SECTION 2

Thin Spray-on Liner Products

2.1 INTRODUCTION

Traditional surface rock support systems have relied on mesh, straps and shotcrete to control or mitigate ground falls. It is only since the early 1990s that thin spray-on liner (TSL) products have been developed to provide surface support of excavations in rock. A TSL is a thin coating applied to a rock surface. The last few years have seen efforts in developing a number of new products specifically geared towards mining operations. In parallel, a number of mining operations have investigated the potential of commercially available sealants as support systems. In this review the emphasis is on liners that arguably provide support to the rock surface.

The information in this section is to a large extent based on information made available during the International Workshops on thin spray-on liners held in Perth, Johannesburg and Quebec City. It is of interest to note that a number of products introduced during this time are no longer available, while a number of other liners have already been reformulated aiming for better performance in laboratory and field trials.

2.2 DESIRABLE TSL PROPERTIES

It is recognised that given the inherent variations in ground and mining conditions there is not one support system that is applicable to all conditions. Furthermore, different mining operations adhere to different ground control philosophies based on local experience and often dictated by legislation. In particular, health and safety concerns have to be addressed prior to introducing a new material on site. This has often been cited as one of the main reasons for the delay for a number of TSL products or even the rejection of particular products.

An "ideal" TSL should have a range of mechanical properties and respect a number of operational, environmental and economic criteria. Table 1 presents such a list of desirable characteristics (Espley-Boudreau, 1999).

TABLE 1 Ideal spray-on liner properties and characteristics (Espley-Boudreau, 1999)

Property or characteristic	Recommended range
Non-combustible	Flame spread rating$_{max}$ < 200
High tensile strength	> 5 MPa
High adhesive strength	>1 MPa on rock substrates
Tough (hardness)	Shore A, hardness 80
Elasticity	100% to 150% elongation
High shear strength	> 1 MPa
Rapid cure time	< 1 hour
Water resistant	Able to be sprayed onto humid/wet surfaces
Temperature tolerant	0° C to 40° C
Rapid application rates	> 1 m^2/minute
Long pot life	> 2 hours
Environmentally friendly	Only mild solvents
Low cost	< $15/$m^2$
Simple application	Minimal surface preparation

In defining the requirements for a new TSL product to be used as a mesh replacement at its Sudbury operations, a Falconbridge team identified and ranked the desired qualities for a TSL (see Table 2).

The most important criterion was defined as the net cost justifying the use of TSL as a mesh replacement. Of interest was the high ranking given to the performance of a liner in the Falconbridge developed bagging strength. Consideration was also given to a range of material properties and the potential to comply with environmental standards.

TABLE 2 Ranking of desirable liner properties (Swan and Henderson, Chapter 21)

Quality	Description	Ranking 1 to 4
Net cost	Cost should justify change from mesh	4
Bagging strength	Initial objective to replace #7 gauge weld-mesh	3.8
Environmental	MSDS; Health & Safety; minimal protective equipment requirements	3.8
Fire retardency	Must not continue to burn after flame removal	3.5
Adhesion	Must adhere to friable ore; should bond with multiple applications	3.5
Flexible	Must deform as failing rock bulks; should resist blast damage	3.0
Sprayability	Should use standard spraying equipment; minimise losses; mix at nozzle	2.8
Humidity	Must work in relative humidity that exceeds 90%	2.8
Set-up time	Quick-setting, achieving minimum required strength after 8 hrs	2.8
Product life	Must be stable in presence of acid, alkaline, CO^2 gas and diesel emissions	2.6

It follows that different operations may arrive at a different set of priorities or at least a different weighting system. An issue raised during the series of workshops is whether a liner should be rigid or flexible. It has been argued that a rigid liner may be more suitable if no significant ground deformation is expected. The implication is that a particular quality may provide an advantage, or a hindrance, depending on site-specific conditions.

