Full scale tests to compare the strength of polymer liners with high tensile steel mesh

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FULL SCALE TESTS TO COMPARE THE STRENGTH OF POLYMER LINERS WITH HIGH TENSILE STEEL MESH

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ABSTRACT: Compared with welded steel mesh which is a passive support medium, Thin Spray-on Liners (TSL) have many advantages and it is believed that TSL have the potential to take the place of steel mesh support in underground coal mines. In this study, full scale tests were firstly conducted to determine the ultimate strength of a plain polymer liner and two types of plain steel mesh. In terms of load bearing capacity, it was found that the polymer liner was stronger than the mesh with thinner diameter wire and weaker than the mesh with thicker wire. The liner was much stiffer than both of the two steel mesh sizes. The polymer and steel mesh were further loaded with fractured concrete pieces. The results showed that the polymer-concrete composite not only achieved much greater maximum load but was also stiffer than the steel mesh-concrete test structure.

INTRODUCTION

As a traditional surface support, welded steel mesh has been successfully utilised in underground coal mines as a skin confinement medium for roof and rib strata for many years. It is, however, difficult to automate the installation process, thus it is both time consuming and labour intensive. Moreover, steel mesh is a passive support and does not provide surface confinement until substantial rock displacement occurs. To meet the roadway development requirements of future longwalls the coal industry requires a significant increase in roadway development rates over those currently achieved. Thin Spray-on Liners (TSL) are an innovative rock support material which can be applied automatically so that increased roadway development rates can be achieved. In addition, they have many other merits over steel mesh, for example, they can be applied remotely to improve personnel safety and they bond to the rock surface generating resistance to rock displacement immediately after application.

Many laboratory tests have been conducted to evaluate the performance of welded steel mesh used in underground rock surface support. The effect of the size of the mesh loading area and bolt spacing on the load-displacement behaviour of welded steel wire mesh was investigated by Thompson (2001). He found that the stiffness of the mesh increases with decrease of the bolt spacing and that the size of the mesh loading area did not have much influence on the peak load resisted by the mesh, but significantly affected the mesh displacement at peak loads. A series of laboratory tests were conducted by Dolinar (2006) to evaluate the influence of bolt tension, the type of load bearing surface and the size of the bearing plate on welded steel mesh performance. The results showed that bolt tension, bearing plate size and load bearing surface influenced the yield, peak load and the stiffness of the mesh. Increasing the bearing plate size can significantly enlarge the mesh peak load and stiffness as larger plates enabled the load to be distributed to more wires.

The mechanical properties and behaviours of TSL products have also been investigated and reported in numerous publications (Lukey, et al., 2008; Nemcik, et al., 2009a; Nemcik, et al., 2009b; Nemcik, et al., 2011a; Nemcik, et al., 2011b; Nemcik, at al., 2013). A recent study (Shan, et al., 2013) investigated behaviour of welded steel mesh and TSL in reinforcing strata with weak bedding planes and strata prone to guttering.

In order to study the feasibility of replacing steel mesh with TSL in support in underground coal mines, direct comparison between them must be conducted. In this study, the strength of the commonly used 5 mm thick steel wire mesh was measured using full scale laboratory tests. The full scale test method was designed to determine the ultimate strength of a 5 mm thick glass fibre reinforced polymer sheet 1.4 m by 1.4 m in size followed by large scale deflection tests conducted to investigate the behaviour of the polymer liner and steel mesh under simulated rock loading condition.
FULL SCALE LABORATORY TESTS OF POLYMER LINERS AND HIGH TENSILE STEEL MESH

Steel mesh test

The best way to study steel mesh behaviour is to conduct full scale tests that represent in situ conditions. Many researchers have performed tests on welded wire mesh in the laboratory, but most were of a smaller, laboratory scale tests. Tannant (2001) tested 1.5 m by 1.5 m squares of various types of mesh, but this was shown to produce different deformation characteristics when compared with larger mesh tests or with numerical modelling (Gadde, Rusnak and Honse, 2006). In order to evaluate steel mesh performance accurately, the size of the mesh sheets tested in this study were 1.5 m by 4 m and 1.35 m by 3.6 m, which are the biggest to date. This full scale test size removes the 'end effects' influence on stiffness and ultimate deflection, apparent when using smaller samples. The load was applied to the mesh by pulling a 300 mm diameter steel dome upwards to simulate rock loading.

