testing method on "dog-bone" shaped pieces of plastics (ASTM D638 1998) has been selected by most of the researchers (Fig. 8) (Tannant et al. 1999, Archibald 2001, Spearing & Gelson 2002) to assess tensile properties, initial stiffness (modulus) and elongation capacity of TSL material at failure. TSLs have different rigidity properties and therefore their dimensions should have the ability to deal with rigid, semi rigid and non-rigid products. Thicknesses between 3 mm to 14 mm can be accommodated with dog-bone testing.

Multiple tests need to be performed in order to obtain reliable measurements of the tensile strength. The test specimen is clamped at each end in a tensile testing machine and then pulled. The specimen should break into two pieces on the narrow section for a valid test. The clamping can be achieved in a number of ways; gluing, screw clamping and fixed gripping platens are some of the methods.

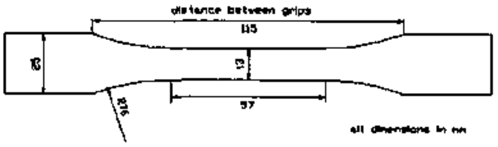


Figure 8 Shape and dimensions of a Type I test specimen using ASTM D638.

Material tensile strengths were determined either at break or yield positions along the measured load-deformation curves. The load is divided by original minimum specimen cross-sectional area at the specimen centre span to obtain the nominal tensile strength. Table 2 summarises adhesive and tensile strengths from various authors as a function of curing time.

Table 2 Adhesive and tensile strengths of various products

Product	Adhesive Strength (MPa)	Tensile Strength (MPa)
Mineguard'	0 56 (24 Hrs)	10-18(1 Hour)
Rockguard	0,43 (24 Hrs)	14-16(1 Hour)
RockWeb*	0.40 (24 Hrs)	18 5(1 Hour)
Masterseal'	0,50 (24 Hrs)	>2.0 (1 Hour)
Tekflex"	>() 16 (8 Hrs) >0.51 (24 Hrs) >0.65 (72 Hrs)	1.0 (8 Hrs) 1 74 (24 Hrs) 2 65 (72 Hrs)
GSM CS 1251'"	1 0(1/4 Hrs)	17 (1/4 Hrs)

'Aiclnbald (2001). 'Swan & Henderson (1999), '"Laceida & Rıspın (2002)

5.6 Pull strength determination

The plate pull test simulates the loads generated in a supporting liner when a loose block of rock moves relative to the surrounding rock (Fig. 9). The test consists of placing a solid circular plate of steel on either a concrete block or rock surface and then spraying the test material over the plate and the substrate surrounding the plate with a uniformly thick and continuous TSL. No TSL is permitted to be placed between the substrate and plate as it is not the aim of this test to measure the direct bonding strength of TSL (Fig. 10 and 11). The plate pull test

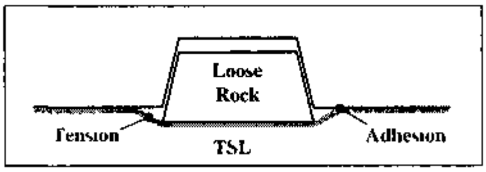


Figure 9 1 inti supports the load from loose rock

procedure can be summarised as follow (Tannant et al 1999)

- Place the pull plate on a concrete or rock surface which has a diameter greater than the pull plate
- Coat the pull plate and the area surrounding the plate with TSL
- Slowly pull the plate perpendicular and away from the substrate after the required curing time

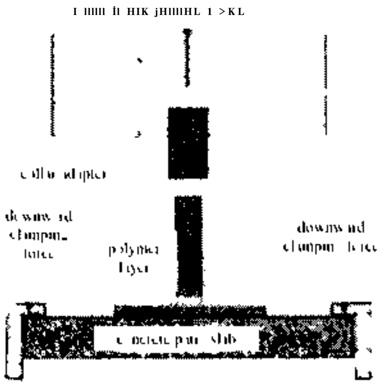


Figure 10 Pull strength test assembly schematic (Aichihald 2001)

