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THE UNIVERSITY OF NEW SOUTH WALES

Experimental study for reducing gas inflow by use of TSLs in underground coal mines

Never Stand Still | Engineering | School of Mining Engineering

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Presentation Overview

- Introduction of myself
- Problem
- What is TSL?
- Support mechanism
- Research background
- UNSW research
- Conclusions
- Discussions

Introduction of myself

QUALIFICATIONS
- B.E. in Mining Engineering, DEU, 1992
- M.Sc. in Mining Engineering, DEU, 1995
- Ph.D. in Mining Engineering, DEU, 2000

EMPLOYMENT
- 1994 - 2003 DEU, Department of Mining Engineering, Izmir, Turkey - Research Assistant
- 2002 - 2003 WITS University, School of Mining Eng., Johannesburg, South Africa - Visitor Researcher/Post-Doctorate Fellow
- 2003 - 2006 De Beers Consolidated Mines, Group Technical Support, Mining Research Division, Johannesburg, South Africa - Project Manager
- 2006 - 2011 UNSW, SME, Senior Lecturer and PG (Research)
- 2012-present UNSW, SME, A/Prof and Scholarships Academic Coordinator and Research Coordinator

TEACHING AREAS
- Mine Planning
- Mine Design & Feasibility
- Resource Estimation
- Technology Management
- Mining Methods

RESEARCH INTERESTS
- Ground Control
- Mine Planning
- Innovation in Education & Training

RESPONSIBILITIES
- Assistant Director of Research
- School Academic Scholarship Coordinator

Problem Statement

- The velocity of the gas migration depends on the coal permeability.

- Mines have to develop effective *gas control strategies* to capture and control, ensuring that gas concentration in the roadways is maintained below the 1.25% to prevent any explosion.

Can we use TSLs as a gas management tool?

- Emerged for economy and safety reasons to replace surface support systems such as mesh and thin shotcrete (<50 mm).
- Particular focus to underground hard rock mines.
- Mostly used in Northern America and South Africa.
- Their use has been slow to be adopted into coal mining.

Main function of TSLs;

- to prevent release of rock fragments, and

- to catch small rock falls between rock bolts

There are many different types of TSL product in the market.

They differ by polymer base and mixture types based on their chemical compositions.

But not been developed to replace conventional ground support techniques

- Should be considered as a ***temporary or combined support*** with other ground support tools.

- TSLs have performed well when combined with

  rockbolts+TSL+shotcrete and

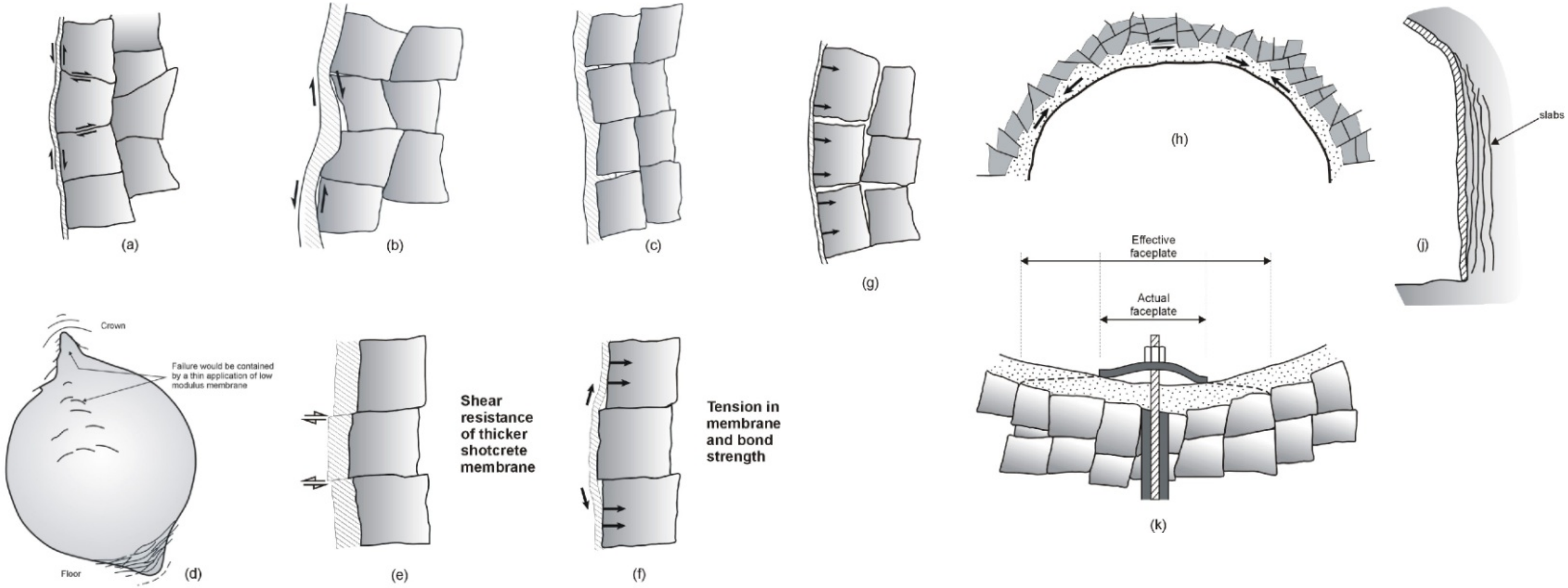
  rockbolts+TSL+mesh+shotcrete.
- Prohibit initiation and propagation of fractures and key blocks and,
- so improve the rock strength and excavation stability.

Definition

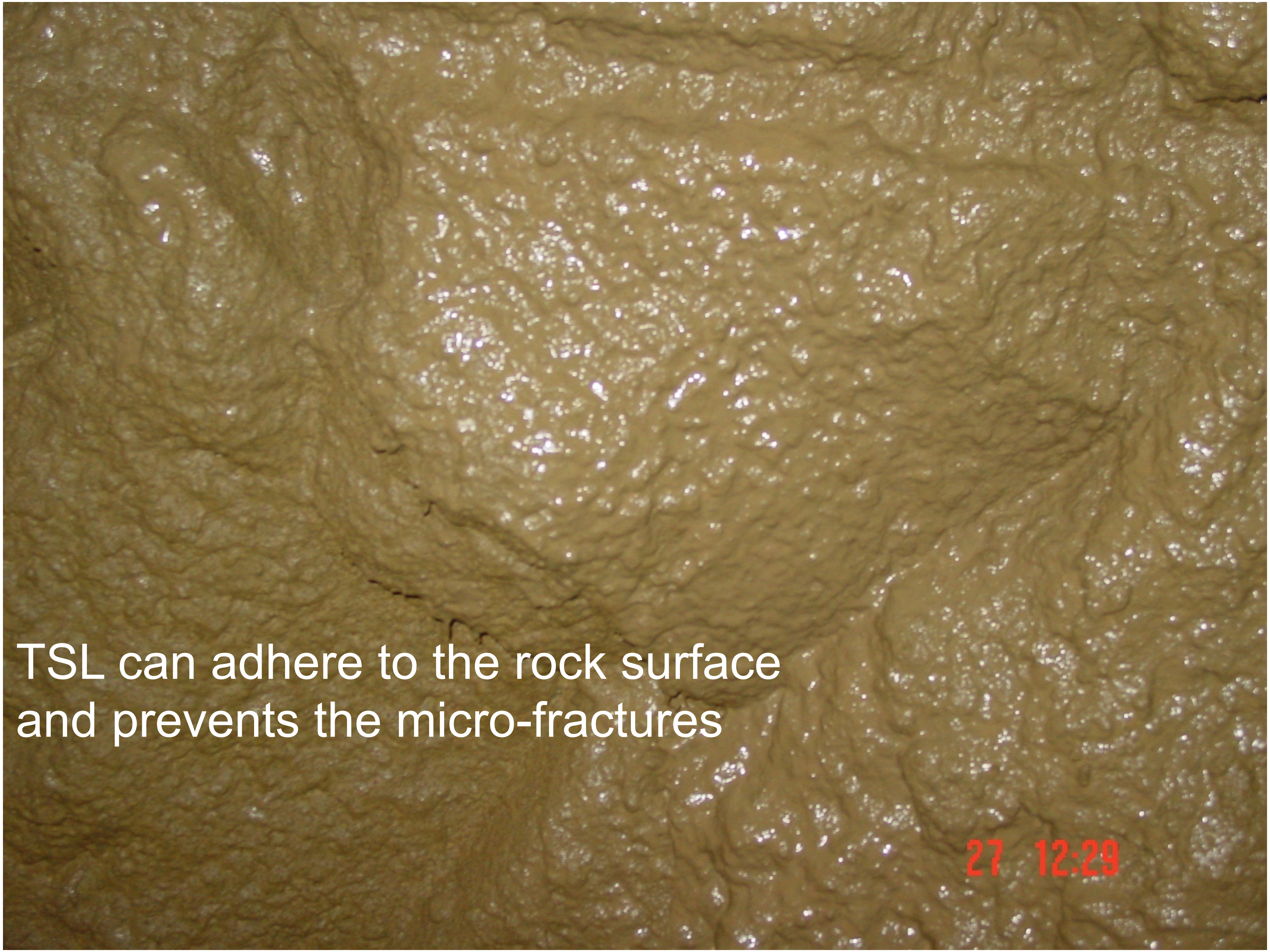
TSL is polymer based material which can be sprayed onto the rock to a thickness of 3 to 5 mm and is normally part of support system and seals between rock and mine environment.

