Determining the ultimate strength of 'tough skin', a glass fibre reinforced polymer liner

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DETERMINING THE ULTIMATE STRENGTH OF ‘TOUGH SKIN’, A GLASS FIBRE REINFORCED POLYMER LINER

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ABSTRACT: Fully encapsulated roof bolts have been proven to confine the roof and rib strata actively, while steel mesh only provides passive support and protection from falling rocks as they dislodge from the roof. To provide better stability of the mine roadway skin, replacement of the steel mesh with a spray on polymer liner is being investigated. Among the many benefits that may be realised by the application of quick setting spray on polymer liners as skin support are an increase in development rates and improved safety for working personnel. Extensive testing of a range of available polymer formulations is currently being undertaken; this particular study is to determine how Thin Spray on Liners (TSL) behave in conditions encountered in underground coal mines and demonstrates their superior properties over steel mesh as an alternative form of roof skin support.

INTRODUCTION

The role of Tough Skin, a candidate TSL being developed at the University of Wollongong, is to act as a composite material that provides reinforcement to the skin of a mine roadway. To act as a composite with the roadway skin the polymer must have strong adhesion to the strata, but strong adhesion is only beneficial if the polymer is also strong and tough. Strength testing on potential polymer liners is done predominantly on small samples where failure mode or material properties can be examined comparatively in order to evaluate and reformulate the material until an optimum formulation can be determined. Large scale tests are required to predict the potential behaviour of the TSL underground, while an in situ trial is the final confirmation of the product performance. Various tests were performed on a routine basis, including the non destructive loading of a polymer sheet where a load of terracotta pavers was placed onto the sheet to verify its strength. This work extends these tests, loading large sheets of reinforced polymer to failure.

LOADING THE POLYMER SHEETS TO FAILURE

Previous tests involved applying evenly distributed loads of 1 t terracotta pavers to a 1 m by 0.8 m Tough Skin polymer sheet and a similar size section of steel mesh as shown in Figure 1. The measured deflection of the Tough Skin sheet was approximately 40% lower than the deflection of the steel mesh subject to the same load (Nemcik, et al., 2009).

Figure 1 - Glass fibre reinforced polymer Tough Skin and steel mesh loaded to 1 t.

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To measure the ultimate load capacity of the polymeric material a series of reinforced Tough Skin sheets were loaded to failure. The one tonne load used in the previous tests was inadequate as a much larger load is needed to fail the sheets. An experimental steel frame was built to hold a sufficiently large reinforced polymer sheet that was then placed in a 500 t Avery compressive testing machine. Due to clearance in the Avery and the size of the steel frame used to clamp the sample, the actual tested area was limited to 800 mm x 600 mm. To place an evenly distributed load onto the Tough Skin polymer sheet a semi inflated air bag was installed on top of the sheet. The airbag was inflated without protruding out of the steel enclosure, covered with a steel plate and loaded as shown in Figure 2.

![Figure 2 - Polymer sheet loaded with the assistance of an air bag](image)

The load applied to the Tough Skin polymer sheet and its deflection was monitored using a 5 000 kN load cell and a LVDT. Strains on the bottom surface of the sheet were monitored with electrical resistance strain gauges glued directly to the polymer surface as shown in Figure 3.

![Figure 3 - Strain gauged Tough Skin polymer sheet loaded to failure](image)

Testing the first sample using an airbag was only able to achieve results up to a certain point, failure of the Tough Skin did not occur as the air bag volume reduced substantially due to the compressive load and the hydraulic press cylinder of the machine reached the end of the stroke. During testing the machine was loaded at 2 mm/min until the end of the stroke at 100 mm was reached. The maximum force applied to the 5 mm thick Tough Skin sheet was 68 kN, while a deflection of 35.3 mm was measured. Unloading the sheet saw a recovery of 23.9 mm with a permanent displacement of 11.4 mm. The large amount of displacement recovery after unloading shows that the sheet was mostly within the elastic region of deformation during testing. The load versus deflection of the Tough Skin polymer sheet and recorded strains are shown in Figure 4.

![Figure 4 - Load versus deflection graph](image)

As the Tough Skin polymer sheet did not fail it was not clear how much force the polymer could withstand at failure due to an evenly distributed load, but a load of nearly 7 t with no indication of failure is substantial and well above that expected in normal mining conditions. The results indicate that the use of the airbag to achieve an evenly distributed load over the entire surface was successful, however, if the bag was filled with a non-compressible fluid such as water the displacements would have been lower and...
the failure load reached. The use of water looked promising and would have solved the problem of using air but unfortunately the air bags available for the experiment were unsuitable for use with water.

