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Strength Properties of Fibre Glass Dowels Used for Strata Reinforcement in Coal Mines

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ABSTRACT: Glass-Reinforced Polymer (GRP) bolts, commonly known as Fibre Glass (FG) dowels are increasingly applied for strata reinforcement in mines. The most popular dowels used in coal mines are the 22 mm diameter fully threaded type. A series of tests were undertaken to evaluate various strength properties of FG dowels. These include tensile failure tests by the double-embedment method, single and double guillotine shear tests, double shear tests in concrete medium and punch shear tests. Punch shear tests were used to evaluate the dowel shear strength parallel and perpendicular to the fibre glass strands or elements direction of extrusion. The study found that the tensile strength of the 22 mm diameter fibre glass dowels was in the order of 30 t. In the shear testing, the peak shear load was influence by the encapsulation grout type and the level of fibre glass axial pre-tension. Also, there was a nearly fivefold difference in the shear strength value of fibre glass dowels tested parallel as against perpendicular to the dowel axis.

INTRODUCTION

Glass-Reinforced Polymer (GRP) bolts, commonly known as Fibre Glass (FG) dowels are increasingly used in Australian coal mines as a mean of rib support in heading development and for coal face equipment recovery. The increased mechanisation of coal winning particularly by longwall mining necessitated the use of non-metallic rib dowels for rib support, where extraction includes cutting of bolts. FG dowels are made by pultrusion, a process that combines extrusion and pulling of molten or curable resin and continuous fibres usually arranged in unidirectional layers, through a die of a desired structural shape ("pull" and "extrusion"). FG dowels are made of glass strands pulled through a saturated thermo set resin and heated (Lowenstein, 1973). Presently FG dowels used in coal mines rib support have continuous rope thread profiles providing deformations for high bond strength with resin and rock. Other factors contributing to the increased application of polymeric dowels, as elements of support instead of steel, include:

- Improvement in the strength properties of the non-steel based dowels. The ultimate tensile strength of presently made 22 mm diameter dowels can range between 57 - 85 % of steel rebar of the same diameter.
- Easy and safe handleability of the non-steel dowels particularly FG ,
- Lightweight, fire resistant and easy to handle,
- FG dowels are relatively cheap,
- Cuttable, longer lasting and can be supplied a greater length.

Presently, there are two types of GRP bolts in the market, they are plastic and FG dowels, however, FG dowel is characterised as having lower yield deformation against shearing, and can twist on torqueing. Properties and characteristics of polymeric bolts are variable depending on the chemistry of the product, dowel diameter, solid or hollow core, surface profile shape and composition. FG dowels are used as rib support dowels. Dowels of the same core diameter can vary in length, identified by dowel colour and colour coding. Typical dowel lengths with colour coding include dowel length 1.2 m (blue), 1.5m (orange), 1.8m (red) and 2.1 m (green).

Procedures used for evaluating strength integrity of dowels are based on Australian and various international standards. These include American Standards of Testing Materials (ASTM. C-759, 1991), The British Standard (BS 7861- Parts 1 and 2, 1996), International Standard ISO 10406-1 (2008), South African Standard, SANS1534 (2004) and others. In general, many well-known standards are invariably interrelated; however, the suitability of any particular standard, for testing the given property of the dowel, will depend on the purpose of the dowel use and host medium properties. The current reporting

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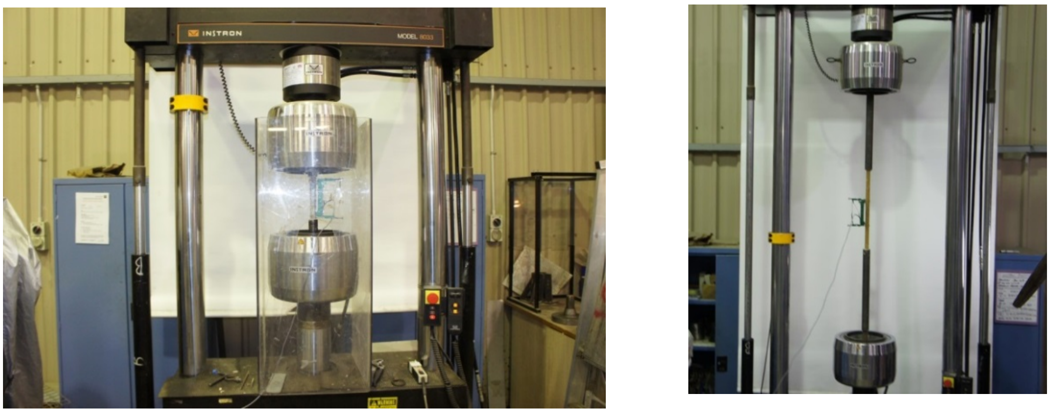
of the shear strength of dowels is normally based on guillotine testing of the FG rod in steel apparatus. Guillotining of the GRP dowels in steel shear apparatus yields lower shear values and is a desirable test. It is important that the shear strength of dowels must be determined based on simulated ground conditions, and therefore it is logical to test dowels in rock or cementitious medium of concrete. Accordingly there is a need for establishing a credible testing methodology and procedures of marketed dowels. The double shear testing of dowels in concrete blocks represents a novel approach to simulating the shear behaviour of dowel in rock formation *in situ.* This paper discusses tensile and shear strength characteristic of 22 mm core diameter FG dowels, which are used in Australia coal mines.