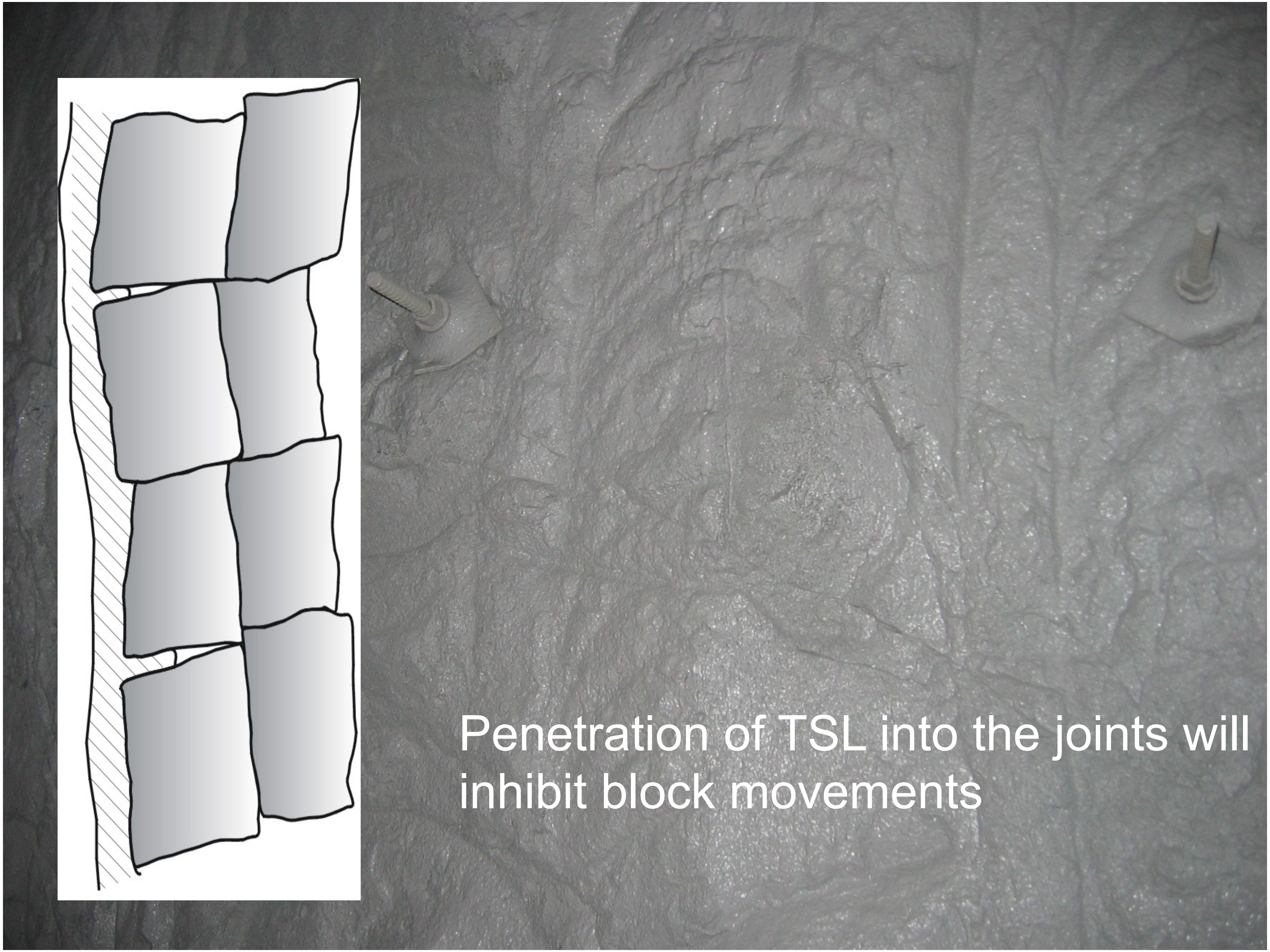
Applied by mixing and spraying a combination of liquid/liquid or liquid/ powder components onto the rock face as quickly as possible, where a TSL sets quickly and develops a strong bond with the rock.

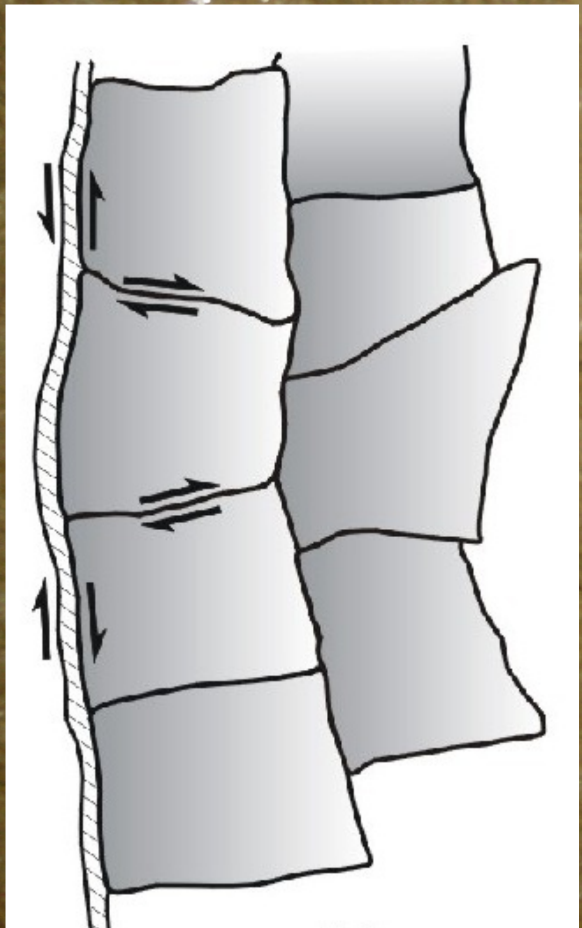
Support Mechanisms of Surface Support Liners



Stacey, 2001


TSL can adhere to the rock surface
and prevents the micro-fractures
27 12:29


Penetration of TSL into the joints will
inhibit block movements

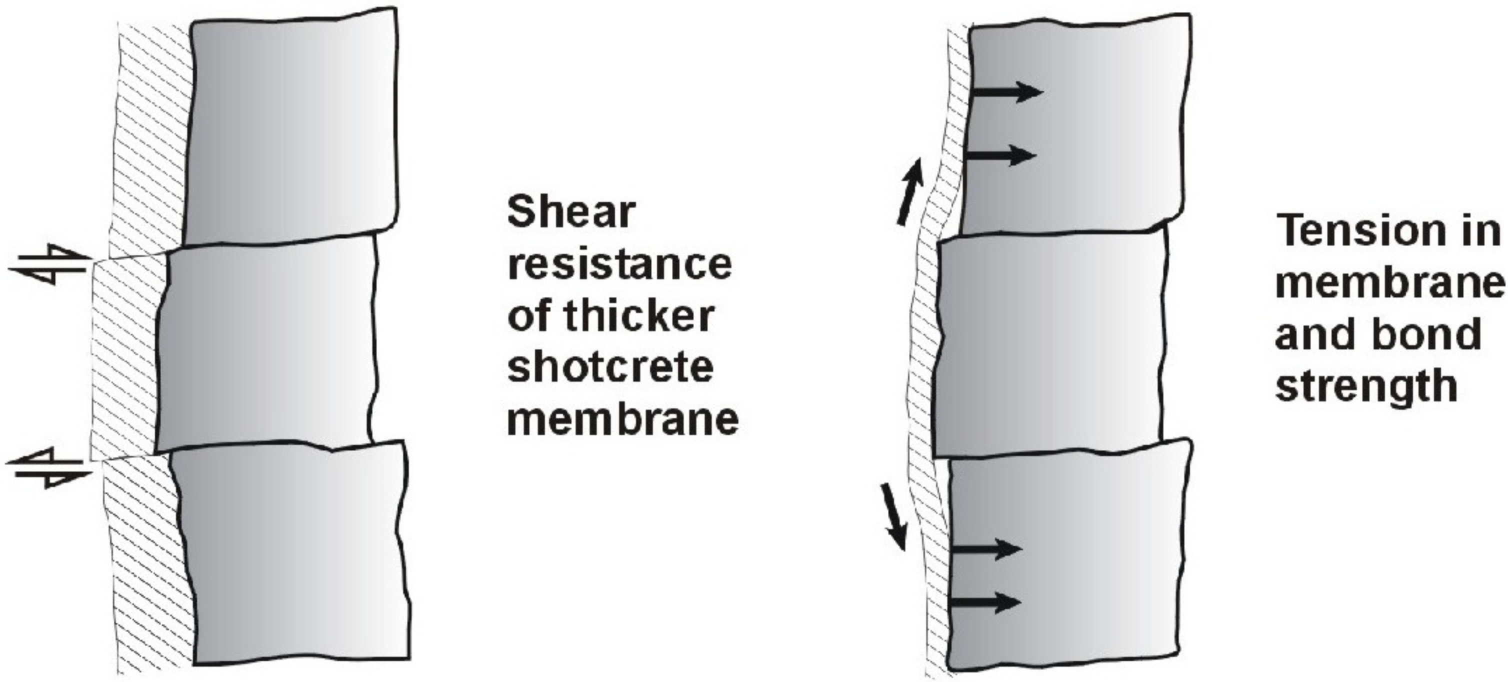


The interlock (is promoted by the bonding of TSL to the rock, and tensile strength) of the TSL. Shear on the interface between rock and TSL is prevented by the bonding.