Figure 4 - Test 1 a) Load versus deflection     b) Strain versus deflection

In the second test a smaller area of the Tough Skin was loaded to failure. A 150 mm diameter steel spherical seat was used to load the centre of the polymer sheet as shown in Figure 5. To lessen the effect of strain concentrations, where the spherical seat would come in contact with the polymer sheet, a dense rubber mat was placed between the two surfaces. The sample was again loaded at a rate of 2 mm/min. As expected the area of maximum strain and hence the location of failure was directly beneath the point of loading. Polymer yielding was characterised by non-brittle failure propagation and no loss of integrity where the polymer sheet had not yielded. Failure of the Tough Skin was reached at a load of 45 kN and a deflection of 52 mm.

Figure 5 - Loading of the Tough Skin polymer sheet to failure with a 150 mm diameter steel plate

The failure load in test 2 was lower than the load applied via the air bag in test 1. This was to be expected as the load during test 1 was evenly distributed over the whole sheet while in test 2 the strains at the point of loading were more concentrated resulting in tear of the polymer.

In the third test the Tough Skin was bonded to a number of terracotta pavers and the pressurised air bag was trialled again. This time the bag was pressurised to 220 kPa in order to minimise deflection during loading. In this test not enough pressure was generated to yield the polymer as it was predicted that airbag damage due to the excessive air pressure would occur, resulting in unsafe conditions. The load developed in test 3 was 100 kN (10 t) with 38 mm of the deflection, as can be seen in Figure 6. A comparison of load versus displacement results for tests 1 and 3 are presented. It is obvious from this figure that bonding of the pavers, test 3, to the polymer had significant influence on the load distribution.

Test 4 was conducted with the same loading conditions as in test 2, but using a layer of pavers as a buffer on top of the Tough Skin as shown in Figure 7. The three layers of loaded pavers were used to distribute the load away from the point of loading, minimising any early polymer tear due to stress concentrations. The pavers were initially bonded to the polymer sheet but unfortunately adhesion was lost between the sheet and half of the pavers during loading. Tests 2 and 4 show similar trends of load versus deflection.
DISCUSSION

The tests presented here indicate that a 5 mm thick reinforced Tough Skin sheet is strong, tough and resilient to compressive or shear failure and tear. As expected, load distribution plays a major role in the apparent strength of the Tough Skin, point loads cause the polymer to tear resulting in failure at lower loads when compared with uniformly distributed loads. The role of Tough Skin is to become a composite member of the strata at the skin level where high adhesion of the polymer to the substrata plays a major role in early reinforcement of fractured roadway skin. A stiff, strong and tough polymer formulation can complement the bolt system not only in the early stages of roadway development, but also in later stages of the roadway's life where it could also provide sufficient support to broken strata encountered in tailgates and other heavily loaded areas experienced in most coal mines. The strength of a 5 mm thick layer of Tough Skin appears to be comparable to the 5mm heavy duty steel mesh currently used to support heavy strata conditions.

Testing of heavy duty steel mesh at the University of Wollongong indicates a similar strength to unbonded Tough Skin, while Tough Skin that bonds to the substrata promises a better roadway skin support mechanism than steel mesh can provide. When bonded to the substrata, Tough Skin will provide a stiff and resilient coat to the roadway surface, reinforcing the fractured surfaces and strengthening the loose rocks. In most coal mines no significant dynamic loads exist and gradual yielding of strata is usually experienced. Ideally, when yielded, Tough Skin should transit to a post-failure mode of highly elastic but strong material with audible warning that indicates to the mine personnel that excess strata movement is present. This can be possible with an appropriate reinforcing fibre formulation that will remain strong and flexible after the polymer matrix has yielded. It is envisaged that a tear in the Tough Skin liner can be repaired using portable air driven spray on equipment that can patch the Tough Skin to the desired thickness.
CONCLUSIONS

The purpose of this study was to quantify the probable loads that a 5 mm thick polymeric liner can carry while spanning between the bolts. This work has shown that steel mesh is not stronger than the tested Tough Skin. All four tests indicate that the ultimate capacity of the de-bonded Tough Skin spanning small distances is of the order of 4-10 t. Most of the tested steel mesh types do not exceed these values. If the bolted horizon remains relatively intact, the dead loads imposed on the Tough Skin would not exceed its strength. When heavy strata conditions occur with bolts losing their integrity then it is probable that in places the Tough Skin strength could be compromised, this however is no different to the situation where steel mesh has to cope with similar loads.

The tested polymer size was smaller than the average span between the bolts in most coal mine roadways as the loading equipment did not allow full size samples to be tested. The authors believe that larger samples would not outperform or underperform the tested results. As part of further work on determination of Tough Skin mechanical properties, full scale application of Tough Skin is recommended. Full scale trials would enable detailed monitoring of the Tough Skin behaviour and a direct comparison to the test results described here.

REFERENCES