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Specification and Guidelines on Thin Spray-on Liners for Mining and Tunnelling

July 2008

The Technical Committee on Thin Spray-on Liners was formed in 2004 with the objective of producing a specification and guidelines for their use for non-structural rock support in the Mining and Tunnelling Industry.

All comments on this specification and guidelines should be submitted to the EFNARC secretary: secretary@efnarc.org.

Acknowledgements

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1 SCOPE

This document provides a Specification and Guidelines dealing with Thin Spray-on Liners (TSLs) used in the Mining and Tunnelling Industries for non-structural rock support and for sealing rock against gas and moisture transfer and weathering. Whilst the primary support is provided by steel anchors and/or arches and/or reinforced shotcrete, the TSL provides an initial stabilising layer which will contribute to the overall support.

2 INTRODUCTION

This specification provides minimum standards of performance and methods of application for Thin Spray-on Liners (TSLs) used in the mining and tunnelling industries.

TSLs have by convention been classified as either reactive or non-reactive systems (see 5.5).

These guidelines principally deal with the market leading non-reactive Class S (see 3) TSLs based on cementitious polymer-modified systems that cure by water loss from the polymer emulsion allowing the polymer film to form and gain strength. As the end product is essentially a polymer filled with cement it retains many of the characteristics associated with polymer systems such as good flexibility, high tensile strength and high elongation at break. The coating also provides a barrier against gas and moisture movement. Other materials may be used provided they satisfy the performance and safety requirements given in Table 1.

The main advantages of TSLs when compared with shotcrete include the following:

- a) thinner applied thickness – easier materials handling
- b) increased toughness, durability, resilience, and resistance to impact
- c) stronger permanent bond to the substrate
- d) reduced dusting
- e) much greater tolerance to ground movement and resistance to cracking.

Although many tests have been proposed for the measurement of the load bearing capacity of TSLs these have been very difficult to interpret and produced inconsistent results. A linear block support test has thus been developed (appendix 1) which gives an indication of the load bearing capacity of the TSL in terms of the mass of the largest block which can be supported.

TSLs can be applied either before or after the primary support provided operators do not work under unsupported ground.

3 FIELDS OF APPLICATION

TSLs can be divided into two¹ classes depending on their end use:

- | | |
|---------------------------------|---|
| (i) Class B - basic: | principally used as an anti-weathering coating |
| (ii) Class S - standard: | used to permanently stabilise the integrity of rock structures whilst accommodating the stresses associated with strata movement, e.g. as an anti-weathering coating, mesh replacement, moisture and gas barrier. |

¹ It is possible that up to two additional classes will be added in the future, these are discussed in Appendix 2

4 REFERENCED STANDARDS

The following standards are referred to in the specification. However, any subsequently published or revised European Standard (EN) should always take preference over standards referred to herein.

The hierarchy of authority is EN standard, ISO standard, National standard, ASTM.

Tensile Strength:	DIN 53504 Type S2 or ASTM D638
Bond strength:	EN 1542 pull-off test using reference concrete EN 1766 (type MC 0.40) as substrate. A 50mm dolly is preferred.
Shear strength:	DIN EN 1373 or ASTM D732
Flammability:	EN 13823 The Single Burning Item (SBI) test ASTM E84 surface spread of flame. 3-4mm thick layer applied to EN1766 concrete slab.
Products of combustion:	NES 713
Supplemental tests:	a) Tear strength ASTM D624 b) Permeability to water vapour, methane, radon etc DIN 52615, DIN 16726, SN 021582 c) Crack bridging – DIN EN 1062-7
Water quality	EN1008
Shore A hardness	BS EN ISO 868:2003
Water tightness	EN 1928 or DIN 16726
Freeze thaw resistance	e.g. SN 73 1326 or SS 13 72 44

5 DEFINITIONS

5.1 Liner

A continuous membrane applied to strata to provide a means of non-structural surface reinforcement.

5.2 Thin

Applied thickness typically less than 10mm.

5.3 Wet spray

Pumping liquid(s) to a nozzle and applying to a substrate by spraying.

5.4 Dry spray

Supply of a dry blended product to a nozzle with compressed air and mixing with liquid within the nozzle and applying to a substrate.

5.5 Reactive/non-reactive systems

TSLs are classified as either reactive or non-reactive depending on their film formation/curing mechanism. Reactive systems rely on the cross linking of polymers (e.g. epoxy, polyurethane, methyl methacrylate etc) whereas non-reactive systems are cement/water/polymer systems which rely on the removal of water from the system for the polymer to film form.

6 PRODUCT REQUIREMENTS

6.1 Performance requirements

General and Special requirements are summarised in Table 1. The requirements shall be based on tests undertaken under laboratory conditions at $21\pm 2^\circ\text{C}$ and $60\pm 10\%$ rh. Unless otherwise stated, all results are for 3-4mm thick specimens after 28 days cure.

