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Enhancement of the tensile strengths of rock and shotcrete by thin spray-on liners

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ABSTRACT

Thin spray-on liners (TSLs) have been available for application in mining and civil engineering situations for about 20 years. They were initially used as sealants, but have subsequently been developed as surface support liners. Although they are used in substantial quantities in mines in South Africa and Canada, widespread application for support purposes has been met with some scepticism. Observations from users, however, have indicated that, contrary to this scepticism, TSL support performance was almost always better than expected. A reason for the scepticism is probably a lack of quantification of the benefits. This paper aims to address this lack of data to some extent. It provides quantification of the enhancement of tensile strengths of rock and shotcrete due to the application of TSLs. The quantification was achieved using Brazilian indirect tensile testing, and several commercially available TSL products. Some tests were also carried out on small rock beams using three-point bending. The results show that, depending on the TSL product used, the tensile strength of a strong, brittle rock can be increased by approximately 30%, and that of shotcrete by more than 40%. TSL application on a weak porous sandstone resulted in an early tensile strength reduction, probably due to absorption of moisture. This was not the case with TSL application on shotcrete.

Many of the rock support mechanisms provided by sprayed liners depend substantially or completely on the tensile strength contribution of the liner. Hence the data provided in this paper makes a contribution to knowledge, of value in the design of support for excavations in rock.

1. Introduction

Shotcrete has been in use for almost a century, and has been applied as a support medium for underground and surface excavations since the 1950s (Spearing et al., 2001). It is a very widely accepted component of rock support in tunnels and other underground excavations. In the 1990s, thin spray-on liners (TSLs) were introduced (Lacerda, 1994), initially being considered as sealants, owing to their limited thickness of a few millimetres. Whilst shotcrete is considered as a structural support, thin and flexible TSLs cannot be considered to have structural strength, and hence there was, and is, scepticism regarding their use for rock support. However, observations from users have indicated that, contrary to this scepticism, TSL support performance has almost always been better than expected. The value of TSLs for rock support purposes is now being recognised, and they are being used in increasing quantities, particularly in the mining environment. In South African mines TSLs are being used routinely for the purpose of surface support, and, from a survey of the main suppliers, annual usage is in the region of 7500 tonnes of TSL material. Experience of support performance has been good in both static and rockbursting conditions, and in blast resistance, and the use of TSLs in the deep level environment has been proven to be very cost effective compared with shotcrete (Carstens and Oosthuizen, 2004; Carstens and Badenhorst, 2008).

Investigations into the mechanisms of support provided by a range of liners have been carried out over the past decade or so, particularly in Canada, Australia, South Africa and the USA. Much of this work is contained in the proceedings of a series of conferences on liners: International Seminar on Membrane Support, Perth, August 2001, (Australian Centre for Geomechanics); Second International Seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, Mesh, Johannesburg, July 2002

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Fig. 1. Failed Brazilian tensile test specimen.

(Southern African Institute of Mining and Metallurgy); Third International Seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, Mesh, Quebec City, 2003, (Department of Mining, Metallurgical and Materials Engineering, Laval University); and summarised in the book "Surface Support in Mining" edited by Potvin et al. (2004).

A range of mechanisms of surface support behaviour, and loading behaviour, of liners has been described by Barrett and McCreath (1995), Stacey (2001), Tannant (2001) and Stacey et al. (2009). These support mechanisms might occur individually and in combination, and those that are considered to be particularly relevant to thin, flexible liners may be summarised as follows:

- Promotion of block interlock – this is the interlock that is promoted by the adhesive bond between the liner and the rock, and by the tensile strength of the liner.
- The development of shear strength on the interface between the liner and the rock as a result of irregularity of the interface surface.
- The penetration of liner material into joints and cracks (Fowkes et al., 2008), which will inhibit movement of blocks.
- Bridging of joints and cracks in the rock, which will inhibit the opening of the cracks, mainly due to the tensile strength of the liner.
- Prevention of block displacement due to the shear strength of a stiff liner, and the tensile strength of a thin bonded liner.
- "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 of the liner, which will serve to resist the deflection of the liner to form a basket; secondly, the tensile strength of the liner itself.