Improve light reflection


A TSL can reduce;
Ground degradation (weathering, swelling, slaking)
Ground alteration (moisture, heat, humidity)
& Improve tunnel stability
18 9:58 PM

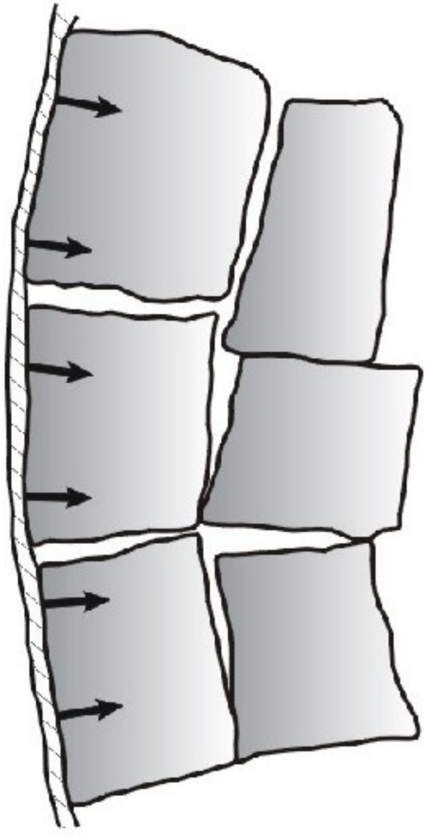
Support Mechanism
(block interlock)



Prevention of block displacement by two mechanism: the shear strength and the tensile strength of the liner

Stacey, 2001

Support Mechanism
(air tightness)

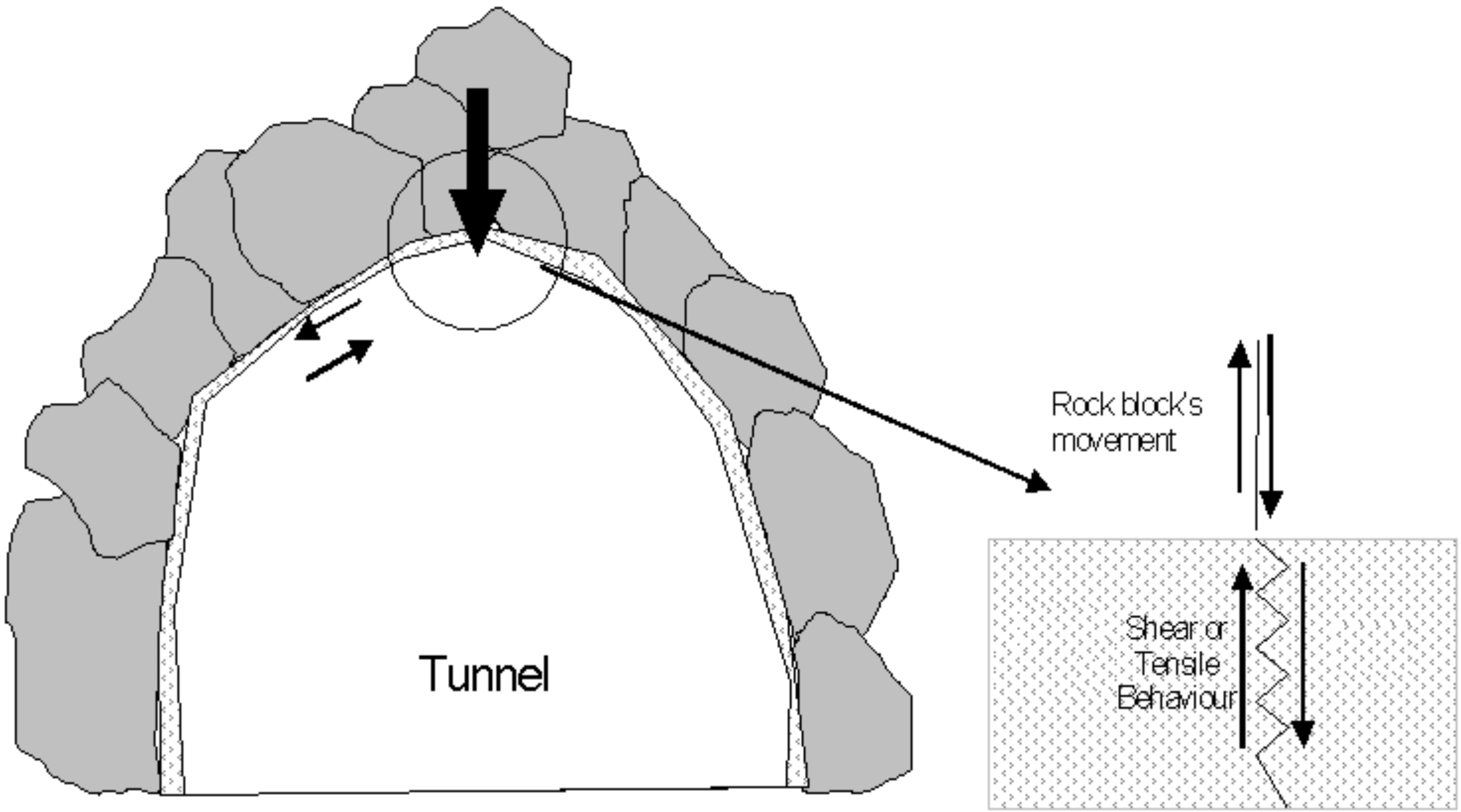


If dilation can be prevented, failure will be inhibited. If the applied surface support is air tight, entry of air will be prevented or limited, and hence dilation will be restricted.

Air tight surface support promotes ‘suction’ support pressure.

Stacey, 2001

Support Mechanism (structural arch)



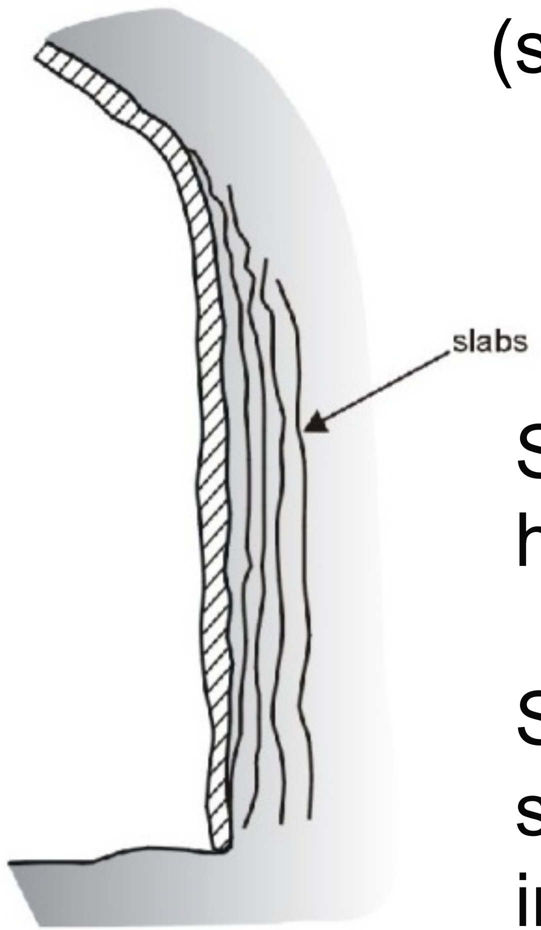
Compressive stresses induced in structural surface support resistance.

Support Mechanism (basket mechanism)

When the surface support **develop**s the form of **a basket**, which then contains the failed rock, it will be acting mainly in **tension**.

In this situation there are two considerations: firstly, the flexural rigidity or ductility, which will serve to resist the deflection of the liner to form a basket; secondly, the tensile strength of the liner itself.

Support Mechanism (slab/beam enhancement)

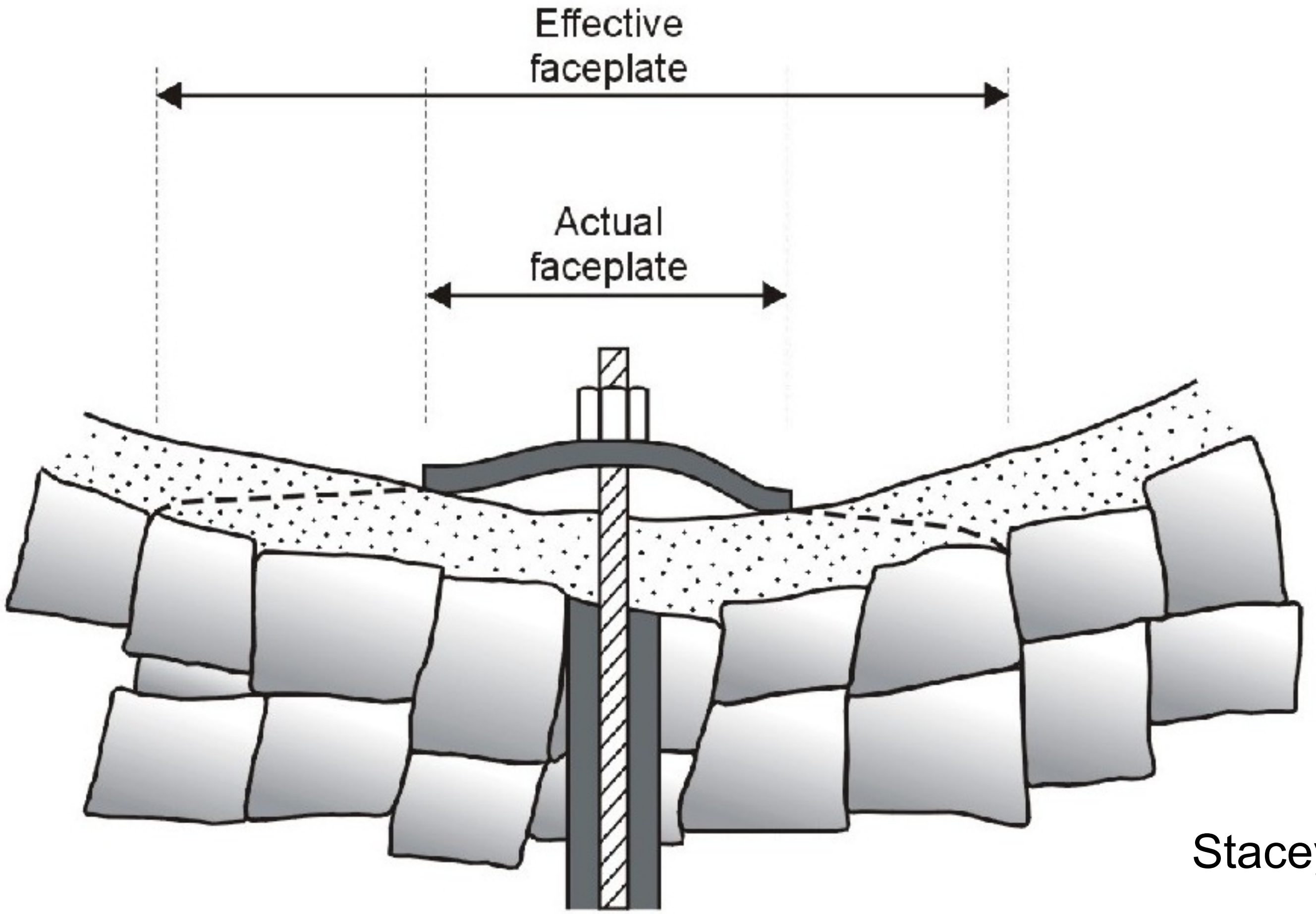


Slabs may fail due to buckling under high stress conditions.

Surface support decreases the slenderness of the slab and increases its buckling resistance.