Table 1: Performance requirements

Performance characteristic		Specified test method	Class B	Class S
A	Tensile strength	DIN 53504 Type S2 or ASTM D638		> 2MPa at 7 days
B	Rate of strength development: (Time to reach a Tensile Strength of 2MPa at $50\pm 5\%$ rh and $80\pm 5\%$ rh at 23°C)	DIN 53504 Type S2 or ASTM D638		< 7 days at $50\pm 5\%$ rh < 14 days at $80\pm 5\%$ rh
A	Linear load resistance	TSL Linear Block Support Test (Appendix 1)		>5kN/m (equivalent to a 2 tonne block - DSK ² requirement)
A	Tensile E-modulus	Stress/strain on DIN 53504 Type S2 or ASTM D638 specimens		< 0.02GPa
A	Elongation at break	DIN 53504 Type S2 or ASTM D638		>10%
A	Shear strength	EN 1373 or ASTM D732 on sawn granite.		>0.25MPa at 24 hours
A	Ultimate bond strength	EN 1542 to EN 1766 (type MC 0.40) concrete grit blasted to SA 2½	Bonds to host rock	>1MPa
A	Fire classification	EN 13823 under conditions of EN 13501-1:2002	Reaction to fire behaviour B or better. Smoke index s1. Flaming particles/droplets d0	Reaction to fire behaviour B or better. Smoke index s1. Flaming particles/droplets d0
A	Flammability	ASTM E84 (surface spread of flame and smoke index development)	Class 1	Class 1
A	Products of combustion	NES 713	Pass as suitable for underground use	Pass as suitable for underground use
B	Crack bridging	DIN EN 1062-7		>1mm
B	Tear strength @ 28 days	DIN ISO 34-1 DIN 53515		>20N/mm
B	Water tightness	EN 1928 or DIN 1048		No water leakage after 28 days at 7 bar
B	Freeze thaw resistance	e.g. SN 73 1326 or SS 13 72 44		>50 cycles
B	Permeability to water vapour, methane, radon etc	DIN 52615, DIN 16726 or SN 021582		Water vapour $< 1.10^{-6}$ m/s Methane $< 4.10^{-16}$ m/s Radon $< 1.10^{-9}$ m/s
B	Surface Electrical resistance	DIN 22107 Part 6	$< 10^9 \Omega/\text{cm}$	$< 10^9 \Omega/\text{cm}$
B	Electrostatic charge transfer	EN 13463 Part 1	It must not be possible to charge the TSL	It must not be possible to charge the TSL

² DSK Deutsche Steinkohle (German Coal Mines)

Classifications for intended use:

A - Mandatory requirement for all intended uses - standard test method and performance limits are specified.

B - Special requirement for particular situations - standard test method is specified and performance limits are to be met or the result declared on request.

Polymer cement based TSLs are expected to have good long term durability due to saturated polymers being used and the long term stability of inorganic cements. In most applications in mines and tunnels TSLs are not exposed to sunlight.

6.2 Declaration of Conformity

6.2.1 Testing

Initial type testing shall be carried out by the manufacturer to prove the conformity of each product covered by this specification, with the requirements of Table 1.

6.2.2 Quality control system (or Factory production control system)

The manufacturer shall operate a quality control system in accordance with the principles of EN ISO 9000 at each facility where products covered by this specification are produced. Compliance with this requirement should preferably be verified by an approved certification body which shall issue a certificate to each production facility where procedures have been verified. After initial certification, an audit of each production facility shall be carried out by the approved certification body not less than once per year. If any non-compliance with the requirements of EN ISO 9000 is found, the certification body shall either:

- a) require correction of non-compliance within a stated time which, if not carried out, shall result in withdrawal of the certificate, or
- b) immediately withdraw the certificate, if correction is not possible.

6.2.3 Declaration of Conformity by the Manufacturer

Provided the requirements of 6.2.1 and 6.2.2 have been fulfilled, a declaration of conformity with this specification shall be made available by the manufacturer for each product or system which satisfies the appropriate requirements in this specification.

A new declaration of conformity shall be provided following any change in formulation or in constituent materials which results in a change of the characteristics of the product.

The time between repeat conformity tests shall be not more than 3 years.

6.2.4 Declaration of Conformity by the Contractor

The Contractor shall make available a declaration of conformity that all work will be undertaken to a quality plan and the TSL will be installed by trained operatives in accordance with this specification.

7 EXCHANGE OF INFORMATION AND TIME SCHEDULE

7.1 General

Consultations and exchange of information between all parties concerned with the Mining/Tunnelling/Quarrying operations should be arranged so that each has full knowledge of the particulars of the TSL work and be able to co-operate in producing the conditions required to complete a satisfactory installation.

Some of the items listed in 7.2 and 7.3 may need additional precautions or procedures: responsibility for these should be determined in advance of the work.

7.2 Selection of TSL to be applied

It is essential that there should be full consultation with all interested parties to ensure that the product is entirely suited for the conditions both during application and in subsequent service. Consideration should therefore be given to temperature, humidity, water ingress and compatibility with the substrate. This is to check for good adhesion to the substrate and any interference with polymer film formation from highly charged ions. Ideally a pre-trial should be carried out.

7.3 Time schedule

Allowances should be made for the following:

- a) time between commencement and completion of work
- b) period necessary for the TSL to reach its working strength.

8 MATERIALS

TSL systems are generally supplied pre-packed, either in one or two pack form:

(i) Cement polymer systems:

- a) Two-pack in which one pack, consisting mainly of a dry blend of cement, graded fillers and other constituents, is mixed with the second pack containing the correct dosage of polymer dispersion. In most cases the second pack contains sufficient liquid to mix with the dry component; otherwise the second pack has to be diluted with a specified quantity of water.
- b) One-pack consisting mainly of cement, graded fillers, powdered polymer in re-dispersible form and other constituents, which is mixed with a specified quantity of water on site.

Each type of pre-packed material shall be used in accordance with the manufacturer's instructions.