Figure 1 shows the full scale pulling test set up. The mesh was bolted to a ‘Strong Floor’ with bolts spaced at 1 m intervals. In order to eliminate or at least minimise slippage of the mesh, a torque wrench was used to apply 240 Nm of torque to the bolts to provide a consistent pre-tension force, and timber spacers were also placed between the bolt holders. The dome was used to apply a centre load to the mesh. The tests were run in displacement control model with the loading rate being 24 mm/min which is slow enough to simulate static loading. During the test, the load was measured by a 100 kN load cell with an accuracy of ±0.2 kN and the displacement was monitored by a Linear Variable Differential Transducer (LVDT) with an accuracy of ±0.6 mm. The load and displacement were recorded by a computer during the tests.

Two types of mesh (roof and rib) were subjected to the full scale pull test. Mesh type A (roof mesh) consisted of 5.3 mm diameter longitudinal and transverse steel wires with 7 mm diameter longitudinal reinforcing wires passing below the load bearing plate, and mesh type B (rib mesh) consisted of 4 mm diameter wires without reinforcing wires. The size of mesh A was 1.35 m by 3.6 m and that of mesh B was 1.5 m by 4 m.

Altogether five welded steel mesh sheets were subjected to the pull test, with four of them being mesh type A and one mesh type B. The load versus displacement curves are shown in Figure 2. The ‘saw tooth’ in the curves was caused by slippage of the mesh underneath the rock bolt plate, while the large drops in load generally indicate wire failure. It is obvious from the graph that the 5.3 mm mesh displays greater peak load capacity compared to the 4 mm mesh. The peak load of mesh A was approximately 48 kN, but the peak load of mesh B was only 21 kN, less than half mesh A. It is interesting to note that while the difference in peak load for the two mesh types is significant, the diversity in displacement at peak load is not so remarkable. It is also worth noting that the two different mesh types did not show much difference in stiffness before approximately 310 mm displacement. At larger displacements wire failure occurred when testing mesh B while mesh A could still bear the increasing load. Observations
during the tests revealed that almost all of the wire failure of mesh A occurred near the loading dome, however, all wire failures for mesh B occurred near the load bearing plates.

![Graph showing load-displacement curves of full scale pull tests](image)

**Figure 2 - Load-displacement curves of full scale pull tests**

**Test on polymer liner**

The aim of this experiment was to determine the ultimate strength of a 5 mm thick fibre reinforced polymer sheet of dimensions 1.4 m by 1.4 m.

**Sample preparation**

Figure 3 shows the sample preparation procedure. The mould was firstly placed on a table and waxed seven times to guarantee that the polymer would not bond to the mould surface during curing. The mould was levelled to ensure even distribution of the polymer material. Resin was poured into the mould to cover the surface, glass-fibre mat cut to size was placed on top of the resin and rolled into the polymer with a specialised roller. This process was repeated twice with a final cover of resin rolled into the last fibre mat. It is important to note that although the fibre reinforced polymer sheet was designed to be 5 mm thick, the actual thickness was 4.5 mm.