Finn (Chapter 5) has suggested that the ideal TSL should provide a stiff support with a tensile strength greater than 5 MPa. The material should reach its yield point after a displacement of 250 mm, after which it will have an ideal plastic behaviour. Other operators have defined the required behaviour for a TSL based on specific site objectives. Hepworth and Lobato (Chapter 25) report that at the Neves Corvo mine in Portugal it was defined that a TSL should provide a substitute for shotcrete where faults are exposed, to provide adequate support for areas in the mine susceptible to weathering and as mesh replacement for rehabilitation. At Inco, TSL systems were originally investigated primarily for mesh replacement and potentially for replacing some or all bolts. There was also some suggestion for using TSLs to replace shotcrete in certain applications.

2.3 TSL MATERIAL CHEMISTRY

Material chemistry is important in that it dictates the mechanical behaviour of TSLs. A further requirement, often legislated, is that the final product complies with health and safety regulations. Archibald (Chapter 16) suggests that one of the reasons that TSLs have not been applied widely lies in the perception that unacceptable occupational health and safety risks develop when such materials are used. The other reason being operator resistance towards the use of flexible TSL systems over established support such as bolts-and-mesh and shotcrete.

Polymers used in TSLs include polyurethanes, polyurea and methacrylate products. Health and safety issues have often been associated with TSL products that use isocyanates as one of the components. Isocyanates are controlled substances in most mining jurisdictions. Espley-Boudreau (1999) and Pappas et al (Chapter 15) have indicated that, provided proper procedures are used, it is possible to use a series of tested products without adverse influence on mine workers.

2.4 MATERIAL HANDLING

Field trials have demonstrated that the introduction of new TSL products is often influenced by the availability of suitable materials handling procedures. A number of products have been denied access to mine sites owing to real or perceived health and safety concerns. The presence of an isocyanate component in the polyurethanes and polyureas has been identified as the main health hazard. This links to issues associated with use of personal protective gear during handling and application of products. The use of liquid/liquid or liquid/powder also has an influence on the packaging of products and the ease of application and the choice of equipment.

All liner products must conform to local legislation in regard to flammability and self-extinguishing characteristics. Failure to comply with these in effect bars a product from a mine site.

2.5 TSL PRODUCTS

The available TSL products can be divided into those specifically developed towards providing a surface support for mines and those already used for other applications, often as sealants, where different operations have explored their capacity to also provide some level of support.

A number of products have been identified during the international seminars and workshops. In certain cases it was not always possible to have access to all pertinent data. This is due to the fact that a number of products were tested while still in development and consequently the information was specific to particular formulations. This is confirmed by the fact that several products are no longer commercially available. It is felt that as the TSL industry matures these problems will be resolved and the mine operators will have access to full data in order to select the most appropriate TSL products for particular conditions.

Mineguard™

Archibald et al (1992) reported on the first documented work on the potential of TSL technology as ground support in Canada in the early 1990s. This has resulted in a polyurethane based product, Mineguard™ which was subject to extensive laboratory testing throughout the 1990s in order to arrive at a formulation. Mineguard™ is a two-component liquid system which, when cured, provides flexible support. Component A consists of an isocyanate formulation in which monomeric methylene bisphenyl isocyanate and an oligometric prepolymerised derivative are mixed. Component B consists of various hydroxyl polyols (polyester/polyether hydroxyl resins). During the late 1999s Mineguard™ was subject to several in-situ applications and was judged to offer adequate support with appropriate ground preparation (Espley-Boudreau, 1999). Nevertheless, owing to real and perceived issues associated with material handling and equipment it has not become part of the routine ground support arsenal.

Everbond and Evermine

In the mid 1990s CSIR in South Africa investigated the potential of a latex-based product, Everbond, as thin spray-on liner support system (Wojno and Kuijpers, 1997). The latest incarnation of this technology is now marketed in South Africa by Mead Mining under the name Evermine. This product is formed by combining a water-based acrylic resin with a highly water absorbent powder component to develop a flexible support system. This is a non-reactive system that is relatively slow to cure. Its performance under laboratory conditions has been well documented. Recent field trials have identified the importance of surface ground preparation and the need for specialised crews to man the equipment (Nagel and Joughin, 2002).