All water used for mixing the TSL shall be of potable quality or shall comply with the requirements of EN1008 or be from a supply which has been shown by tests to be of suitable quality. (For example the presence of highly charged ions such as Fe^{3+} in mine water can cause the polymer to flocculate).

(ii) Reactive systems (e.g. polyurethane or methyl methacrylate based):

These are normally *two-pack* consisting of a resin component and a hardener/catalyst component. The resin component is normally liquid but the hardener can either be in liquid or powder form depending on the system used.

9 DESIGN

9.1 Selection Parameters

Factors influencing the selection of a TSL system should include amongst others:

- a) rock/substrate type
- b) temperatures to which the TSL will be exposed
- c) nature and duration of any chemical contact with the TSL
- d) wet or dry service conditions

- e) colour and appearance
- f) required TSL thickness
- g) required strength development
- h) rate of strength development
- i) linear load resistance (Appendix 1)
- j) crack bridging ability
- k) site conditions at time of applying (e.g. temperature, humidity, water ingress)
- l) cost
- m) available application time
- n) lighting conditions.

The most appropriate TSL for any situation will depend upon the particular conditions to which it will be subjected, and the choice should be made in discussions between all the interested parties, including client, engineer, contractor and supplier. It is not possible to provide a simple guide as to where to use different TSLs, since so many parameters can affect the decision for a particular situation.

9.2 Curing time

The TSL shall be allowed to cure according to the manufacturer's instructions before mining or tunnelling operations can recommence.

For polymer cement systems at site temperatures below 10°C cure times will be substantially increased unless some form of external heating is used. During curing, temperatures must be kept above 5°C. Ambient relative humidity and ventilation air speed are also very important.

9.3 Joints

When applying a new area adjacent to an existing area there should be an overlap of at least 0.1 metres.

10 PREPARATION OF SUBSTRATE

The substrate should be prepared either in accordance with the TSL manufacturer's instructions or such that there is no loose material or surface dust. This can often be accomplished by high pressure water jetting alone. However, any loose large lumps may need to be removed mechanically. Just prior to application of the TSL wash down the substrate to remove dust. Cement / polymer based TSLs can be applied whilst the substrate is still damp.

11 WORK ON SITE

11.1 General

Because of the wide variety of types of product available commercially, this specification can only provide the basic principles that should govern the site application procedures. It is imperative therefore that the manufacturer's instructions are studied in advance of the work starting, since particular recommendations or restrictions may influence the overall programme, and these have to be precisely followed. Surface roughness must be taken into account when assessing the quantities required to apply the coating to the required thickness.

11.2 Materials storage

Storage should be arranged so that consignments can be used in the order of their delivery dates within the shelf life of the product. It is important that labels do not become detached from their containers.

11.2.1 Powder components

Bags of product components must be kept dry and stored preferably in a weatherproof building. If the floor is concrete, the bags should be stacked on timber pallets away from walls.

11.2.2 Liquid components

The containers of resins or polymer dispersions should be stored in a weatherproof building, unless the Manufacturer has stipulated other storage conditions for the stated shelf life. Polymer dispersions must be protected from frost at all times.

11.3 Batching

All materials should be accurately proportioned and mixed in the correct sequence in accordance with the manufacturer's recommendations. With two-part liquid powder systems the liquid component must be added to the mixer before blending in the powder component. With two-part powdered polymer/cementitious powder systems the polymer powder must be first mixed with potable water prior to adding the cementitious component. With the single pack system the powder feed rate and the water flow rate must be set accurately in accordance with the manufacturer's instruction prior to application.

The usable life of the mixed materials depends upon the temperature of the mixed materials.

The manufacturer's literature should give an indication of the working life of the properly mixed product at one or more temperatures. Higher temperatures will shorten the working life of the products.

It is essential to ensure that the product has been designed to be used in the expected ambient temperature range.

11.4 Mixing for wet spraying

In order to mix and spray a two component liquid/powder or liquid/liquid TSL system, it is essential that the correct application equipment is used following advice from the product manufacturer. If non-recommended pump units are to be used trials must be undertaken in conjunction with the product manufacturer prior to use.

The mixer should be clean and free from excessive amounts of water or other cleaning fluids as these can adversely affect the performance of the TSL.

Ensure that all hose connections are in place and power is supplied to the pump unit. It is also recommended that a source of water for cleaning be available for cement based systems.

Turn on the mixing unit and add the amount of liquid component as recommended by the manufacturer of the TSL. Part packages should not be used.

For cement polymer systems, with the mixing blade turning at a low rate (if possible) to agitate the liquid, slowly add the correct amount of powder component of the TSL as recommended by the manufacturer to the mixer, taking best care to ensure that no large lumps are allowed to form. Once all of the powder component has been added, increase the speed of the mixer (if possible) until the mixture is being stirred vigorously. Leave the product mixing for the length of time recommended by the manufacturer, typically 3-4 minutes. Excessively vigorous mixing shall be avoided as this can lead to undesirable air entrainment. Care should be taken to ensure that any material adhering to the sides, bottom and corners of the mixer is thoroughly blended in.

Once the TSL is well mixed and free from any lumps or agglomerations, application can begin according to the manufacturer's recommended process.

For cold climates the polymer emulsion may be supplied as a redispersible powder. In this case potable water is first added to the mixer followed by the polymer powder. Once a smooth lump free emulsion has been formed the cementitious component is added and mixing and application are then the same as for the liquid/powder above.