Stacey, 2001

Support Mechanism (extended 'faceplate')



Stacey, 2001

Durability enhancement

Some rock types deteriorate on exposure and when subjected to wetting and drying. The 100 mm reinforced fibrecrete has potential to seal rock surface.

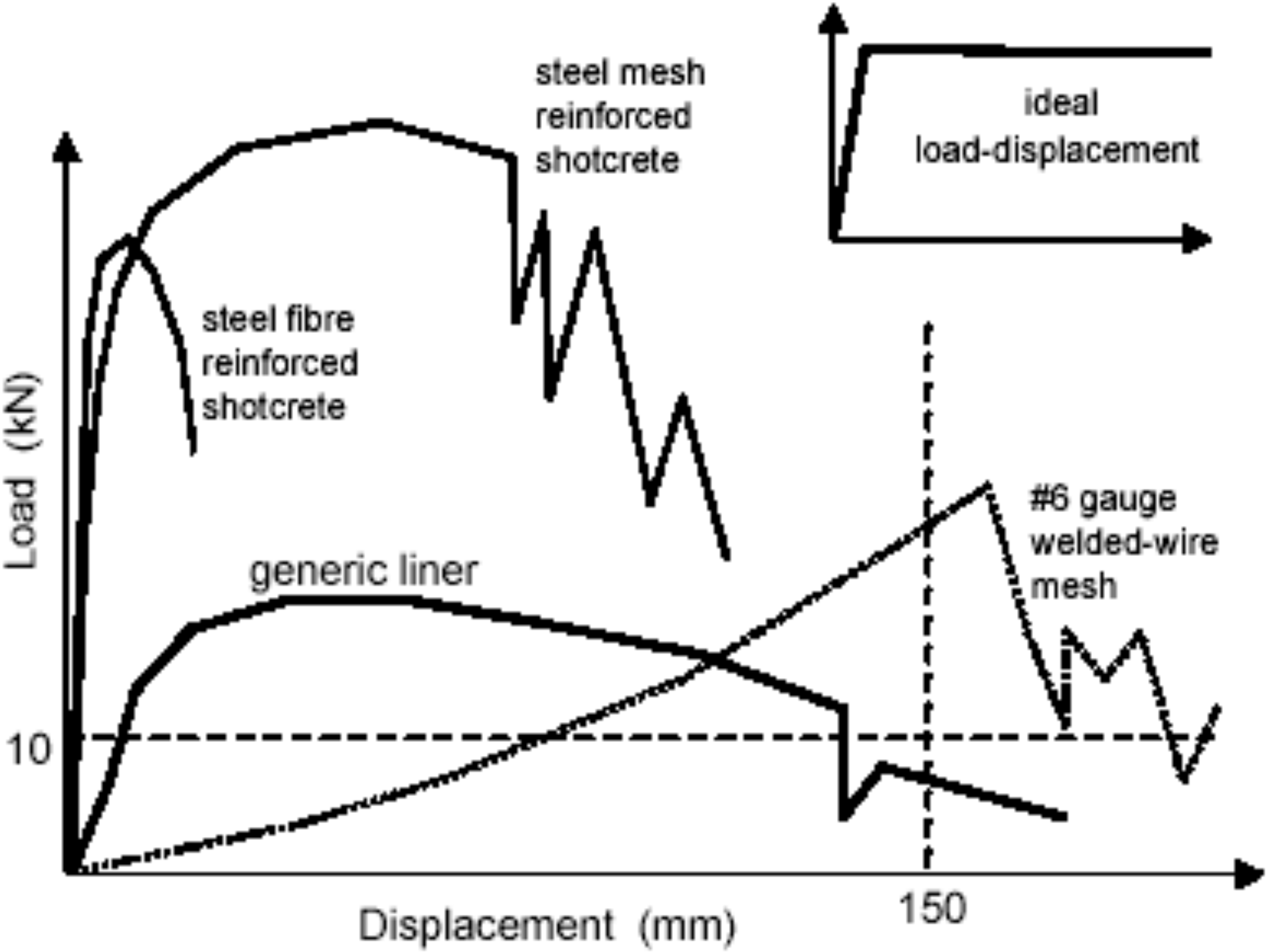
The mechanism of TSLs is to seal the rock to prevent exposure and hence preserve the inherent strength of the rock.

Mechanical Protection

Mechanical damage will quickly destroy the effectiveness of the surface support.

Shotcrete (<50mm) has potential to prevent mechanical impacts, but…

Cementitous TSLs also have mechanical protection.



steel mesh
reinforced
shotcrete
ideal
load-displacement
steel fibre
reinforced
shotcrete
Load (kN)
#6 gauge
welded-wire
mesh
generic liner
10
150
Displacement (mm)

D. Tannant

Mechanical Properties of TSLs

- Tensile Strength (Elongation)
- Adhesion (Bond) Strength
- Tear Strength
- Shear Strength
- Creep Behavior

Typical applications

- Support between rock anchors
- Supporting areas with limited access and/or logistics constraints
- Mesh replacement
- After blasting immediately supporting as a primary support
- Temporary support (before shotcrete)
- Temporary support in TBM tunnels (poor ground)
- Reduce rockburst damage
- Pillar reinforcement
- Face support
- Large machine borehole lining and stabilization
- Stabilization of return air tunnel
- Rehabilitation
- Orepass lining
- Prevention of Rockfalls
- Rigid ventilation seals
- Ground degradation (weathering fretting, swelling, slaking)
- Ground Alteration (moisture, heat, humidity, chemical contamination)

Potvin et al (2004)

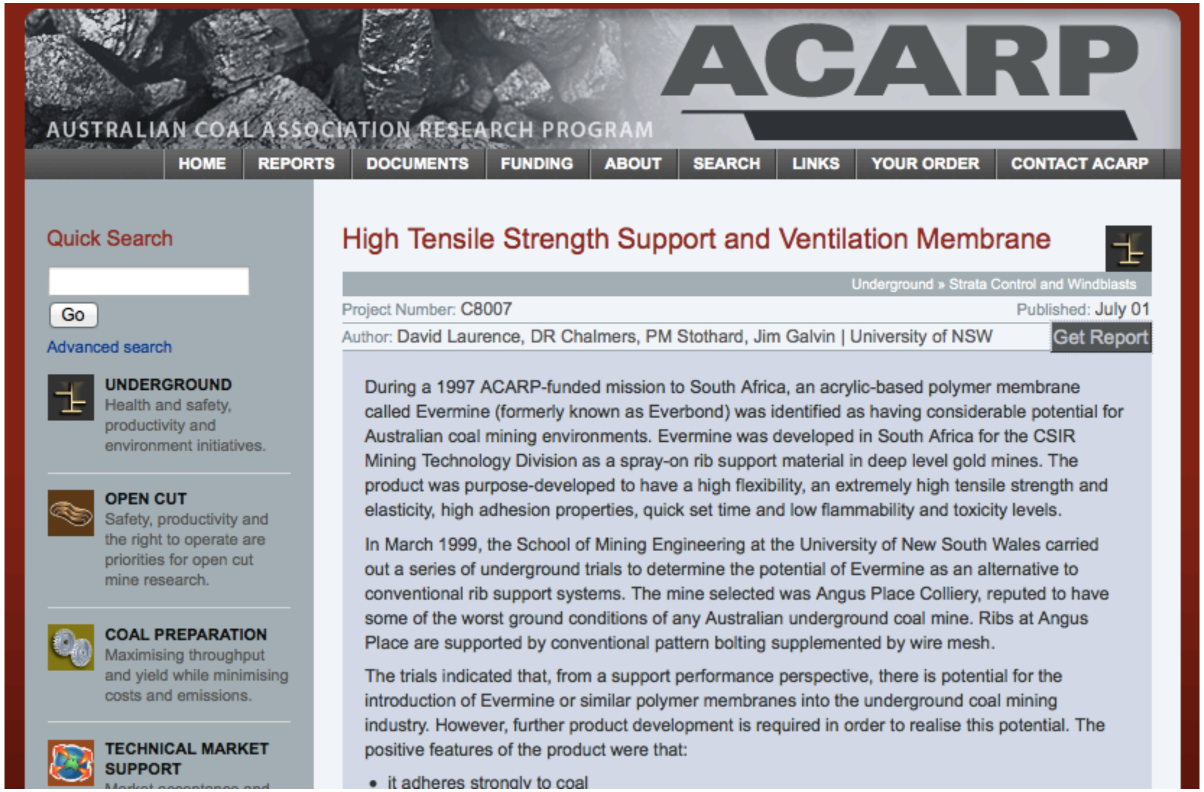
Related Research Background

Limited research conducted for underground coal applications:

- ACARP, UNSW 1998
- EFNARC REPORT, 2008
- UNSW Research, 2010
- ACARP, UoW 2011

ACARP – *Laurence, Chalmers, Stothard, Galvin, 1997*. UNSW

- It is the first research conducted on coal. This study shows the potential of use of TSLs in underground coal mines.
- They conducted a series of tests and trials in different underground coal mines using a TSL product.



EFNARC Report (2008)

Identified the following possible advantages of using TSLs compared with shotcrete:

- thinner applied thickness; increased toughness, durability,
- resilience, stronger permanent bond to the substrate;
- reduced dusting; much greater tolerance to ground movement, and resistance to cracking.

The report clearly, mentioned the advantage of using TSLs as a barrier, and against gas and moisture movement.