Tekflex®

Fosroc (now Minova International) developed Tekflex® as a possible mesh replacement at Falconbridge's Fraser Mine in 1997. A prerequisite defined by the mine was for the liner to be of very low toxicity so that it would not raise concerns over solvents or toxic components with workers. It contains two separate components: a liquid polymer latex, and a hydraulic cement powder. The components are mixed in a single bin and an air compressor provides the necessary nozzle pressure to spray the liner. Another product, Tekflex® White, was developed in 2002. Tekflex® White achieves the same strength in four hours as the original formulation of Tekflex® developed in eight hours. This is roughly equivalent to the strength of #7 wire-mesh. This product has a higher degree of flexibility coupled with high tensile strength. Its off-white color improves underground lighting and facilitates identification of sprayed and non-sprayed areas. Tekflex® T was developed as a water barrier to route any overhead running water to a location at ground level where it may be diverted as required. This product is often sealed with a further layer of shotcrete. Due to adhesion between the Tekflex® T and shotcrete it reduces the water permeability of a structure. The Tekflex® T and shotcrete work synergistically to provide strength and water tightness. Tekflex® Black was developed in 2002 as a partial replacement for shotcrete in specific applications. It maintains the flexibility and strength of Tekflex® White and can be used for much of the same applications as Tekflex® White. The major advantages of Tekflex® in this application have been in reduced materials handling as well as cost savings. The Tekflex® products are now available from Minova International.

Tunnelguard

Tunnelguard was developed in 1994 in South Africa by SA Mining and Engineering as a support element to seal and consolidate various problematic rock types and prevent oxidation of the rock. Tunnelguard is a cementitious liner with a polypropylene fibre additive that provides its binding and sealing capacity. It is available as a three-part mix (a two-component cementitious powder and liquid polymer). It is sprayed using a portable continuous mixer and pump to provide the required thickness. Another product from SA Mining, Tunnel Flex, is currently being tested in order to provide a more flexible TSL.

Castonite™

Castonite™ was developed in 1999 in South Africa by Rohm Haas and their technology partners. The original application was for architectural purposes but it was modified for underground use as a thin support liner. Castonite™ is a two-component liquid gypsum and polymer TSL that is applied using a twin moyno pump in coal and hard rock mines. It has passed the ASTM E162 radiated heat test and ASTM E72 (a mine sealant test). Castonite™ is available from Strata Products.

Masterseal®

Master Builders (now Degussa Construction Chemicals Ltd) have been developing thin spray-on liners since 1999. A series of products of different chemical compositions have been introduced since then. Masterseal® 840 R01A is a methacrylate based reactive product which uses liquid/liquid components and results in a flexible TSL. Another prototype is CS1261, which is a reactive liquid/liquid product that sets relatively fast and provides for a more rigid liner. At the present time, only one type of support liner is commercially available, the Masterseal® 845A. This is a non-reactive cementitious blend/polymer powder product. The product is mixed with water in the spraying nozzle. This is a one-component system and consequently easier to manage than a two-component product. Setting times vary from 10 to 15 minutes and it is possible to apply shotcrete once the TSL has set.

Rockweb

Spray-On Plastics Ltd have been involved in the development of a polyurea-based product called Rockweb since 1994. The latest version of Rockweb employs a two-component liquid/liquid system. The first component is an isocyanate, mixing a monomeric methylene bisphenyl isocyanate and an oligomeric/prepolymerised derivative. The second component is based mostly on amine-terminated polyols (polytheramines). The two components are mixed at 1:1 ratio and Rockweb cures in a matter of seconds to provide a flexible liner that reportedly adheres well to damp and dusty surfaces. The performance of Rockweb under laboratory conditions has been documented by Archibald (Chapter 4).

Ardumin TM O20

Ardex of South Africa also developed a TSL product, Ardumin TM O20. This is a blend of hydraulic cements, admixtures and graded fillers. It is a liquid/powder system which has a relatively fast curing time and rapid early strength. At the present time there is no comprehensive information available on the performance of Ardumin TM O20 under laboratory conditions. Nagel et al (2002), report of a preliminary field trial, under humid conditions, in a South African Mine.