TENSILE STRENGTH PROPERTIES

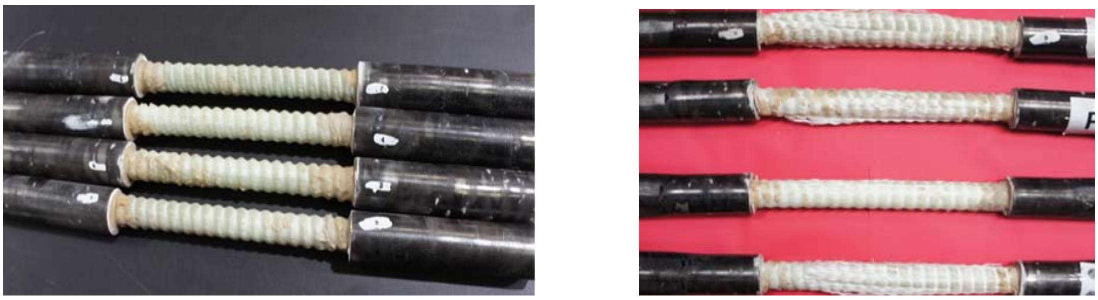
Eight FG solid core dowels were tested for failure. Each 500 mm long dowel section was double embedded in 150 mm length steel tubes and pull tested to failure. Oil based standard J-LOK resin was used to install the dowels in steel tubes. FG dowels were pull-tested in a 50 t Instron universal testing machine. The elongation of the 110 mm length of the middle section was monitored using an accurate extensometer as shown in Figure 1 and b. Monitoring of the bolt section elongation was necessary in order to eliminate any displacement of bolt ends between the jaws of the test machine or the encapsulated bolt ends in the steel tubes being displaced.

To alleviate the concern of the possible influence of short lengths of tested samples end in steel tubes on test values, tests were also made on 1.2 m long dowels with ends being embedded in 450 mm long steel tubes as shown in Figure 1b. Solid threaded bars were connected to the end of each embedded encapsulation tube, to enable anchoring/clamping of the dowel and tube assembly to the jaws of the testing machine. The internal lining of embedded tubes was threaded with 2 mm threads and in accordance with recognised test standards such as ISO-10 406-1:2008. Figure 2 show short and long encapsulated dowels before and after testing. Figure 3 shows the load displacement of both short and long dowel test results. The pull test results revealed that end encapsulation of the dowels had no significant influence on the outcome of strength test results. The average displacement of the short encapsulated bolt at yield strength is in the order of 6%; however the displacement amount at yield strength appears to be significantly longer at around 9%. More tests are needed to verify this finding.

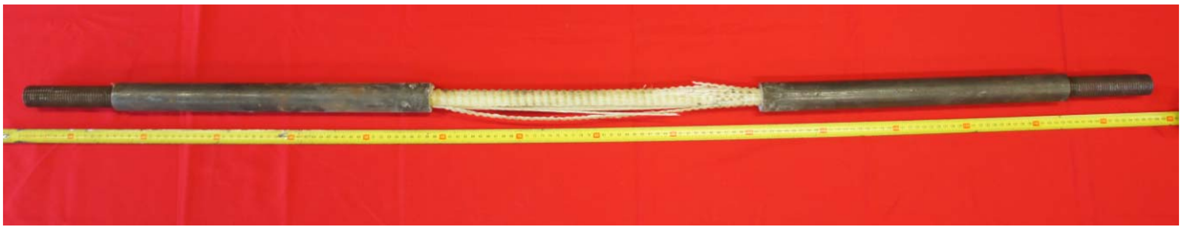


(a) 500 mm long dowel section (b) 1200 mm long dowel

Figure 1: Fibre glass bolt tested for tensile failure with extensometer



(a) Intact 500 mm long dowels with short end encapsulation samples (b) post-test 500 mm long shor