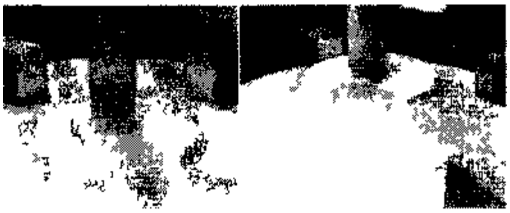


Figure II Test assembly before and at finish of pull strength test (Aiclnbald 2001)

The test is completed when the load begins to drop or when the plate is pulled free of the substrate A combination of adhesion loss and tensile rupture is the expected and desired ultimate failure mode and not that of shear rupture through the TSL

The failure modes observed during Aichibald s (2001) pull testing can be seen in Figure 12

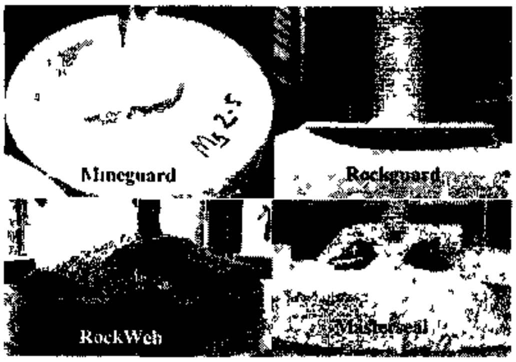


Figure 12 Typical views showing pull test failure conditions at completion of failure tests (Aichibald 2001)

*> 7 *Large scale pull test*

Espley et al (1999) assessed the load carrying capacity of a TSL by coating an interlocking series of 50 mm thick hexagonal concrete paving blocks The TSL is applied to the concrete blocks from above and left to cure A pull-type loading is applied by a "Î00 mm square steel plate located in the centre and underneath the assembled paving blocks until the TSL has failed as illustrated in Figure 11

Espley et al (1999) observed that the TSL is able to enhance the interaction between the loose blocks and thus a significant portion of the supporting function arises from block-to-block interaction

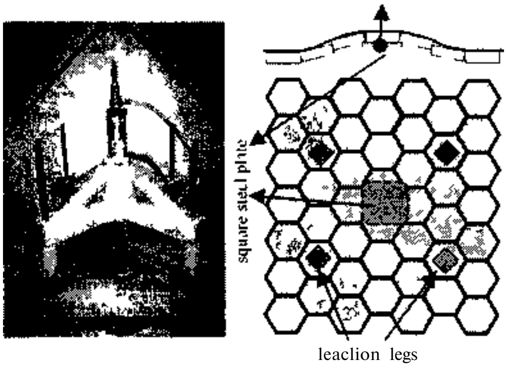
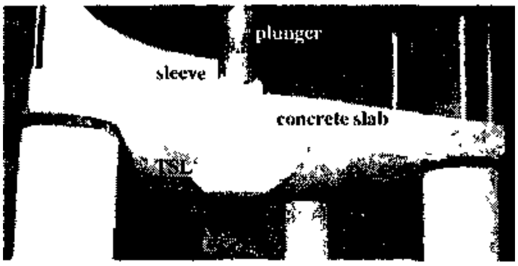


Figure II Test setup and typical test results from a large-scale pull test on Mmtguaid coated concrete blocks (bspkyetal 1999)

5 A' *Punch test*

Spcaiing et al (2001) performed the so called MBT Method (Membrane Displacement Test) where the TSL is punched by a plunger at the end of a hole in a concrete slab as illustrated in Figure 14 This test is very similar to the plate pull test in terms of the movement of the TSL i.e. punching or pulling alrectively results in the same TSL behaviour.



hguie 14 Punch testing setup (Speanng el al . 2001)

5 9 *Compression Failure Tests on Coaled Samples*

TSL coated cylinders *o(* concrete and rock were tested by various researchers (Espley et al. 1999; Archibald & DcGagne, 2000) to demonstrate TSL's ability to contain and reduce the damage resulting from potential pillar-bursts. Tests were done under uniaxial loading conditions and the results demonstrated significant positive benefits at the laboratory scale in terms of non-violent post-peak failure response, and the liner's ability to absorb some of the stored strain energy (Fig. 15).