Continuous mixer-pumps may be used if the polymer and cement components are pre-blended into a single pack product by the manufacturer. Such equipment needs to be carefully set up as regards powder feed rate and water flow rate prior to use. The consistency of the mixed material shall be checked at frequent intervals to confirm the proportions are correct. Suitable equipment can be recommended by the product's manufacturer.

For two-part liquid systems the two components can be supplied to the spray nozzle via a static mixer.

11.5 Wet spraying

Once the material has been mixed in the correct manner, as set out above, spraying can commence.

The material should be sprayed through a nozzle approved by the manufacturer.

Output from the pump should be set so that material is emitted from the nozzle at a steady rate. At the same time the air supply to the nozzle should be increased until a fine spray is achieved. Output from the pump and input from the air should be adjusted until this happens.

Once this is achieved, the TSL can be applied. Distance from the nozzle to the surface to which the TSL is being applied should be between 1 and 3 metres. Care should be taken when applying the TSL that all surfaces are evenly coated to the depth recommended by the manufacturer.

Overlap spraying onto adjacent sprayed (and cured) areas of TSL is simply achieved by spraying an overlap width of >10cm. The cured underlying TSL should be cleaned of all loose material and dust prior to the application of the fresh TSL.

11.6 Dry spraying – cement polymer systems

Under no circumstances should the TSL powder be sprayed without the addition of water at the nozzle.

The amount of added water has an effect on the curing time but above a certain level no influence on the end performance.

11.6.1 Conditions for successful spraying

For the successful dry spray application of a TSL the air temperature must be above the minimum recommended by the manufacturer (typically >5°C). The product once applied must not be allowed to freeze until it has fully cured.

A minimum amount of water needs to be added at the nozzle in accordance with the manufacturer's recommendations, typically this is around 30%.

11.6.2 Dry Spraying

The pump must be completely dry before spraying can commence. Test-run the pump empty. Fill the pump hopper with TSL powder directly from the bag. Turn on the air, followed by the water and then the powder feed. When the TSL dispersion is coming out of the nozzle, spray it on to a test wall in order to adjust the pump output. Initially, the pump output should be low. The air output at the nozzle should give sufficient pressure to create a direct fine spray at 2m from the nozzle. Once a steady state has been reached the pump output can be raised. As a

guide it should be possible to operate the nozzle manually without any difficulties caused by too high an air volume.

The spraying distances for both manual and robotic applications should typically be between 1.5 and 2.5m and be carried out in parallel strokes. Subsequent coats should be sprayed in a direction perpendicular to the previous coat. Manipulation of the nozzle should be such as to promote the full coverage of the TSL into the surface texture of the substrate.

Overlap spraying onto adjacent sprayed (and cured) areas of TSL is simply achieved by spraying an overlap width of >10cm. The cured underlying TSL should be cleaned of all loose material and dust prior to the application of the fresh TSL.

11.6.3 Manual and remote controlled robotic application

Hand application is the most common and appropriate way for small diameter tunnels and shafts. To meet the recommended nozzle-substrate distance it might be necessary to apply manually from a lifting platform. Alternatively the nozzle may be mounted on a remote controlled robotic arm. Usually three operators are required for the application of the TSL. The first controls the nozzle, the second manages the feeding hoses for the nozzleman and performs thickness and coverage control, as well as prevents possible mistakes during the application and the third feeds materials and operates the pump.

11.7 Automatic Application for both wet and dry spray systems

In large scale and continuous applications there is a clear advantage in applying TSLs with a fully automatic robotic system. Such systems guarantee a constant and defined thickness. By evaluation of the surface profile and roughness the material consumption can be precisely controlled. Advice on such systems can be provided by the TSL manufacturers.

12 HEALTH AND SAFETY PRECAUTIONS

12.1 General

- a) care shall be taken to ensure that all procedures comply fully with national and local Health and Safety and Environmental regulations.
- b) before starting any operations the manufacturer's Materials Safety Data Sheets for the products to be applied shall be studied and all recommendations followed in addition to those listed here.
- c) an environmental impact assessment on the soil and groundwater should be carried out. Local regulations and the actual application must be taken into consideration particularly if there is any likelihood of contact with drinking water. Polymer cement systems should have no significant impact as hydrated cements are considered environmentally benign and the polymers used are also used in the food industry.

When mixing and applying TSLs, precautions should be taken in accordance with good site practice and include the following:

- a) full protective clothing should be worn to prevent all contact of the products with the skin. Protective gloves should be worn at all times. Goggles or full face shields should be worn during mixing and spraying of polymer cement systems. For reactive systems it may be necessary to wear a fresh air ventilated hood.
- b) it is good practice to apply an appropriate barrier cream on the hands at the beginning of each session.
- c) any splashes of product on the skin should be washed off immediately using soap and water.
- d) any splashes of the product in the eye should be treated immediately by washing with copious amounts of water. Medical treatment should then be sought taking full product details so that correct medication can be supplied.

- e) none of the TSL materials should be swallowed. If any is accidentally ingested a doctor should be consulted immediately. The consumption of food and drink shall be prohibited in the vicinity of the mixing and spraying operations.
- f) smoking should not be allowed in the vicinity of the mixing or spraying operations.

13 INSPECTION AND TESTING OF WORK

13.1 Inspection

The work should be inspected during progress and after completion, special attention being paid to the following:

- a) quality and preparation of the substrate
- b) climatic conditions, throughout the application stages
- c) mixing/batching of the TSL
- d) visual inspection of consistency
- e) spraying the TSL and measuring the applied thickness
- f) date and time of application.

