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# BEARING CAPACITY OF A GLASS FIBRE REINFORCED POLYMER LINER

**Jan Nemcik, Ian Porter, Ernest Baafi and Joshua Towns**

**ABSTRACT:** The development and testing of stiff polymer to be used as part of roof and rib support system for underground mining is discussed. Laboratory tests were conducted to examine the bearing capacity of thin spray polymer liners (TSL) Polymer, which included both puncture test and the optimum size of steel bearing plates. It was found that a 60 mm diameter steel disc carried approximately 60 t, and that a 250 mm diameter steel plate had no major effect on the integrity of the TSL. Further polymer bearing capacity studies on uneven surfaces must be conducted to simulate actual mine site conditions.

## INTRODUCTION

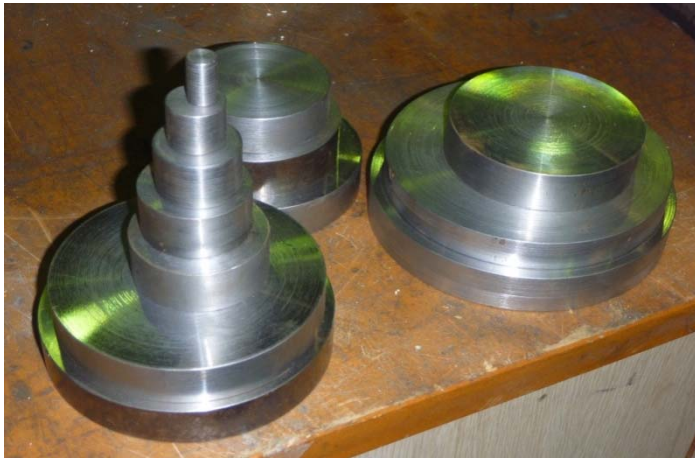
Since 1990 thin spray on polymer liners (TSL) have emerged as a viable mine roadway skin protection. Many of the products have specific applications such as weathering protection of the mine roadways, while stiff liners such as shotcrete are used as part of the ground support. Now a fast setting stiff polymeric liner 'Tough Skin' is under development to be used as part of the roof support system. These polymeric materials have the potential to allow a highly automated face support cycle that promises substantial improvement in roadway development rates and the removal of personnel from the immediate face area, minimizing associated health and safety risks.

To replace steel mesh, Tough Skin must exhibit several desirable properties such as: high strength and stiffness; good bond to rock or coal substrata under wet or dry conditions; adequate toughness with high elongation and yielding characteristics when loaded to failure and high resistance to puncture loads as Tough Skin must be able to withstand high bolt plate loads.

Tough Skin has the role of reinforcing the coal mine roadway skin and complimenting the bolts that provide reinforcement to rock strata (Lukey, 2008). Roof bearing plates used in conjunction with high capacity roof bolts are utilised in underground mining operations as a means of primary and secondary support. The bearing plates have the secondary objective of securing steel mesh support which provides a passive system guarding against rock falls and minor roof collapse. The load bearing steel plates often yield when severe roof or rib conditions occur. If used as skin reinforcement, the TSL must be strong enough to resist any bearing plate loads without puncture. To minimise the possibility of puncturing or tearing of the polymer due to high bolt forces, various plates with suitable profiles need to be designed with the objective of minimising the compressive load at the plate boundary. Bearing plates are often square with sharp edges, a feature unsuitable for application with polymeric TSL. New bearing plate designs are needed to ensure gentle load distribution at the plate/TSL boundary to minimize any stress concentrations. They need to be of sufficient dimensions and suitable shape to be able to spread the concentrated forces of the roof bolt and rib bolt across a broader area of the mine roof or coal rib. To avoid stress concentrations on the corners of the plate especially where an uneven roof is present a circular plate and a large contact area is suggested to minimize stress at the plate boundary.

## PUNCTURE TEST

A puncture test was designed to quantify the bearing capacity of a 5 mm thick polymer sheet reinforced with glass fibre. To measure the load bearing capacity of the polymeric material, a series of steel discs shown in Figure 1 were used to load the TSL material to failure. The 5 mm thick glass fibre reinforced polymer liner used for testing is shown in Figure 2. A 500 kN Instron servo-hydraulic universal testing machine and a 5000 kN Avery compression machine were used to conduct the tests. The test involved nine steel discs of varying diameters, compressed into a polymer sheet sample as shown in Figure 3.