![Sample preparation images](image)

**Figure 3 - Procedure for polymer sample preparation**
Test procedures

The test setup is illustrated in Figure 4. The fibre reinforced polymer sheet was placed on the steel test frame and four steel channels placed on its edges were bolted to the test frame so as to restrain its translational movement. In order to replicate in situ conditions, four bearing plates beneath the polymer sheet were positioned in a rectangular shape with a span of 1 m and bolted to the steel channels, simulating a 1 m bolt spacing in situ. The polymer liner was loaded to failure by a spherical steel seat pushing downwards. Displacement loading was chosen in this experiment, with the loading rate set at 6 mm/min. Load and displacement were monitored using a load cell and a LVDT.

Figure 4 - Test set up

The load verses displacement behaviour of the polymer liner is shown in Figure 5. The maximum load achieved was 26.2 kN and the corresponding displacement was 83 mm. It is worth noting that the polymer liner can still bear a load of around 7 kN after initial failure.

Figure 5 - Load-displacement curve for the full scale test on a polymer sheet

LARGE SCALE BAGGING TESTS IN THE LABORATORY

Large scale bagging tests were conducted to enable comparison between the behaviour of plain steel mesh and a polymer liner when supporting broken strata. In particular it would allow comparison between passive support behaviour and the composite behaviour afforded by a bonded liner.

Large scale bagging tests on steel mesh

Steel mesh cut into a rectangle of 1000 mm by 800 mm was placed in a steel frame consisting of upper and lower sections tightly clamped at the edges with 18 bolts, the bolts also stopped the mesh from slipping as they were place on the inner edge of the outside wire. The actual loading area became 800 mm by 600 mm as 200 mm around the edge was taken up by the frame, which also helped resist slip of the mesh. A concrete slab 600 mm in width, 800 mm in length and 100 mm thick was cast using a mixture of 68.7 kg sand, 20.6 kg cement and 10.2 kg water. The concrete was then broken into sections...
to simulate fractured strata in an underground coal mine roof and re-assembled on the top of the steel mesh as shown in Figure 6. To load the steel mesh evenly, a 100 mm thick layer of crushed basalt aggregate was positioned on the top of the concrete slab. A rubber mat was placed between the concrete and the aggregate to prevent the crushed basalt from falling into the cracks between the concrete pieces. Another rubber mat on the top of the aggregate protected the base of a mild steel circular loading platen which was set at the centre of the steel mesh on top of the crushed basalt. The sample was then loaded by a 5000 kN hydraulic press, the deflection of the steel mesh was measured using a wire potentiometer.

As shown in Figure 7, the first peak load of 80 kN occurred at a displacement of approximately 35 mm. The load began to oscillate between 60 kN and 80 kN as the displacement increased from 40 mm to 80 mm. The load oscillation was a result of steel strand necking and failing. When each steel strand failed the load dropped, but then increased again as the load was redistributed to the unbroken steel strands. The progressive failure of the steel mesh strands, however, caused a decrease in bearing capacity and subsequent structural failure of the system. The data presented in Figure 7 indicates that the mesh had structurally failed at a displacement of 80 mm. The maximum load achieved in this test was 82 kN at a displacement of 51 mm.

A sheet of fibre reinforced polymer was loaded to failure and the results compared with the steel mesh tests. The polymer liner was 4.5 mm thick reinforced with 3 layers of glass fibre (Figure 8). The test set up was similar to the test on steel mesh, except that the polymer sheet was bonded to the concrete pieces to simulate the in situ spray application of the polymer for underground use. The sample was again loaded using the 5000 kN hydraulic press, the deflection of the polymer sheet was monitored with a laser LVDT.
The test was divided into two stages: initial loading and reloading. The load versus displacement results during the two stages are shown in Figure 9. In the initial loading stage, audible sounds were noticed when the load was approximately 100 kN with a corresponding displacement of 10 mm. It was then decided to unload the sample to obtain an unloading curve before loading the polymer liner to failure. The polymer sheet was allowed to recover for 5 min after unloading. From the data it is apparent that the displacement reduced from 15.4 mm back to 7.8 mm with recovery of 7.6 mm after unloading and recovery. In the reloading stage, audible sounds were again heard at approximately 100 kN, the maximum load achieved was 128.7 kN at a corresponding displacement of 26.7 mm. It is important to note that a sudden fall in load occurred after the peak load was reached, but the sample was still able to bear a load of around 80 kN (8 t), after which the load bearing capacity gradually reduced with further deflection.