(c) Post-test 1.2 mm long test sample

Figure 2: FG dowels prior to and post tensile failure testing

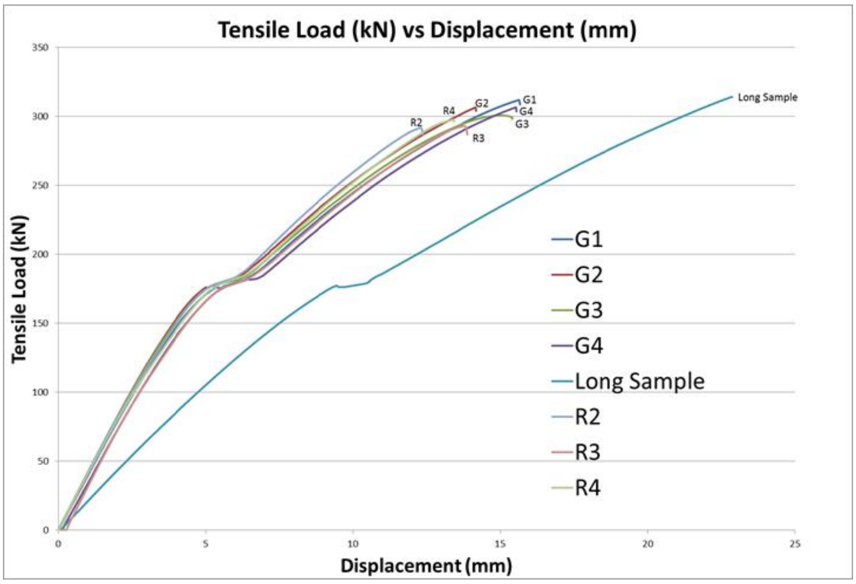


Figure 3: Tensile load versus displacement of 500 mm long and 1.2 m long dowels

SHEAR TESTING OF DOWELS

Single shear guillotine test

Figure 4 shows the single shear apparatus used for shear testing of FG dowels. Commonly known as guillotine and is in compliance with the British Standard 7861 (2009), the instrument allows direct shearing of dowels and steel rebar to failure. Figure 5 shows examples of tested samples. Figure 6 shows load-displacement graphs of single shearing tests of only six, 300 mm long dowel sections. Details of the test results are also shown in Table 1. The average value of the shear strength was 133.51 MPa. The cut face surface of all ten tested dowels was identically stepped at mid face as is obvious in Figure 5. This may be attributed to the possibility of (a) the lateral incremental side movement of the dowel side during the shearing process, as the dowel sample was not grouted to its housing or held tight against the shearing apparatus and (2) the structural composition of the strands lay binding resin.

Figure 4: Single shear guillotine apparatus

Figure 5: Single sheared failed 22 mm diameter dowels

Table 1- Single shear results for ten dowels

Sample	Displacement (mm)	Peak Load (kN)	Shear Stress (MPa)
1	7.25	49.48	130.16
2	8.55	46.59	122.57
3	7.13	48.26	126.96
4	7.35	51.35	135.09
5	7.94	52.74	138.73
6	8.40	49.83	131.08
7	8.26	52.67	138.56
8	8.28	53.26	140.11
9	7.76	50.32	132.39
10	7.64	52.99	139.41
	Ave	**50.75**	**133.51**