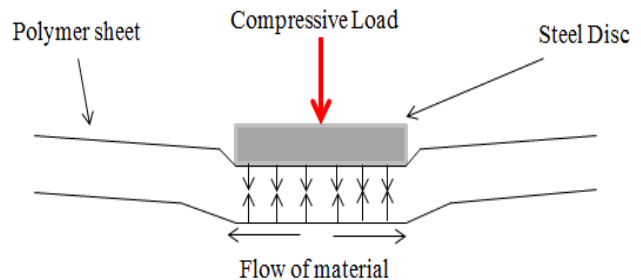
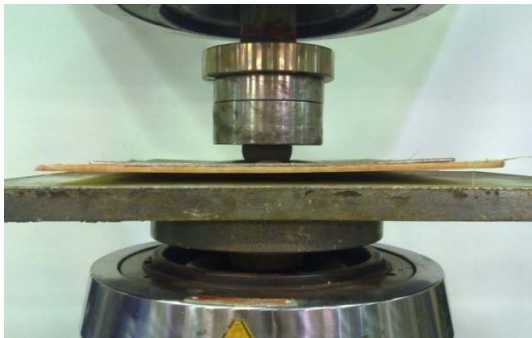


Diameter (mm)	Thickness (mm)
10	17
20	17
30	20
40	20
50	20
60	20
80	20
100	20
120	20

**Figure 1 - A series of steel disc sizes used to load the polymer TSL to failure**



**Figure 2 - Preparation of the polymer based TSL for testing**



**Figure 3 - Loading of a steel disk compressed into a glass fibre reinforced polymer sheet**

As load increased, flow of polymer material caused the plate and TSL to bend upward. As the load approached the maximum bearing capacity of the thin polymer material, separation of polymer layers and shearing occurred below the loaded area. The maximum bearing capacity was identified as puncture of the bearing plate through the polymer sheet with permanent damage. Increasing displacement under a stationary load indicated yielding of the polymer material. As the compression limit of the polymer was reached the next phase of loading indicated a rapidly increasing load with minimal change in displacement. This is attributed to the beginning of the compression of the steel plates and where the tests were terminated.

The test results summarised in Figure 4 below indicate that for disk diameter sizes from 10 mm to 50 mm an approximate linear increase in bearing capacity occurred, increasing 100 kN for every 10 mm increase in the disk diameter. As the outer perimeter of each disk is directly proportional to the disc diameter it appears that the linear relationship between the failure and the size of the disk is a result of the shear failure occurring mainly along the edge of the loaded disk. For larger disc diameters of 80 mm to

120 mm the bearing performance increased to a higher rate of approximately 400 kN per 10 mm increase in diameter. The smaller load bearing areas exhibited a complete deterioration of the polymer structure while loading of the larger diameter discs indicated that an elastic polymer core was left within the centre of the loaded area enabling a higher bearing capacity of the polymeric sheet. The disc bending may have been part of the cause of the reduced stress along the disc perimeter as the spherical seat that was used to load the 20 mm thick steel disks was only 50 mm in diameter. Once each test was concluded and unloaded, the majority of the smaller discs remained embedded within the polymer sheet. After removal of the disc the compressed polymer region was visibly brittle and broke away easily leaving a hole within the polymer sheet. This effect was minimised in larger discs indicating that the shearing stress at the perimeter was reduced possibly due to both the disk bending and exponentially increasing elastic core below the disk centre.

It must be noted that these idealized tests were performed on perfectly straight and smooth surface areas that rarely exist underground. Nevertheless these tests serve as a good estimation of the minimum load bearing areas needed for the bolt plate sizes. The polymer warping issue under high compressive loads as demonstrated in Figure 3 gives another bearing capacity limit that should not be exceeded, as it may compromise the adhesive integrity adjacent to the loaded bolt plates.

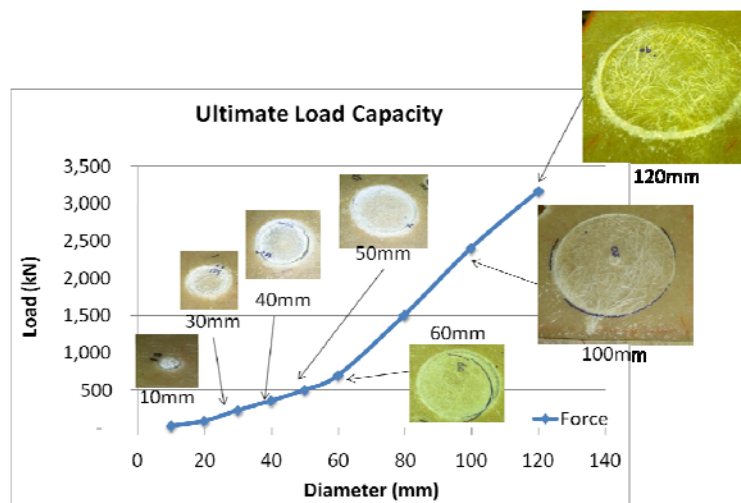


Figure 4 - Summary of the load bearing capacity tests

Extrapolation of data presented in Figure 5 may indicate the ultimate loads for larger bearing areas however; such estimations may not be accurate.