Rock-Hold™

Mondi Mining Systems worked towards developing a resin bonded TSL before logistic problems led the company to work towards what is perceived a more user-friendly methacrylate based system. Mondi® Rock-Hold™ was introduced in South Africa in 1998. It uses a methacrylate powder, which is mixed on a 1:1 ratio with water to provide a thin and flexible spray-on liner. Rock-Hold™ has a relatively slow setting time of approximately 12 hours. Laboratory tests are reported by Lewis (2001) while Henderson and Louw (2001) report three applications in South African gold mines.

RockGuard™

RockGuard™ is a hybrid polyurethane/polyurea based mixture developed in the late 1990s by Futura Coatings Inc. (St. Louis, MO, USA), and is now available from Engineered Coatings Ltd. It is a two-component liquid using an isocyanate formulation of a monomeric methylene bisphenyl isocyanate and an ologometric/prepolymerised derivative mixture, and a hybrid blend of various hydroxyl polyols and amine-terminated polyols. This two-component polyurea coating cures within seconds to produce a flexible system.

Rockguard/Coalguard is also the name given to a TSL product marketed in South Africa by Technological Mining and Marketing. This is a water based product that can be sprayed or brushed on rock surfaces. It sets in three to five hours to provide a flexible liner.

Kohlberger Enterprises Polyurethane

The potential use as a TSL of a polyurethane product from Kohlberger Enterprises was explored in Western Australia (Finn, Chapter 5). The mine opted for a 2.5:1 ratio of polyols to isocyanates as this provided for a relatively fast setting time. Although this product provided evidence of adhering to a wet surface, the mine management concluded that due to quality control and health and safety issues associated with high levels of isocyanates, this TSL was not suitable for underground applications.

SPI Polyurea

Finn (Chapter 5) reports on limited tests on a liner product from Special Products International referred to as SPI Polyurea. This is a two-component liquid/liquid system where the components are pumped into a spray gun in which the product is heated. A relatively fast setting rate was obtained. Owing to concerns about health and safety aspects, none of the tests involved spraying the product underground. There is no record of further tests or applications of this product in a mining context.

Lanko 228

This product was also presented during the workshops as a potential TSL. This is a flexible, cement-based, two-component micro-mortar originally developed as a sealant. It is a two-component system. Component A, 60% by weight, is a powder composed of special cements, fillers and additives. Component B is a milky liquid with a water-based resin base. There is no documentation of mining applications.

2.6 TSL PRODUCT LIST

A complete list of TSL products presented during the workshops is provided in Table 3. As discussed earlier, a number of these products are no longer available and other products are in development at the time of writing. The driving force is the promise of important operational benefits, safety and reduced mining costs. All products are listed, along with the name of the manufacturer or principal distributor. Further information is provided towards the basic chemical composition, reactivity, material type, time to set and whether the final product is a flexible or rigid form of support.

Classifying TSL products under these headings has generated some controversy during the workshops. The controversial issues were associated with time to set and whether a product is reactive or non-reactive. Rispin and Garshol (2003) proposed that reactive liners demonstrate "…..initial reaction and set within ten (10) minutes of application, with a gain in tensile strength to a minimum of 75% of ultimate strength within the first hour after application (at 20° C)". Under this definition, polyurethane, polyurea and methacrylate based products would be classified as reactive, whereas shotcrete and polymer/cementitious blends are non-reactive.

The use of reactivity as a classification tool has also been advocated by Spearing (2003). A reactive liner is defined by rapid cure and strength development in a matter of minutes. It is usually a two-component product that uses a spraying pump. Reactive TSLs are, to some extent, considered as less 'friendly'. Non-reactive liners typically have longer curing time and are usually accompanied by water loss and strength gain in hours. Non-reactive liners are usually single component pumps (liquid plus a solid or liquid/liquid) and are less costly. Spearing (2003) also differentiates them based on whether the TSL is rigid or flexible and on the attained tensile strength (see Table 4). The use of a reactive/non-reactive classification has not been without its detractors. The argument has been made that most TSL products are in fact reactive, as they rely on the reaction between two products.