13.2 Site Testing

At the appropriate time after spraying the TSL, tests may be carried out for the following:

- a) applied thickness using a tyre tread gauge or similar
- b) adhesion to the substrate by qualitative peel test
- c) Ultimate Shore A hardness.

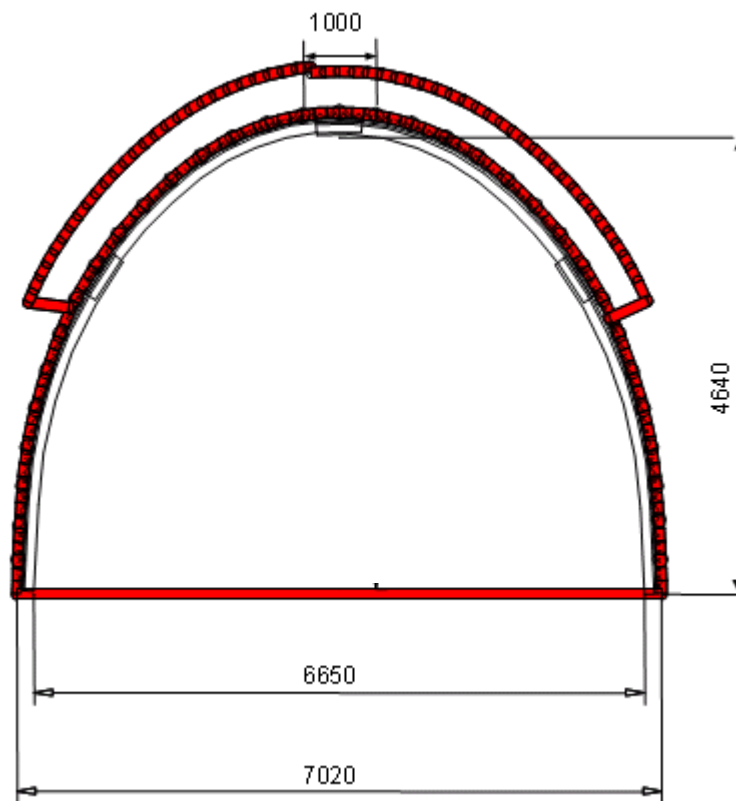
Appendix 1

TSL Linear Block Support Test

1. Objective

Many tests are executed on TSLs to evaluate their mechanical characteristics such as tensile stress / strain, adherence to substrates or shear strength. They are typically defined by norms such as those recommended in the TSL Guidelines but they do not cover the question of how beneficial a TSL is in terms of bearing capacity. Each characteristic mentioned above can play a key role in the mechanism of rock support.

In cooperation with DSK (German Coal Mines) the following was identified as a standard situation on site.



The excavation diameter is 7m and bolts are placed 1m apart and for every metre of advance. For simplicity the mine calculates a maximum 1m x 1m block as the falling block geometry. In order to calculate the block thickness M an empirical formula is used:

$M = 0.06 \times \text{excavation diameter}$ (in above case $7020 \times 0.06 = 421\text{mm}$). The factor 0.06 was found by examining rock falls. Different factors would need to be derived for other mines.

Geometrical simplification of the above leads to a bearing capacity test, where the load is directly related to the length of a linear gap between plane surfaces.

The test setup is shown in Fig. 1.