EFNARC

'achieving the highest standards'

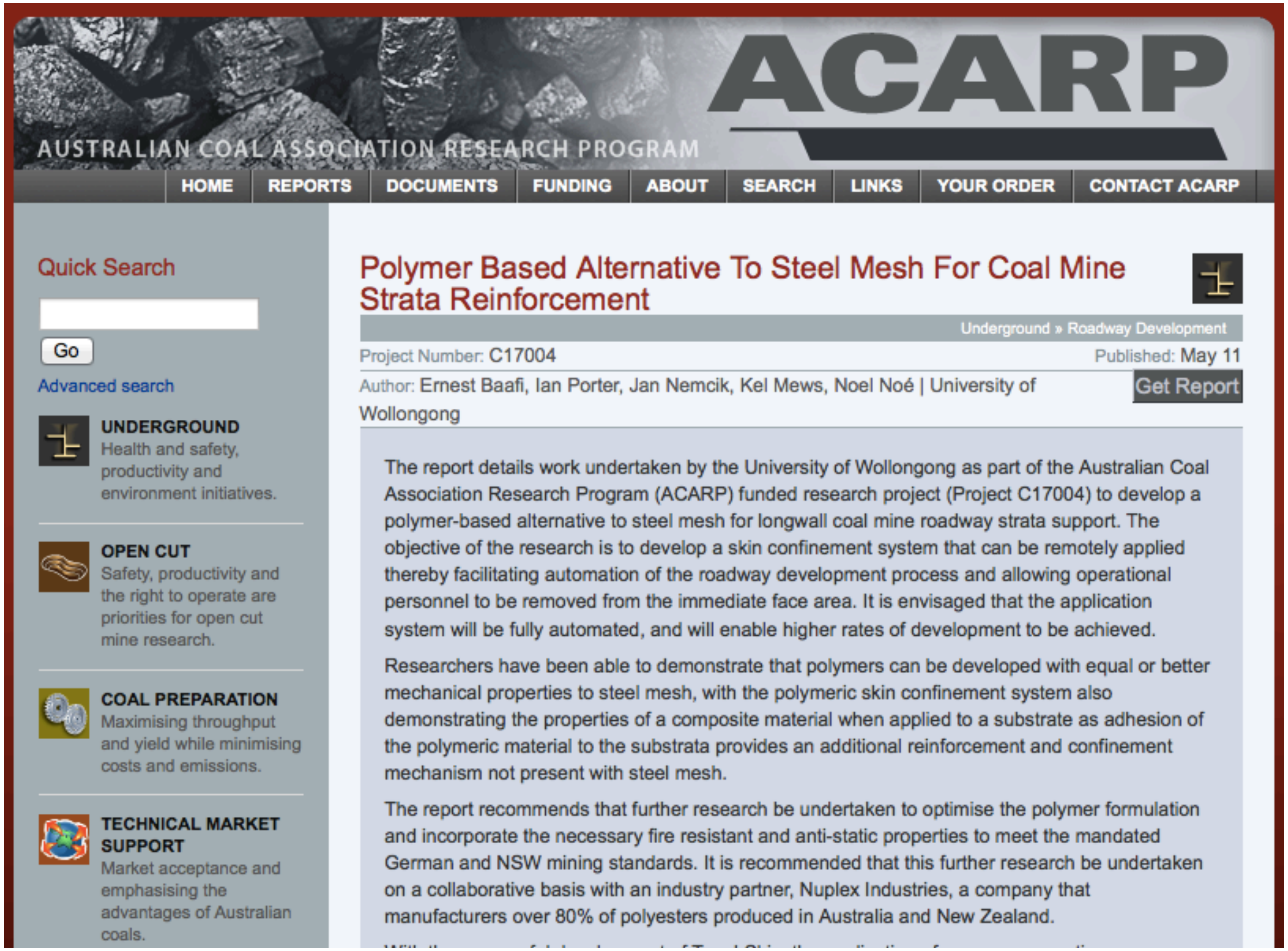
achieving the highest standards EFNARC

Experts for Specialised Construction and Concrete Systems

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

July 2008

ACARP - *Baafi et al, 2011*. UoW



AUSTRALIAN COAL ASSOCIATION RESEARCH PROGRAM

ACARP

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UNDERGROUND
Health and safety, productivity and environment initiatives.

OPEN CUT
Safety, productivity and the right to operate are priorities for open cut mine research.

COAL PREPARATION
Maximising throughput and yield while minimising costs and emissions.

TECHNICAL MARKET SUPPORT
Market acceptance and emphasising the advantages of Australian coals.

Polymer Based Alternative To Steel Mesh For Coal Mine Strata Reinforcement

Underground » Roadway Development

Project Number: C17004 | Published: May 11

Author: Ernest Baafi, Ian Porter, Jan Nemcik, Kel Mews, Noel Noé | University of Wollongong

Get Report

The report details work undertaken by the University of Wollongong as part of the Australian Coal Association Research Program (ACARP) funded research project (Project C17004) to develop a polymer-based alternative to steel mesh for longwall coal mine roadway strata support. The objective of the research is to develop a skin confinement system that can be remotely applied thereby facilitating automation of the roadway development process and allowing operational personnel to be removed from the immediate face area. It is envisaged that the application system will be fully automated, and will enable higher rates of development to be achieved.

Researchers have been able to demonstrate that polymers can be developed with equal or better mechanical properties to steel mesh, with the polymeric skin confinement system also demonstrating the properties of a composite material when applied to a substrate as adhesion of the polymeric material to the substrata provides an additional reinforcement and confinement mechanism not present with steel mesh.

The report recommends that further research be undertaken to optimise the polymer formulation and incorporate the necessary fire resistant and anti-static properties to meet the mandated German and NSW mining standards. It is recommended that this further research be undertaken on a collaborative basis with an industry partner, Nuplex Industries, a company that manufacturers over 80% of polyesters produced in Australia and New Zealand.

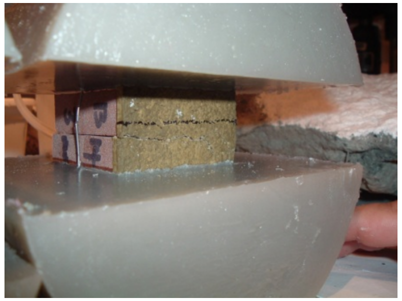
Tests conducted at the UNSW

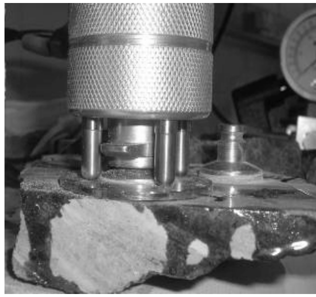
Previous research @ UNSW

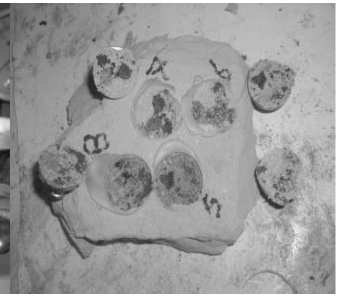
- adhesion strength test
- double-sided shear strength
- coated core test
- bending test
- portable shear box testing
- weathering tests - slake durability, swelling…)

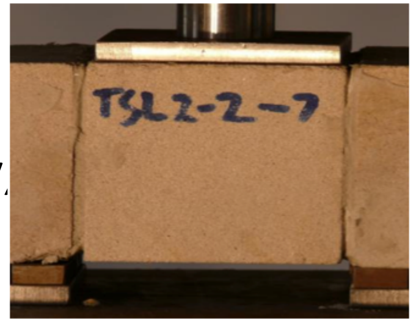
on concrete, sand stone and coal

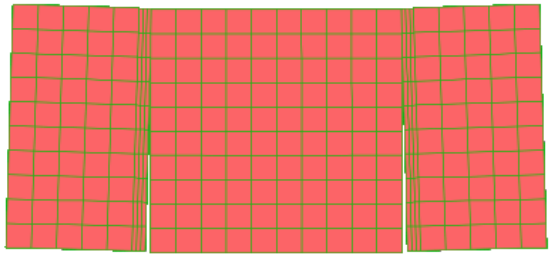
samples including test numerical modeling work

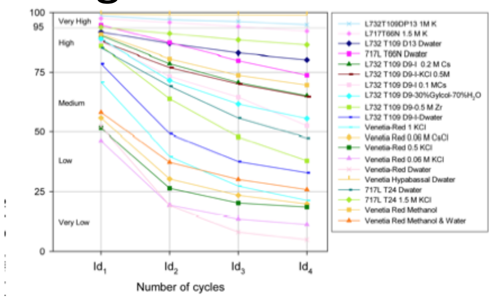


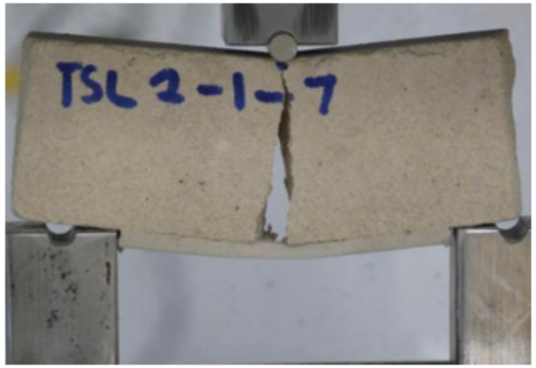












Saydam and Docrat, 2007;

Morkel and Saydam, 2008;

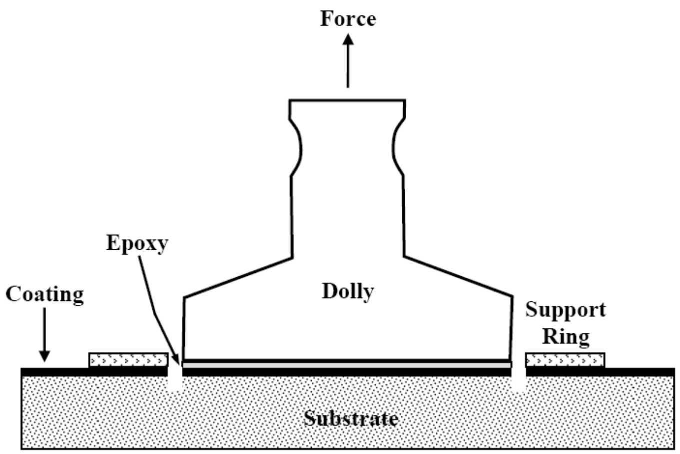
Lau, Saydam, Cai and Mitra, 2008;