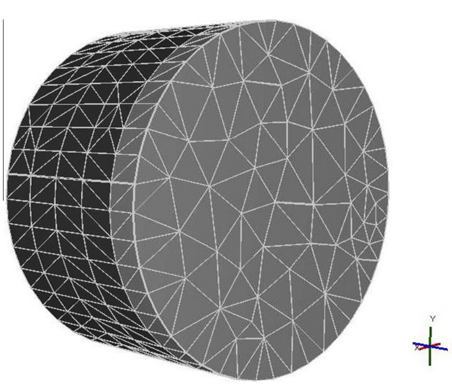

Fig. 2. 3D finite element model (Rizwan, 2014).

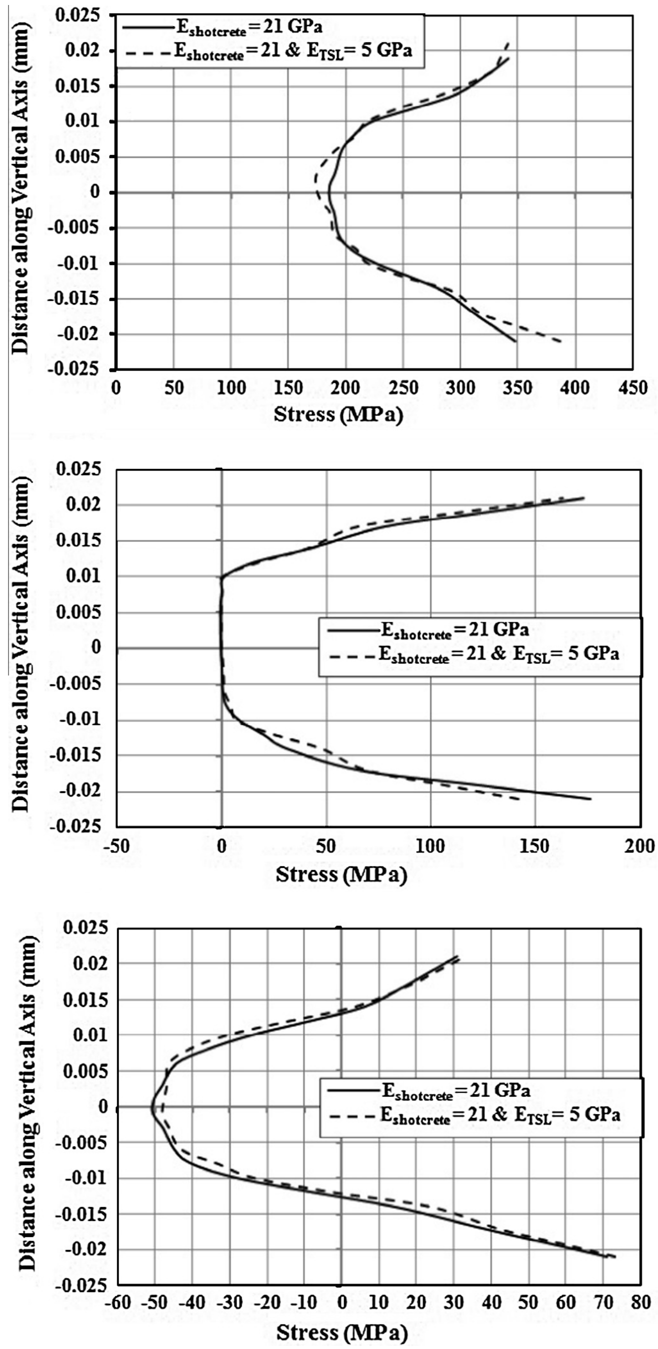

Fig. 3. Example of modelling results for the vertical query line: $E_{shotcrete}$ = 21 GPa, E_{TSL} = 5 GPa (Rizwan, 2014).

- Slab and beam enhancement: slabs of rock may fail due to buckling and roof beams may fail in bending or buckling. Liner support effectively decreases the slenderness of the slab and increases its buckling resistance, and on the underside of a roof beam may enhance the bending performance. Again it is the tensile strength of the liner that will contribute most to this support mechanism.
- "Extended faceplate" area of influence of rockbolts.
- Air tightness: for a rock mass to fail, dilation must take place, with opening up occurring on joints and fractures. Coates (1970) suggested that, if the applied surface support is air tight, entry of air will be prevented or limited, and hence dilation and failure will be restricted. The prevention of such dilation will be