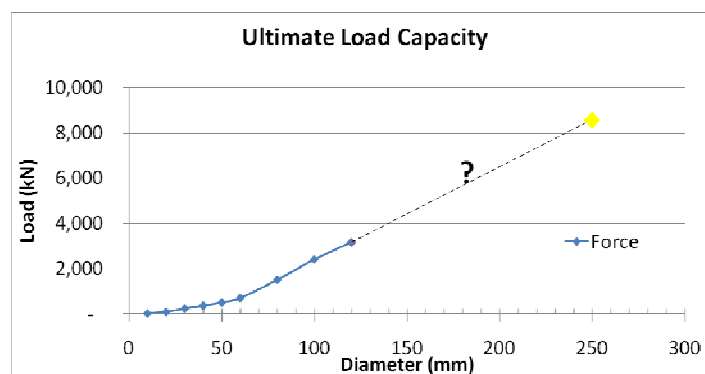
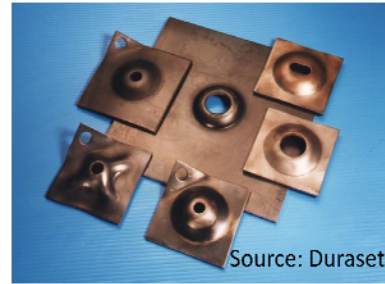


Figure 5 - Extrapolated ultimate load capacity for larger disk diameters

### ROLE OF BEARING PLATES

Bearing plates are a fundamental and integral part of any rock support solution. Currently used steel plates need to be re-designed so they can eventually be adopted by the TSL system and used successfully on polymer surfaces without any risk of compromising the polymer's integrity. Early bearing plates were flat square plates of steel with a central hole to accommodate a roof bolt is shown in Figure

6. Progressive development of high capacity rock and cable bolts has seen the transformation of bearing plates to circular, domed or even triangular designs with varying nut and bolt interfaces.



Source: Duraset

**Figure 6 - Square steel plates commonly used in coal mining industry**

As traditional plates have been designed specifically for installation with steel mesh systems, they exhibit features not suited to polymer reinforcing skin. When identifying a set of performance criteria for a suitable plate supporting the polymer TSL the following features were addressed. The plate should:

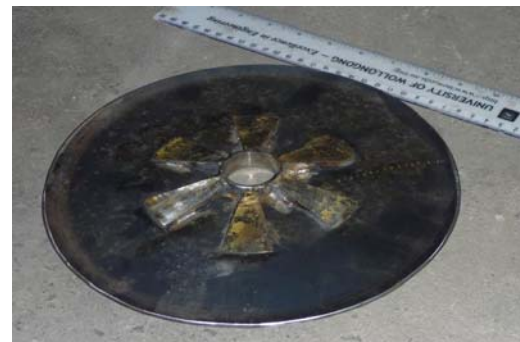
- be of sufficient stiffness to prevent excessive bending;
- be suited to providing compressive resistance to a roof surface coated with polymer TSL;
- not include any sharp contact points that would cause undue stress on the polymer;
- allow for a reasonable degree of deformation to accommodate uneven roof surfaces;
- incorporate drainage outlets to allow passage of water from roof strata to the mine roadway.

After preliminary consideration of the bolt plate, the primary design requirements for a suitable prototype include an appropriate diameter to bear the load of the corresponding roof bolt and a central circular hole that is suitable for the steel bolt design. In addition, the ultimate load capacity of bearing plates should be determined to correspond with the type of bolts, which, they are to be used with. It should be noted that even for fully encapsulated bolts, it should be assumed that high collar loads are still possible due to roof deterioration and load transfer onto the bearing plate. Finally, bearing plates should be designed so that if failure occurs it is progressive and not catastrophic.