It was observed that the polymer liner tilted to one edge of the steel frame as shown in Figure 10. The probable reason was the circular steel seat placed slightly off-centre in the steel box. The tilt of the polymer sheet contributed to the stress concentration at the place where the polymer sheet rested on the steel frame. The initial failure occurred at this edge and then spread to the other edges (Figure 11). A greater maximum load may be expected for a correctly centred steel seat. Observe the concrete sections still bonded to the polymer.
DISCUSSION

The behaviour of two different types of steel mesh (mesh A and mesh B) and a glass fibre reinforced polymer sheet were compared by conducting in situ scale tests in the laboratory. The load was applied by pulling (steel mesh) or pushing (polymer liner) a ‘dome like’ spherical seat manufactured to simulate the in situ loading situation. Figure 12 shows the load-displacement curves from the tests. As expected, mesh A, with 5.3 mm diameter steel wires, had a much greater peak load and a larger load at first wire failure than the 4 mm mesh. Mesh A was slightly stiffer during the initial load-displacement stage than mesh B. The deformation characteristics of the two mesh sheets were similar, with the displacement at peak load of around 500 mm. The peak load of the fibre reinforced polymer sheet was greater than mesh B but lower than mesh A, but was much stiffer than the steel mesh, which means the polymer liner can generate greater resistance at the same rock displacement. It is worth pointing out that the dome like seat is suited for testing the steel mesh, but appeared to be acting as a point load on the stiffer polymer liner.

![Figure 10 - Tilt of the polymer liner](image1)

![Figure 11 - Failure along the frame edges](image2)

![Figure 12 - Comparison of load-displacement curves for all full scale tests](image3)

When comparing the bonded polymer and the steel mesh it is evident (Figure 13) that the polymer liner provides higher support loads at lower displacements while it continues to support the strata at large displacements. The polymer liner provides greater confinement to the strata at lower displacements and when overloaded it is still able to provide significant support to the fractured strata as displacement increases.
It is not practical to prevent the formation of mining induced fractures but it is possible to enhance the excavation surface condition by applying an effective support system at an early stage of mining. The nature of rock support is to preserve the rocks self-supporting ability by the use of the rock support material rather than holding the dead weight of the rock. Even if the plain polymer sheet is weaker than steel mesh, it is able to provide better load bearing capacity when bonded to the broken concrete slab than steel mesh in a similar situation. If the performance of the bonded polymer was replicated in the full scale test, the expected peak load would be around 70 kN (7 tonnes), 50% greater than standard roof mesh.

![Load-displacement curves for bonded polymer liner and steel mesh](image_url)

**Figure 13 - Load-displacement curves for bonded polymer liner and steel mesh**

**CONCLUSIONS**

The objective of this study was to determine the ultimate strength of a polymer liner and steel mesh using full scale tests and to compare the results. Although the 4.5 mm thick polymer liner was not as strong as the 5.3 mm diameter steel mesh, it was much stiffer, providing confinement at an earlier stage. Shown by the large scale tests the most important property of the polymer liner is the ability to bond to the rock surface, creating a polymer-rock composite. As with all composite materials, the whole is greater than the sum of the parts. This suggests that the polymer liner shows superior potential for underground rock support.

The polymer used in the tests was not the actual thin spray-on liner being formulated at the University of Wollongong (ToughSkin), but just an off the shelf product used to validate the test procedures. ToughSkin is a fast setting thin spray-on liner with superior adhesive and mechanical properties which may replace steel mesh for rock support in underground mines. Further full scale tests will involve the spray application of the latest ToughSkin product.

**REFERENCES**