A compression failure test may not be relevant in deriving physical properties of TSLs. however it is usetul to demonstrate the liner's ability to accommodate large strain ranges.

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6 CURRENT RESEARCH PROJECTS ON TSL TECHNOLOGY

The CSIR Division of Mining Technology (Miningtek) together with the School of Mining Engineering of the University of the Witwatcrsrand (WITS) in South Africa have been carrying out a rescaich project titled "Required technical specifications and standard testing methodology for Thin Sprayed Linings" since April 2002 and will be finalised by March 2004.

The main objective of this research project is to provide realistic guidelines for the design and testing of Thin Sprayed Linings for use as rock surface support. The project goal is to define required technical specifications for Thin Sprayed Linings as well as to propose a standard laboratory and underground testing methodology. By meeting these project objectives, mine-based Rock Mechanics Engineers will be provided with better guidelines for choosing the most appropriate TSL product for a specific environment.

The methodology adopted to achieve the project goals is as follows;

1. Identify the main rockmass failure mechanisms which can be prevented by TSL.
2. Group problem areas in the various environments into generic categories and define the required properties for TSLs in each group.
3. Identify industry and technical requirements for TSL for various environments.
4. Review previous research conducted on and results obtained from surface and underground testing of currently available TSLs.
5. Compilation of current testing procedures.
6. Identify shortcomings of current testing procedures and possible modifications.
7. Develop and propose laboratory test procedures by involving end-users and manufacturers.
8. Develop and manufacture testing equipment.
9. Carry out a sufficient number of laboratory tests for the evaluation of the proposed testing suite as well as product performances.
10. Comparison of test results in terms of the suitability of each TSL product in various environments.
11. Iterate and modify testing procedures in line with recommendations from end-users and manufacturers.
12. Report on the standard laboratory testing procedures.
13. Comparative assessment of the suitability ol various TSL products in the underground environment.
14. Quantification of the support (reinforcing) effects of each product under quasi-static and dynamic loading at representative sites.
15. Comparison of both laboratory and underground results and validation of the proposed testing methodology.
16. Technology transfer.

In addition to the formal research project described above, most of mines are running small-scale comparative investigations on the evaluation of support performance of different TSL products in specific environments. Manufacturers, on the other hand, have been testing their products in a laboratory environment and. based on these test results they continually modify their product properties. However, since there are no standard testing procedures accepted and implemented by all parties, the validity of these test results may be questioned.

7 RECOMMENDATIONS & CONCLUSIONS

There is an urgent need for developing standard tests and testing procedures on TSLs as their application will potentially grow in the near future. .Any standard test should be simple, repeatable, practical, cost effective and should relate to actual behaviour. The relevant mechanical properties of TSLs such as tensile, adhesion, tear and shear strengths could easily be addressed by simple test set-ups. Previous testing has dealt mainly with tensile and direct adhesion strengths and enough importance has not been given to shear and tear strengths as well as to creep behaviour.

TSL behaviour can differ significantly with different curing times and under different environmental conditions. Therefore, the effect of curing time, humidity and temperature on TSL behaviour should be studied as part of any testing method. The thickness of TSL and its effect on the performance behaviour are also not covered well in the previous tests and need to be addressed.

The most effective and representative of these tests or test combinations should be agreed to become standard tests through Int. collaboration of researchers on this field. Once this is done, more effective use of TSL will be possible. As the field applications grow the correlation between the laboratory and field results will become more reliable.

ACKNOWLEDGEMENTS

This project is funded by Safety in Mines Research Advisory Committee (SIMRAC) of South Africa.

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