Richardson, Mitra and Saydam, 2009

Gilbert, Saydam and Mitra, 2010

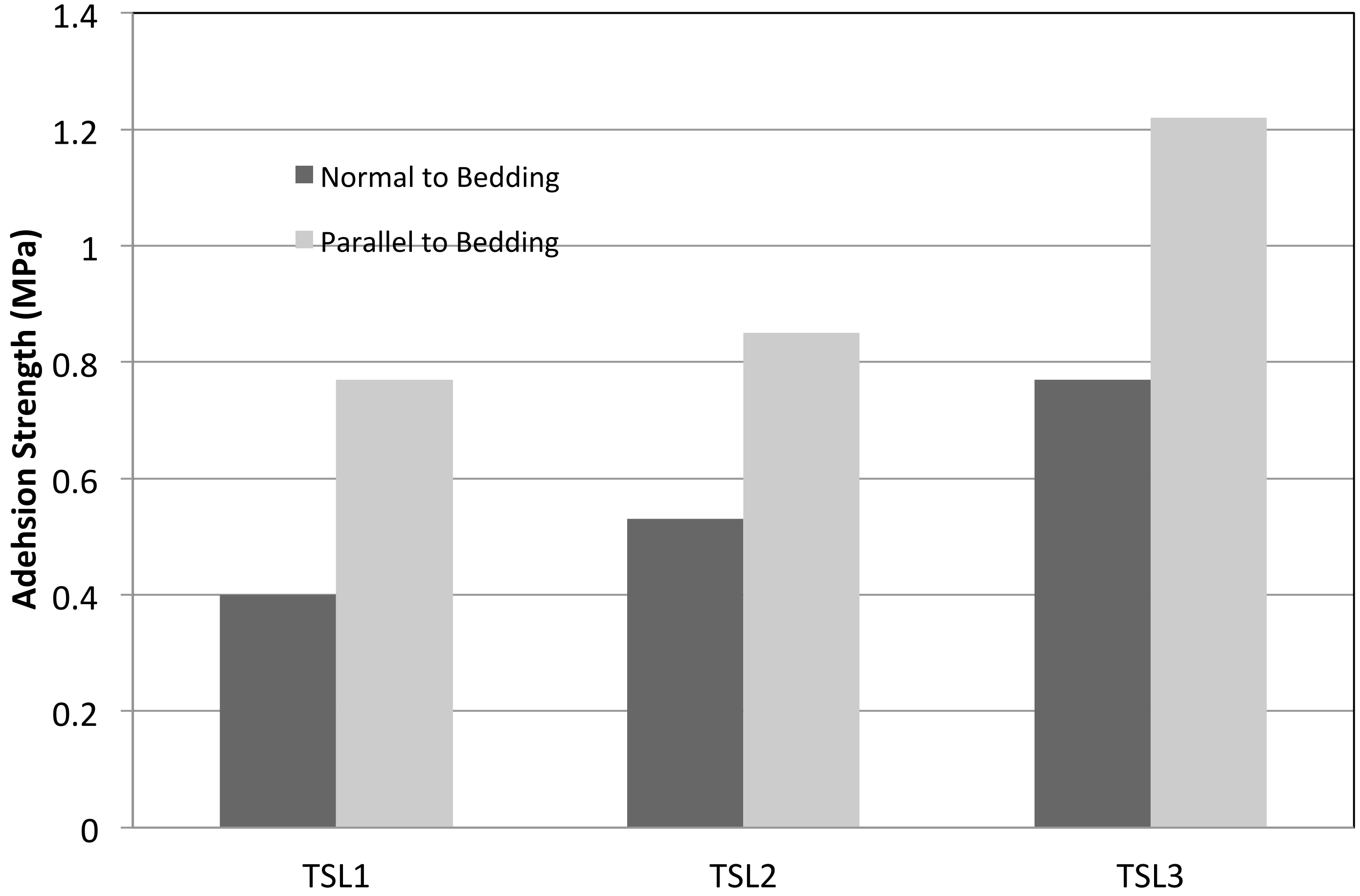
Adhesion Strength Test

- 3 different TSL materials tested
- 4 mm thickness
- Total 21 tests undertaken with a curing time of 7 days.
- SIMRAC guidelines modified (Kuijpers et al, 2004)



Gilbert, Saydam and Mitra, 2010

Adhesion Strength Test Results



Gilbert, Saydam and Mitra, 2010

Gas Management Related Research

- Archibald et al (1999) measured the radon gas blocking capacity and gas permeability of different TSL materials.

- The potential use of liners in reducing gas inflow and decreasing air flow frictional resistance.

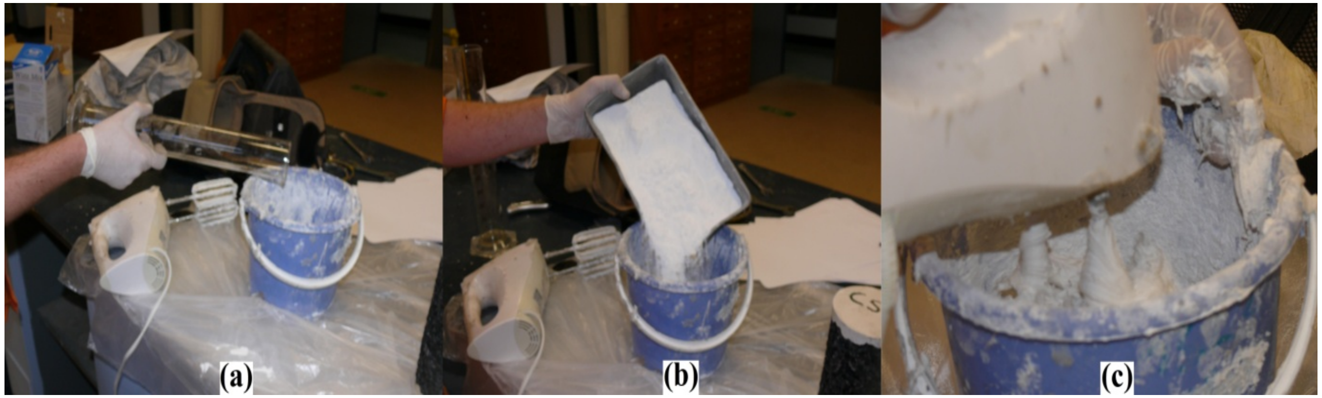
- TSLs have the capability to restrict hazardous gas inflows and optimise flow capacities of ventilation networks that will provide additional benefit for health and safety while reducing mine power costs.

- Saghafi and Roberts (2001) - measurements of the permeability of a TSL product for methane, carbon dioxide and carbon monoxide. Their results indicate permeability of TSLs in the range of nanodarcies.

UNSW - Gas Permeability Tests

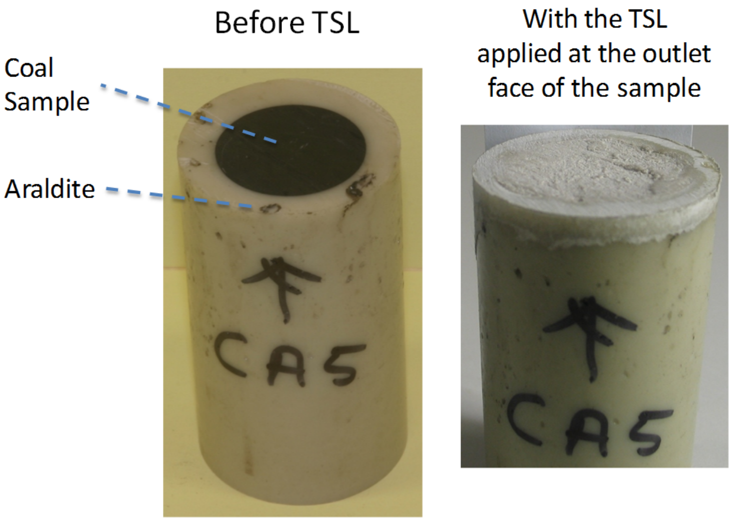
- The same 3 different TSL products, each from two different companies were tested in this study: TSL-1, TSL-2 and TSL-3.

- All three TSLs are cementious acrylic based.

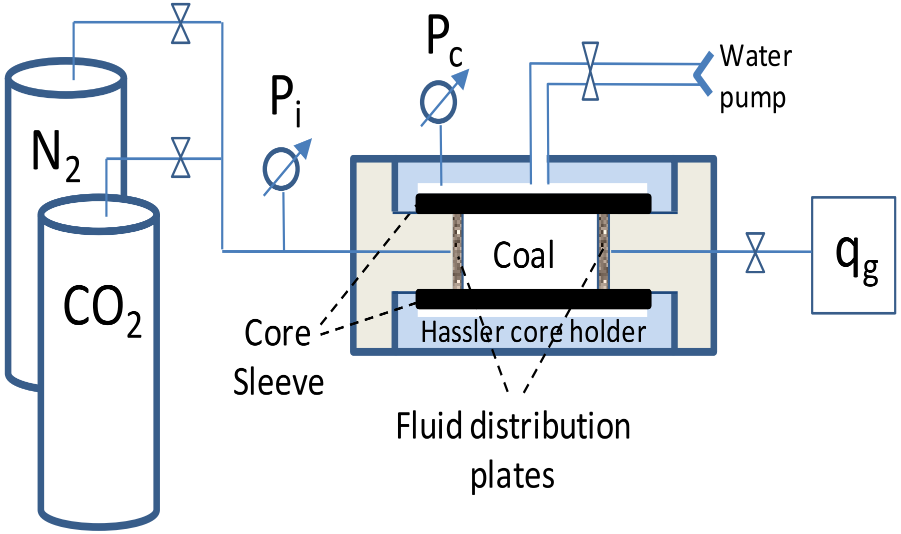


Mixing procedure of TSL-2

Single Phase Gas Flow Test Procedure



Coal sample preparation and TSL application



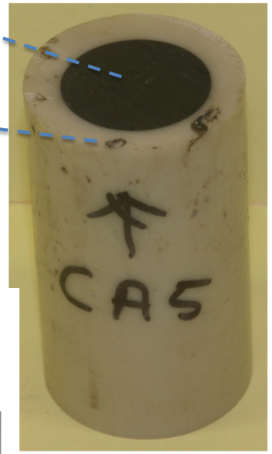
Schematic view of the experimental apparatus used for gas flow tests.

- Core dimensions: 45 mm x 107 mm
- Confining pressure 1500 kPa which equivalent to overburden pressure
- CO_2 has much more tendency to adsorb on coal surface than N_2 and CH_4, while CH_4 has slightly higher affinity than N_2.
- When ejected, CO_2 swells the coal thereby reducing its permeability.
- CO_2 is more viscous and has larger molecular size compared with the other two gases.
- CO_2's desorption rate is relatively slower too.
- Flow behaviour of CH_4 is expected to be in between CO_2 and N_2 flows.