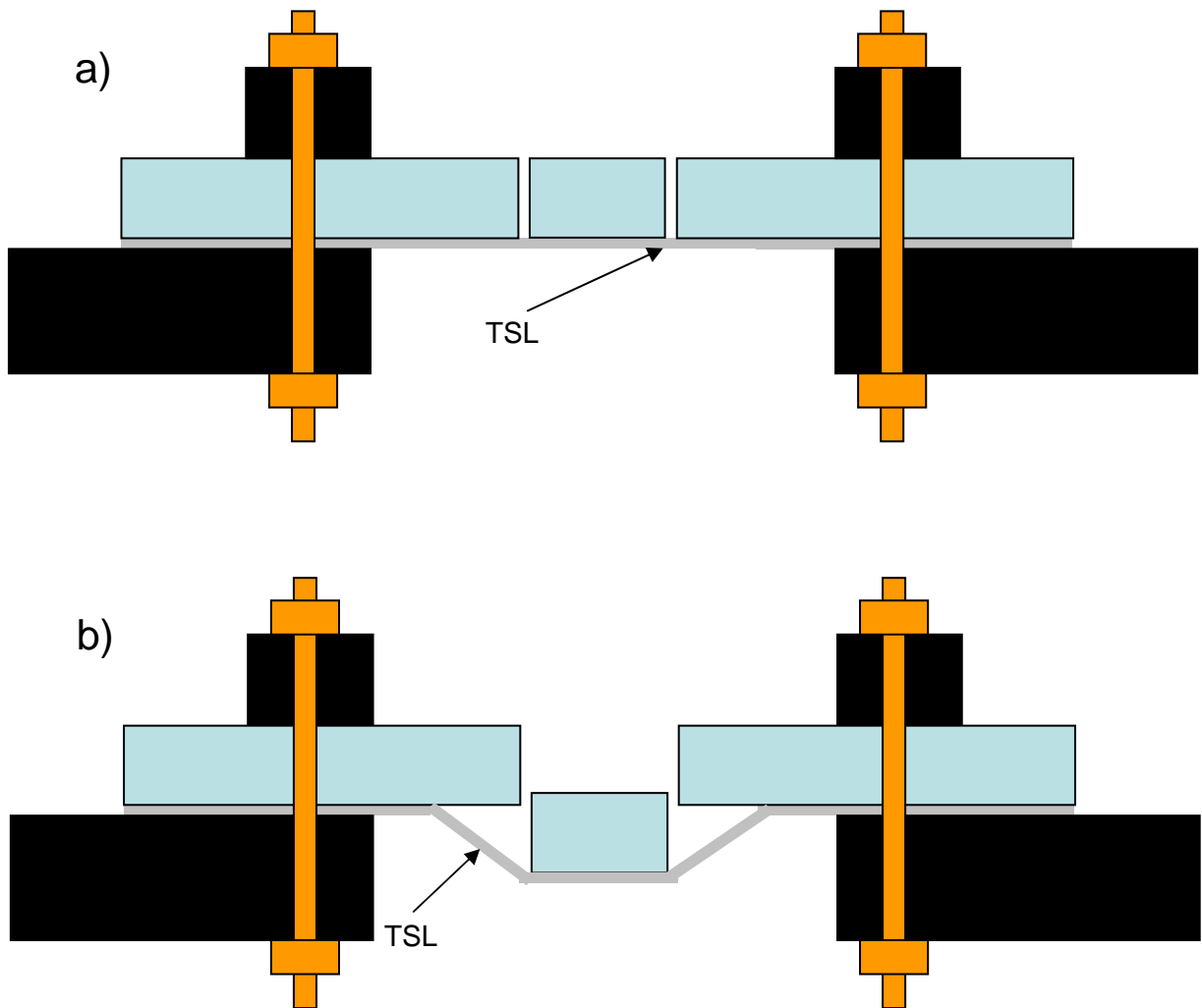


Fig. 1: Setup for TSL Linear Block Support Test

a) fixed test sample before load is applied

b) loaded sample with de-bond as major failure mechanism

In cases where the TSL partially de-bonds (Fig. 1 above) the adherence to the substrate is the limiting factor. A second test to measure the bearing capacity must then be executed as indicated in Fig. 2.

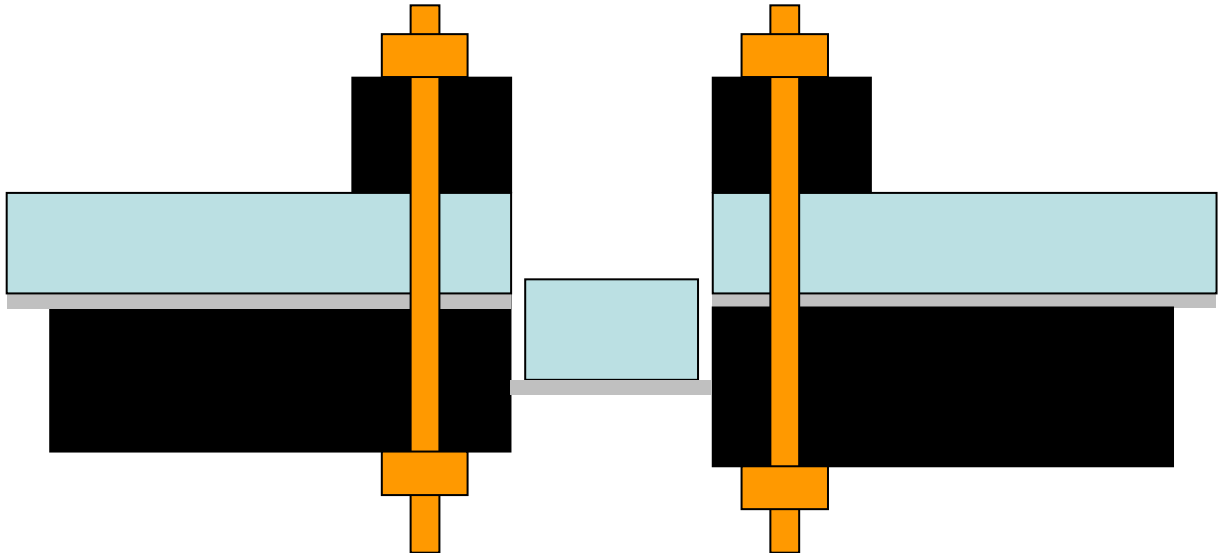




Fig. 2: Gap Shear Load Test

In this case the de-bond of the TSL is avoided so that the pure intrinsic bearing capacity is measured as a shear stress.

2. Equipment

Standard load test equipment such as ZWICK 1485 – UPM (Fitted with a suitable load cell such that the applied load is 10-80% of the load cell's capacity.)

<ul style="list-style-type: none"> ■ test concrete substrate 1. two concrete specimens of 8x4x3 cm 2. one concrete specimen of 4x4x3 cm ■ apparatus 1. formwork 21cmx3cmx3cm 2. several aluminium plates of 4cmx3cmx3mm 3. several aluminium plates of 21cmx3cmx3mm 4. scalpel knife 5. triangular spatula 6. plastic cups 7. measuring cylinder 100 ml 8. laboratory scales 9. safety goggles 	
	

3. Procedure

3.1 Sample Preparation

Step 1:

Aluminium plates and concrete specimens are placed in the formwork as shown in Fig. 3. To avoid later adhesion of the TSL to the aluminium plates they are pre-treated with a mould release agent (spray) such as ACMOS 82-2405.