2.7 FUTURE PRODUCT DEVELOPMENT

The development of TSL products has been rapid. Nevertheless, the application of TSL products in a production environment has been slower than originally expected. This can be attributed to a number of factors including high expectations, material handling, real and perceived health and safety issues, and possibly the lack of generally accepted performance criteria. The fact that there is considerable development of existing and new products bodes well for the future.

TABLE 3 TSL products presented during the workshops

Product	Manufacturer	Chemistry	Reactivity	Material type	Fast/ slow	Flexible/ rigid
Ardumin TM 020	Ardex	Hydraulic cement	Reactive	Liquid/powder	Fast	Flexible
Castonite™	Rohm Haas	Gypsum polymer	Reactive	Liquid/liquid	Fast	Rigid
Everbond II	Mead Mining	Polymer/cementitious blend	Non-reactive	Liquid/powder	Slow	Flexible
Evermine	Mead Mining	Cement/acrylic	Non-reactive	Liquid/powder	Slow	Flexible
GSM CS1251	Master Builders Technologies	Polyurethane-polyurea /acrylic	Reactive	Liquid/liquid	Fast	Rigid
Lanko 228	CHRYSO	Cement/acrylic	Non-reactive	Liquid/powder	Slow	Flexible
Masterseal® 840 R	Master Builders Technologies	Methacrylate	Reactive	Liquid/liquid	Fast	Flexible
Masterseal® 845	Master Builders Technologies	Cement latex	Non-reactive	Powder/liquid	Fast	Flexible
Mineguard™	Mineguard Canada	Polyurethane	Reactive	Liquid/liquid	Fast	Flexible
Rockguard	Technological Mining & Marketing	Cementitious polymer	Non-reactive	Liquid/powder	Slow	Flexible
RockGuard™	Engineered Coatings	Polyurea/polyurethane	Reactive	Liquid/liquid	Fast	Flexible
Rock-Hold™	Mondi / ICTUS	Methacrylate	Reactive	Liquid/powder	Slow	Flexible
Rockweb	Spray-On Plastics	Polyurea	Reactive	Liquid/liquid	Fast	Flexible
SPI Polyurea	Speciality Products Int.	Polyurea	Reactive	Liquid/liquid	Fast	Flexible
Tekflex®White	Minova International Inc.	Polymer/cementitious blend	Non-reactive	Liquid/powder	Faster	Flexible
Tekflex® Black	Minova International Inc.	Polymer/cementitious blend	Non-reactive	Liquid/powder	Faster	Flexible
Tekflex® T	Minova International Inc.	Polymer/cementitious blend	Non reactive	Liquid/powder	Faster	Flexible
Tekflex®	Minova International Inc.	Polymer/cementitious blend	Non-reactive	Liquid/powder	Slow	Flexible
Tunnelguard	SA Mining & Eng.	Cementitious polymer	Non-reactive	Liquid/powder	Slow	Rigid
Tunnel Flex	SA Mining & Eng.	Cement latex	Non-reactive	Liquid/powder	Slow	Flexible
3M Mining Liner	3M	Polyurethane	Reactive	Liquid/liquid	Fast	Flexible

Note: While all care has been taken in presenting the information in the above table, no liability is accepted for errors or omissions.

TABLE 4 TSL performance categories (Spearing, 2003)

Category	Time to achieve 1MPa tensile strength	Tensile strength[1]	Elongation
Non-reactive and rigid	> 1 hour	> 1.0 MPa at 1 day	< 5% at 28 days
Non-reactive and flexible	> 1 hour	> 1.0 MPa at 1 day	> 5% at 28 days
Reactive and rigid	< 1 hour	> 1.0 MPa at 1 day	< 5% at 28 days
Reactive and flexible	< 1 hour	> 1.0 MPa at 1 day	> 5% at 28 days
Reactive, high strength and rigid	< 1 hour	> 5.0 MPa at 1 day	< 5% at 28 days
Reactive, high strength and flexible	< 1 hour	> 5.0 MPa at 1 day	> 5% at 28 days

[1] As discussed in Section 4 of this book on testing methods, the material tensile strength is only one of the performance indicators for TSL products.