Test Procedure

- Coal samples first tested without TSL
- N_2 flow test
- CO_2 flow test
- TSL applied to outlet face of the core
- 3 repeats
- Different thicknesses of TSLs were applied

Before TSL



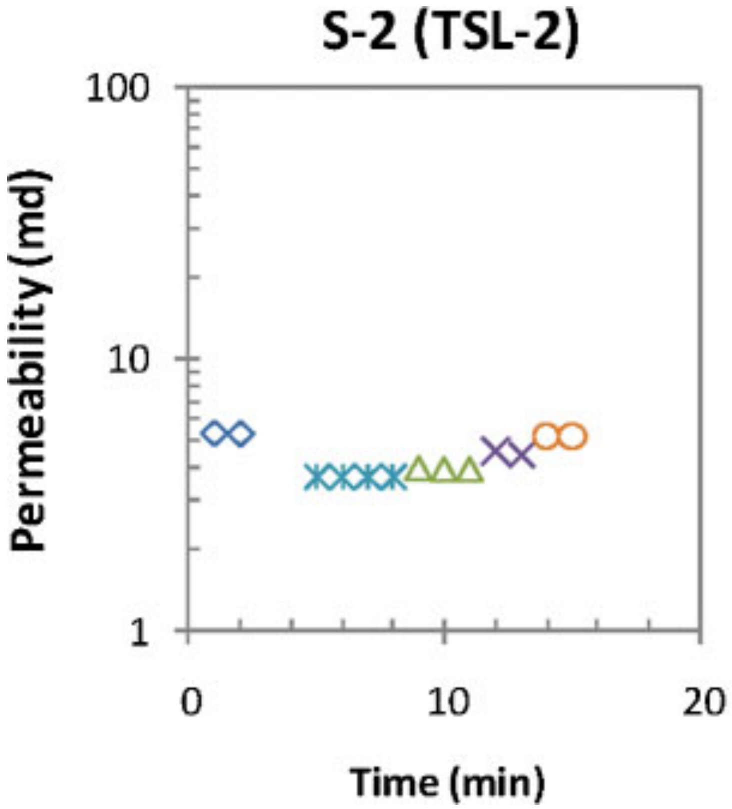
With the TSL applied at the outlet face of the sample

- Due to coal's weak strength its permeability changes under the confining pressure.
- To minimise effect of confining pressure coal samples were covered with an epoxy adhesive.

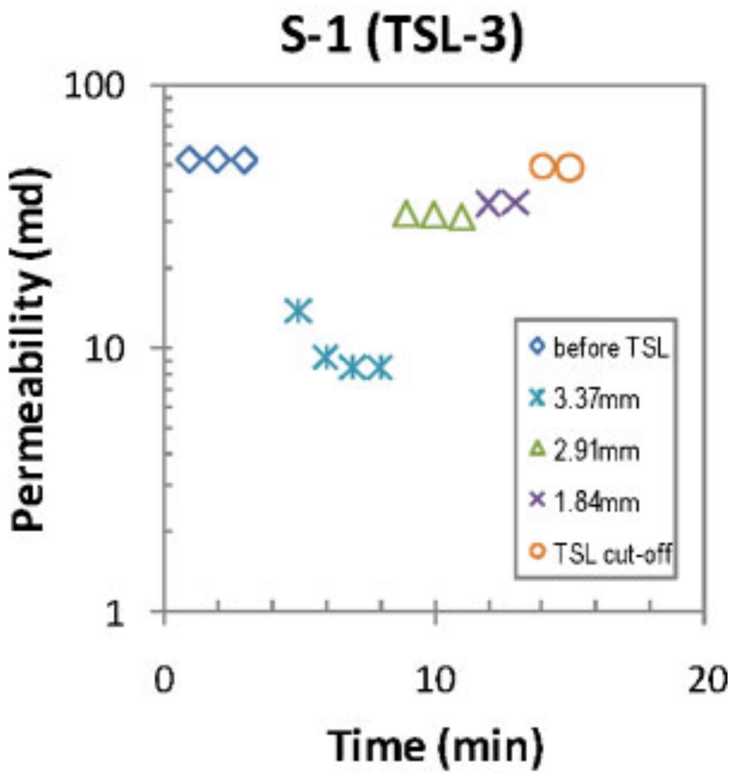
Table 1 Data for cylindrical coal samples of diameter of 25·2 mm

Samples		Length/ mm	TSL type	TSL thickness/ mm
Coal	CA-1	63·5	TSL-3	1·77
	CA-2	62·8	TSL-3	1·80
	CA-3	63·0	TSL-3	3·18
	CA-4	59·6	TSL-2	1·24
	CA-5	64·8	TSL-2	3·18
	CA-6	61·6	TSL-2	2·68
	CA-7	66·6	TSL-1	2·16
	CA-8	66·6	TSL-1	2·16
	CA-9	54·8	TSL-1	5·62
Sandstone	S-1	52·8	TSL-3	Variable
	S-2	54·6	TSL-2	Variable

Tests on Sandstone samples as a benchmark



Low permeability sample



High permeability sample

Results

Table 1 Data for cylindrical coal samples of diameter of 25·2 mm

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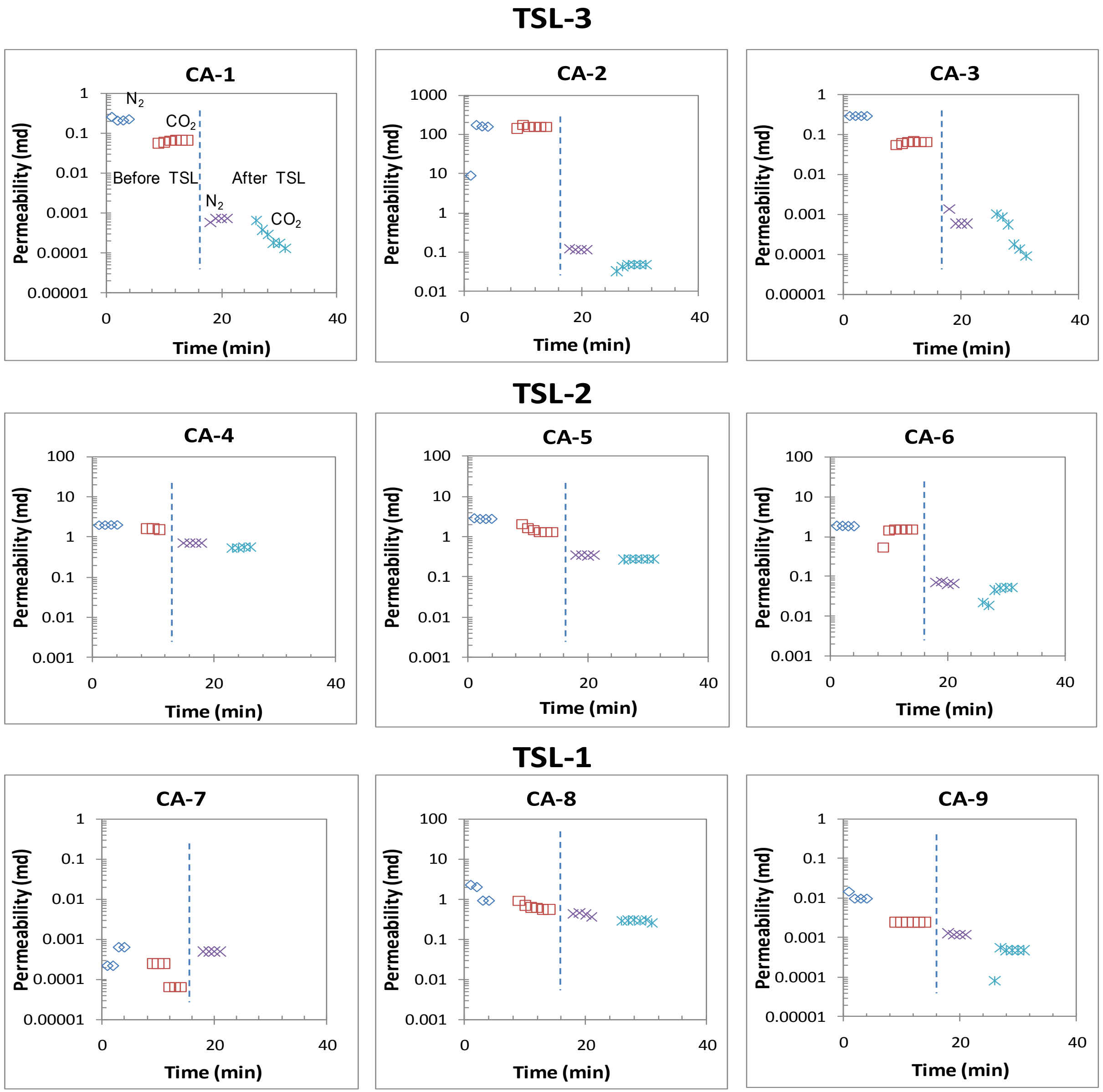
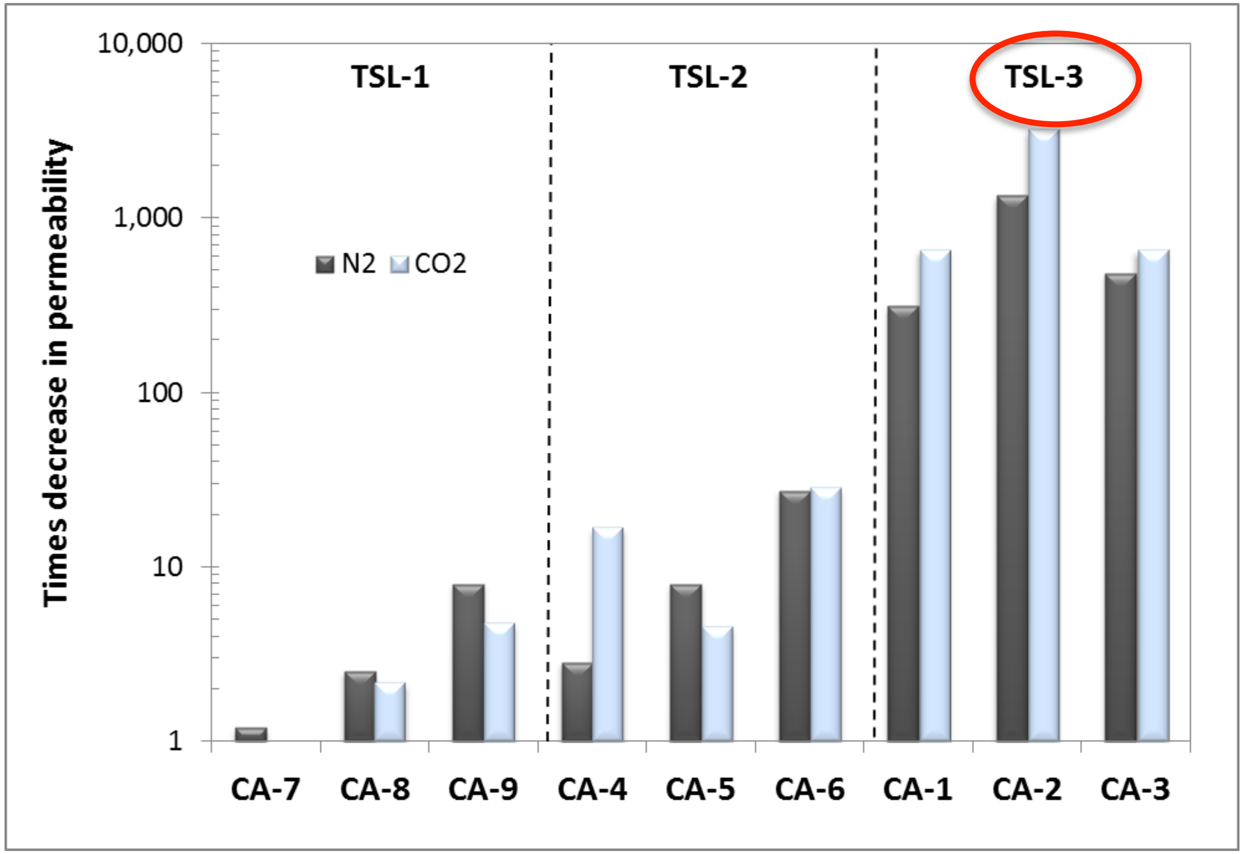
	CA-5	64·8	TSL-2	3·18
	CA-6	61·6	TSL-2	2·68
	CA-7	66·6	TSL-1	2·16
	CA-8	66·6	TSL-1	2·16
	CA-9	54·8	TSL-1	5·62
Sandstone	S-1	52·8	TSL-3	Variable
	S-2	54·6	TSL-2	Variable