From the above reasons it was concluded that an initial design of plate be fabricated to the specifications shown below:

- Circular shape to eliminate undue stress concentrations at plate corners
- Thickness of plate 3 mm to allow for some deformation
- Total diameter 250 mm to ensure sufficient bearing capacity
- Rolled up plate edge to allow for angular installations on uneven surfaces
- Six solid symmetrical ribs to increase central stiffness.
- Drainage holes around collar of plate

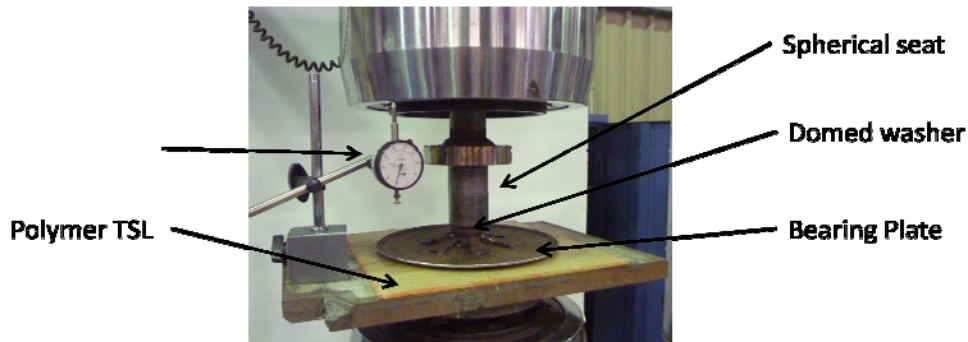
To compare whether the circular plate is better than the square design two plates were manufactured, one square and another of circular design, with identical solid wedge type ribbing as shown in Figure 7.



**Figure 7 - Square and circular steel bolt plates with identical solid reinforcing ribs**



The designed roof plates were used to load the polymer TSL sheet. The primary objective of the testing was to devise a reproducible laboratory procedure to investigate the polymer bearing capacity subject to steel plate loading of various designs. The tests were conducted using an Instron servo-hydraulic universal testing machine equipped with a 500 kN load cell. The arrangement of the test was such that the polymer TSL was placed on a flat steel loading surface with the roof plate compressed on top of it as shown in Figure 8. Each plate was tested under compression on a polymer sheet to allow observations to be made regarding failure characteristics and ultimate load capacity.



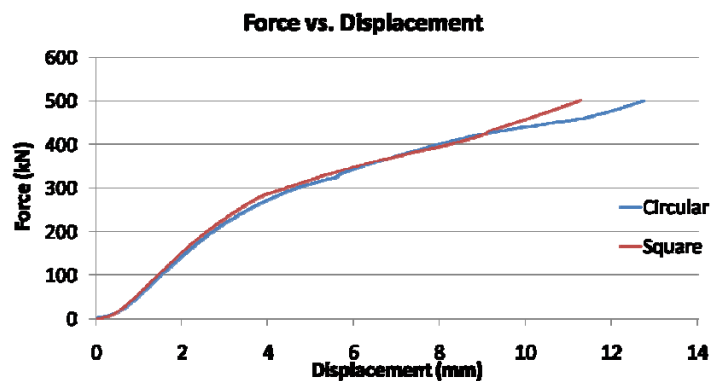
**Figure 8 - Loading of a polymer TSL sheet using the designed steel plates**

When the bearing capacity of both plates were approximately 300 kN the plate deformation caused compression damage to the polymer in the collar zone as shown in Figure 9. Despite that the loading continued to 500 kN the polymer sheet did not suffer any significant damage further away from the plate centre.



**Figure 9 - Polymer puncture zone due to plate centre deformation**

As can be seen in Figure 10, almost identical loading characteristics were observed for both square and circular plates.



**Figure 10 - Compressive loading characteristics of a square and circular steel plate on polymer sheet**

## CONCLUSIONS

The purpose of this study was to investigate the polymer bearing capacity and the characteristics of polymer failure when loaded with steel plates. A test was devised that utilised loading of circular plate of varying diameters to determine the load bearing capacity of a 5 mm thick glass fibre reinforced polymer sheet. As expected the tests indicated that the load bearing capacity increased with the size of the loading disc. An approximately linear relationship between disc diameter and the load bearing capacity of the polymer indicates that the shear stress along the disc perimeter dominates the failure. Discs of small diameter puncture the polymer sheet while larger discs leave a semi-elastic region of polymer below the centre of the disk.

The fabricated 250 mm square and circular steel plates performed to their design capacity with minimum damage to the polymer TSL sheet. Both the square and circular plate loading characteristics were similar and the difference between them was inconclusive. Testing of the bearing plates determined that the dimensions of the plate ensured a bearing capacity that was sufficient to prevent unacceptable polymer damage due to tensioned bolt forces or excessive loads due to strata failure.

It must be pointed out that all tests were conducted on a smooth surface and do not represent the usual roof or rib conditions in the mine and therefore the results represent the minimum plate sizes that can be used. Further polymer bearing capacity studies on uneven surfaces must be conducted to simulate actual mine site conditions.

## REFERENCES

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