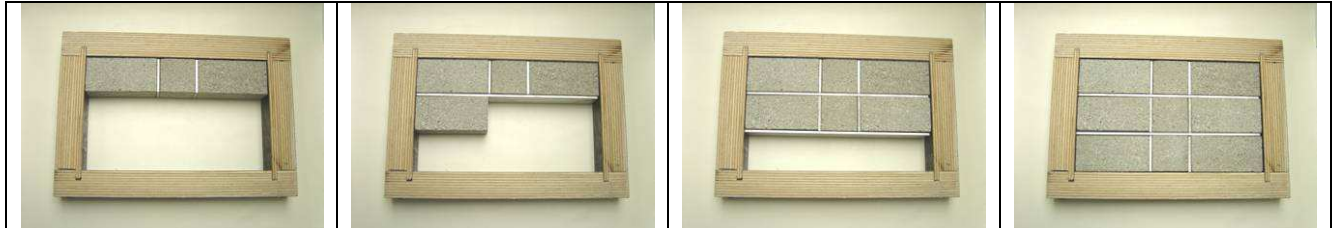


Fig. 3: Formwork Setup

Step 2:

For the thickness control of the TSL two aluminium spacers of a defined thickness, typically 3mm, are placed and fixed on top of the formwork as shown in Fig. 4.



Fig. 4: Spacer Placing and Fixing

Step 3:

The TSL is mixed and prepared in accordance with the manufacturer's instructions and applied by hand as in Fig. 5, or if thickness control plays a minor role, it can also be sprayed onto the framework setup in step 2.

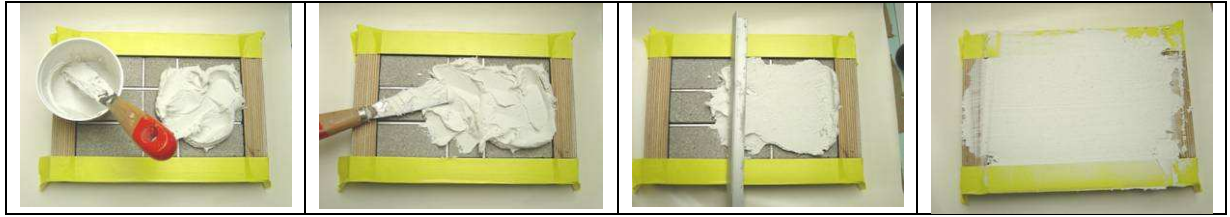


Fig. 5: Manual Sample Preparation

Step 4:

Immediately after application of the TSL the samples shall be stored in a climate chamber until testing. Standard climate is $20 \pm 1^\circ\text{C}$ and $65 \pm 5\%$ rh.

Step 5:

Shortly before testing the samples are cut from the formwork as shown in Fig. 6.



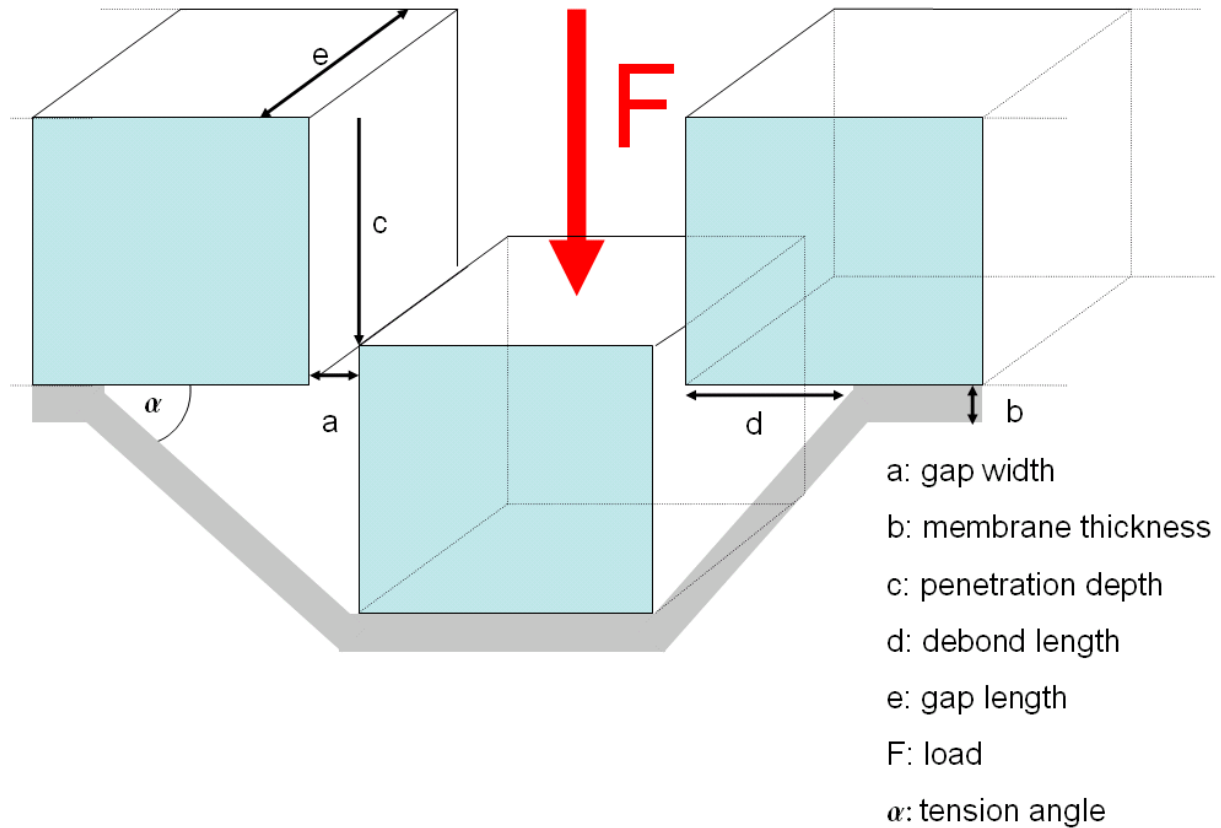
Fig. 6: Cutting the Sample

3.2 Testing

The test specimen is screwed tight to the test device according to Fig. 1 and Fig. 2 taking care not to compress the TSL.

