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

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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

RESPONSIBILITIES
- Assistant Director of Research
- School Academic Scholarship Coordinator

RESEARCH INTERESTS
- Ground Control
- Mine Planning
- Innovation in Education & Training
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
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
Support Mechanism (block interlock)

Prevention of block displacement by two mechanisms: 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 develops 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’)
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.
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)

Related Research Background

Limited research conducted for underground coal applications:

- ACARP, UNSW 1998
- EFNARC REPORT, 2008
- UNSW Research, 2010
- ACARP, UoW 2011
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.
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.
ACARP - Baafi et al, 2011. UoW
Tests conducted at the UNSW

Previous research @ UNSW

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

on concrete, sandstone 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
- \( \text{CO}_2 \) has much more tendency to adsorb on coal surface than \( \text{N}_2 \) and \( \text{CH}_4 \), while \( \text{CH}_4 \) has slightly higher affinity than \( \text{N}_2 \).
- When ejected, \( \text{CO}_2 \) swells the coal thereby reducing its permeability.
- \( \text{CO}_2 \) is more viscous and has larger molecular size compared with the other two gases.
- \( \text{CO}_2 \)’s desorption rate is relatively slower too.
- Flow behaviour of \( \text{CH}_4 \) is expected to be in between \( \text{CO}_2 \) and \( \text{N}_2 \) flows.
Test Procedure

- Coal samples first tested without TSL
- N₂ flow test
- CO₂ flow test
- TSL applied to outlet face of the core
- 3 repeats
- Different thicknesses of TSLs were applied

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>
<thead>
<tr>
<th>Samples</th>
<th>Length/mm</th>
<th>TSL type</th>
<th>TSL thickness/mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA-1</td>
<td>63.5</td>
<td>TSL-3</td>
<td>1.77</td>
</tr>
<tr>
<td>CA-2</td>
<td>62.8</td>
<td>TSL-3</td>
<td>1.80</td>
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<tr>
<td>CA-3</td>
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<td>CA-4</td>
<td>59.6</td>
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<tr>
<td>CA-5</td>
<td>64.8</td>
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<td>3.18</td>
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<tr>
<td>CA-6</td>
<td>61.6</td>
<td>TSL-2</td>
<td>2.68</td>
</tr>
<tr>
<td>CA-7</td>
<td>66.6</td>
<td>TSL-1</td>
<td>2.16</td>
</tr>
<tr>
<td>CA-8</td>
<td>66.6</td>
<td>TSL-1</td>
<td>2.16</td>
</tr>
<tr>
<td>CA-9</td>
<td>54.8</td>
<td>TSL-1</td>
<td>5.62</td>
</tr>
<tr>
<td>Sandstone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S-1</td>
<td>52.8</td>
<td>TSL-3</td>
<td>Variable</td>
</tr>
<tr>
<td>S-2</td>
<td>54.6</td>
<td>TSL-2</td>
<td>Variable</td>
</tr>
</tbody>
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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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<td></td>
<td>CA-2</td>
<td>TSL-3</td>
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<tr>
<td></td>
<td>CA-3</td>
<td>TSL-3</td>
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</tbody>
</table>

• The pre-TSL N₂-injection gave highest permeability,
• The pre-TSL CO₂-injection reduced permeability,
• The post-TSL N₂-injection reduced permeability further, and
• The post-TSL CO₂-injection reduced permeability.

...where CO₂ has more adsorption capacity to coal compared to N₂ and this causes coal swelling and permeability reduction.
Degree of decrease in permeability

![Bar chart showing the degree of decrease in permeability for different samples. The x-axis represents different sample labels (CA-7, CA-8, CA-9, CA-4, CA-5, CA-6, CA-1, CA-2, CA-3) and the y-axis represents the times of decrease in permeability.]
Permeability vs. Adhesion

TSL1

TSL2

TSL3

Adehsion	
  Strength	
  (MPa)

Normal
to
Bedding

GIlbert, Saydam and Mitra, 2010
Effect of TSL thickness to coal permeability

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UNSW

THE UNIVERSITY OF NEW SOUTH WALES
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.