- The pre-TSL N_2-injection gave highest permeability,
- The pre-TSL CO_2-injection reduced permeability,
- The post-TSL N_2-injection reduced permeability further, and
- The post-TSL CO_2-injection reduced permeability.

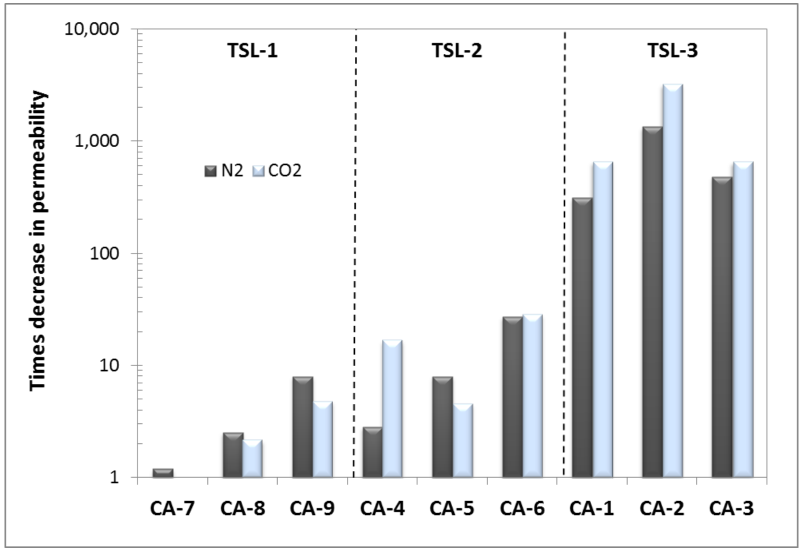
…where CO_2 has more adsorption capacity to coal compared to N_2 and this causes coal swelling and permeability reduction

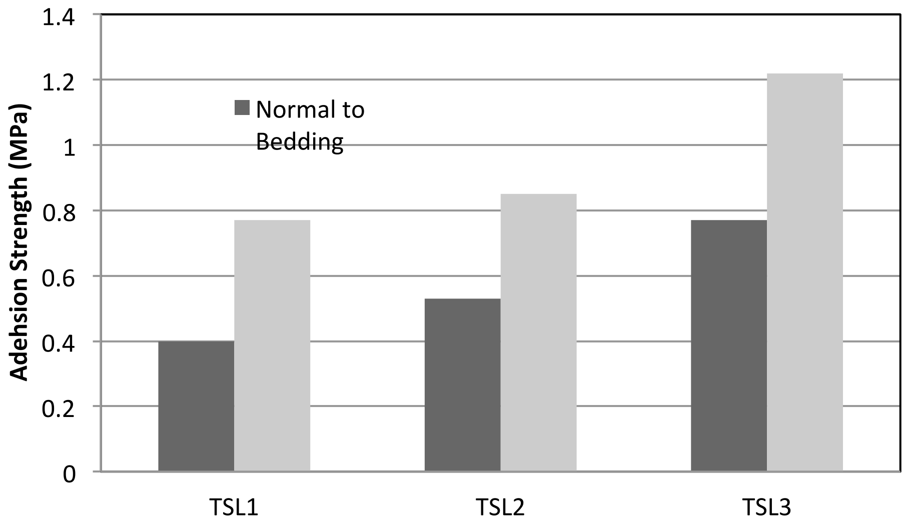


Degree of decrease in permeability



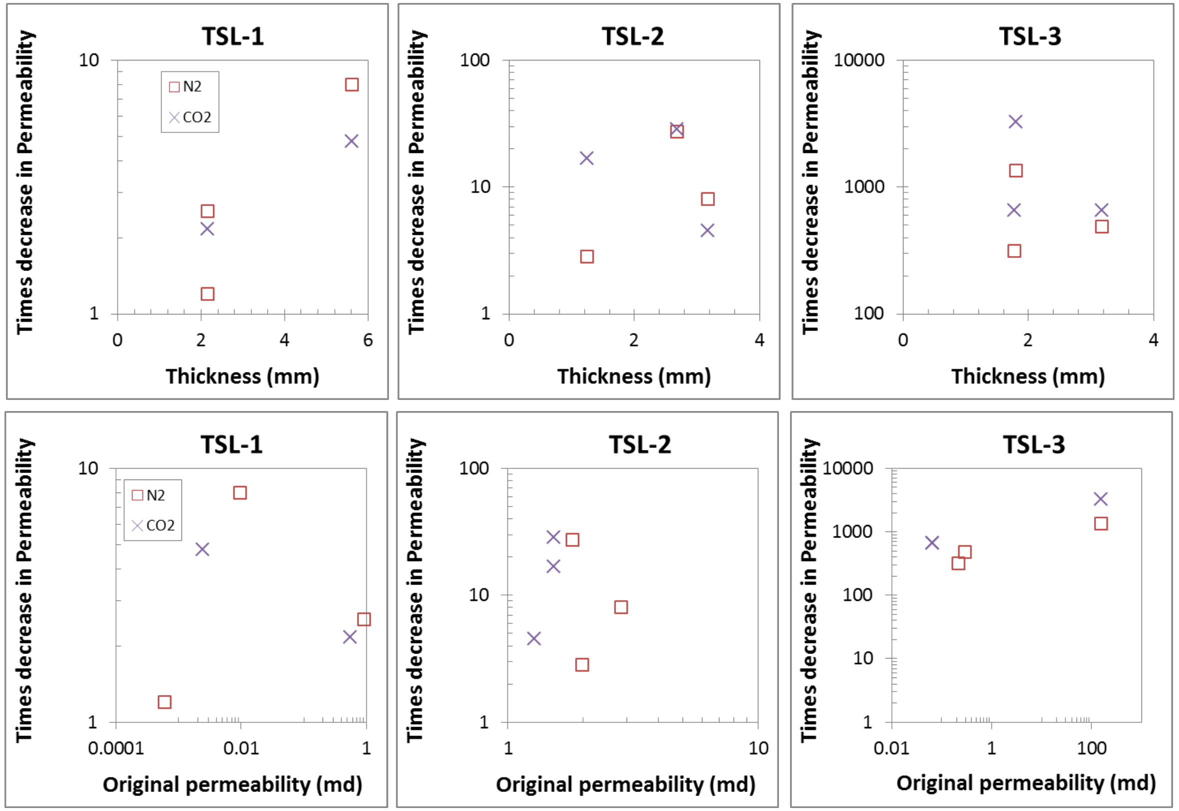
Permeability vs. Adhesion





Gilbert, Saydam and Mitra, 2010

Effect of TSL thickness to coal permeability



Conclusions

- The efficiency of the TSLs to minimise gas inflow strongly depends on the ***type of TSLs***. Among three TSLs used in this study, ***TSL-3 showed a strong efficiency***, reducing the gas permeability by almost three orders of magnitude.

- The efficiency of the TSLs also ***depends on the thickness*** and the initial permeability of coal.

- There is a linear relation between the ***efficiency of the TSLs in controlling gas flow and their adhesion strength*** to the coal sample.

- In comparison to sandstones, the application of TSLs on the coal surface requires more attention.

Discussion

- The Australian mining industry aims to achieve a ***higher production rate***.
- High gassy seams and rib emissions can be a major factor in determining development rates.
- ***Using TSLs as both gas management and ground support tool*** may potentially increase safety and production in longwall mining.
- The experimental observations obtained from this study show that ***certain types of TSLs are very efficient to control gas inflow*** into the coal mines.
- There has been very little research in this area, so there is a clear need for further investigation in order to see whether this technology can make a key impact on gas management in coal mines.