The displacement speed is set to 16mm/min. The load displacement curve is measured until failure of the TSL.

4. Results and Calculation



It is essential in all cases to report the gap width (a) with 3mm as standard, the gap length (e) 4 cm in this case and TSL thickness (b) where also 3mm is recommended. The load F shall be plotted against the penetration depth (c) where F_{max} and (c) at F_{max} shall be reported. After the break of the TSL the de-bond length (d) shall be measured on both sides. The angle α can be calculated by

$$\alpha = \arctan\left(\frac{c}{a+d}\right)$$

In the case of a de-bonded TSL the adherence/bond of the TSL to the substrate is the limiting factor. In order to determine the shear strength of the TSL it is necessary to carry out the linear block test as shown in Fig 2.

Fig. 7 shows the load displacement curve in purple for the Fig 1 layout where debond takes place and the curve in blue for the Fig 2 layout where debond is prevented. In order to compare the two curves the same thickness of TSL must be used in both cases.

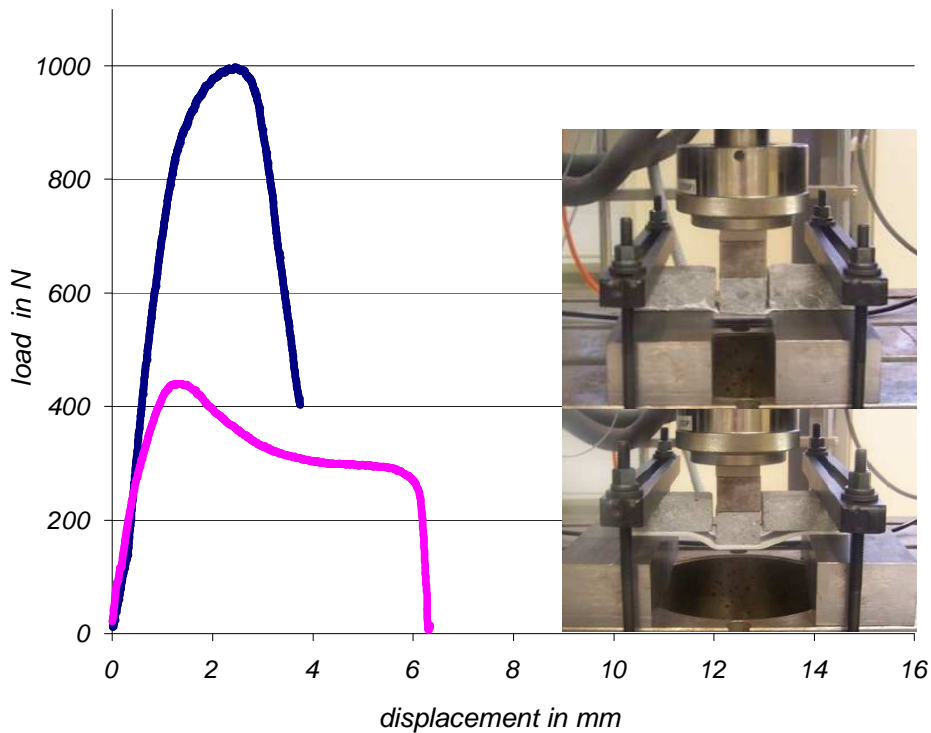


Fig. 7: Example of Test Report of Both Load Tests

The linear load capacity LLC is calculated as

$$LLC = \frac{F_{max}}{2 * e} \text{ and has the dimensions N/cm.}$$

The LLC is used to calculate the potential bearing capacity of a TSL under site conditions by multiplying the LLC by the perimeter of the maximum potential loose block. In the DSK example this is 4 metres (400cm) as the 1mx1m block is in contact with rock on all 4 sides and gives the load to be carried.

When de-bond occurs the TSL thickness is sufficient – i.e. increasing the TSL thickness will not increase the load. The ratio of LLC in pure shear failure and LLC in de-bond conditions gives the safety factor for the target thickness.

Appendix 2

Future developments

There are industry requirements for both High Performance (HP) TSLs and TSLs to mitigate the effects of rockbursts (R).

For these two requirements Classes HP and R were proposed.

It was proposed that Class HP would need to be equivalent to 50mm of reinforced shotcrete. At present in order to calculate the bearing capacity of shotcrete the E-modulus, compressive and tensile strengths are taken into account. However, the bearing capacity for 50mm of a typical reinforced shotcrete it is not considered significant by rock engineers. As the physical properties of a TSL are entirely different to reinforced shotcrete work needs to be carried out comparing the bearing capacities of shotcretes and TSLs directly.

To minimise the effects of rockbursts one has to absorb as much energy as possible. At present there is data for wire mesh, shotcrete and rock bolts. Similar data needs to be derived for TSLs before a Class R can be specified.