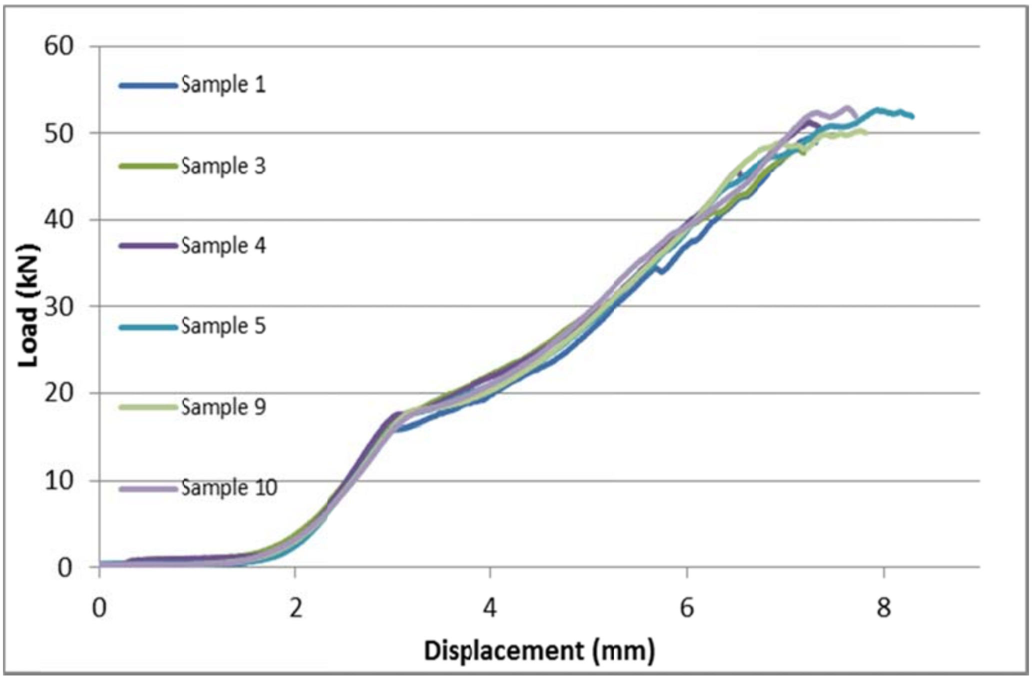


Figure 6: Shear load displacement graphs of single shear testing

Double shear Guillotine test in steel frame

The purpose of this section was to assess the single shear strength capacity of fibreglass dowels using a double Shear Testing Apparatus, which is conveniently named as Double Shear Guillotine test. The test produces steel on dowel interaction, whereas in *in situ* it would be the strata on grout on dowel interaction. However this test was carried out to compare test results with the single shear strength values using the single shear method.

Figure 7 shows the double shear test apparatus used for the study. It consists of two steel pieces. The bottom piece or 'U' shaped piece measured 143 mm x 83 mm x 70 mm. The top piece or 'T' shaped piece is inserted into the 'U' shaped piece. It measures 131 mm x 92 mm x 70 mm. The dowel was inserted through the middle of the combined apparatus and sheared up to a maximum depth of 30 mm. Each tested dowel rod cut into 300 mm specimen length. The shear testing was carried out using the 500 kN capacity Instron Universal Testing Machine, at a rate of 1mm/min.

Figure 7: Double shear guillotine apparatus set up

The shear strength of the dowel was determined using;

$$\tau = \frac{F}{2A} = \frac{2\ Peak\,load}{\pi D^2} \tag{1}$$

Where:

τ = shear strength
F = Peak load at failure
A = dowel cross sectional area
D = Dowel Diameter

Table 2 shows the results of double shear guillotine test, four dowel sections were tested and the average failure load and shear strength of the dowels were 50.48 kN and 123.79 MPa respectively. These results compare favourably with the single shear test results as reported in Table 1. The pattern of the shear failures was similar to the single shear test, but less pronounced as is shown in Figure 8.

Table 2: Double shear guillotine test results

Sample	Peak shear Load (kN)	Single face Peak Load (kN)	Shear Stress (single face) (MPa)
1	103.77	51.88	136.49
2	98.03	49.01	128.94
3	111.04	55.52	146.06
4	90.99	45.50	119.69
	Average	50.48	132.79

Figure 8: failure pattern of dowels in guillotine

Double shear test in concrete

Double shear strength of fibre glass dowels was investigated in three piece concrete blocks consisting of a 300 mm long prism block, sandwiched between two 150 mm side cubes. 40 MPa, Uniaxial Compressive Strength (UCS) mortar blocks were prepared with sand: cement ratio of 3:1. Once mixed the mortar was poured into the internally greased marine plywood mould, measuring 150 mm x 150 mm x 600 mm. The mould was divided into three compartments separated by two metal plates. A plastic conduit, 20 mm in diameter was set through the centre of the mould lengthways to create a hole for FG dowel installation. The cast mortar blocks were left for 24 hours to set and harden. The set blocks were then removed from the mould assembly and kept in a moist environment for a period of 30 days to cure. The central hole of the mortar block was then reamed rifle-shaped to 27 mm diameter, ready for the installation of the dowel with cement grout. The strength of the concrete blocks was determined from testing of the representative 100 mm diameter cylindrical concrete specimens, cast at the time of concrete preparation and pouring.

Two different cementitious grouts were used when installing and encapsulating FG dowels in concrete blocks; (a) Jennchem Top-Down 80 grout (TD80) and (b) Jennchem Bottom-Up 100 grout (BU100). The strength of both grouts varied depending on the product composition and water content. In this study the level of water for each grout was maintained constant at six litres per bag. The FG concrete assembly was left for a minimum of seven days before being tested.

A total of 11 tests were conducted in this study. Dowels for each category of grout used were pretensioned to various loads up to 22.50 kN and then tested for shear. An attempt to apply pretension load of 25 kN was not possible as extra load torque applied to the dowel nuts caused the dowel ends to twist, leading to lower shear loads.The applied axial tension load due to subsequent shearing load, were monitored using two 30 t capacity load cells shown in the assembled setup in Figure 9. A 50 t capacity Instron universal testing machine was used for shearing study. Clearly there are variations to the shear strength properties of the FG dowels based on the level of pretension loads and grout type as shown in Table 2 and Figure 8 t was found that;

a) The shear values of dowels were higher with increased pretension loads.
b) Increased pretension loads greater than 22.5 kN caused dowel ends to twist thus affecting double shear strength values as is evident from the lower value shear load of the dowel pre-tensioned at 25 kN,
c) Shear load values of dowels are affected by the grout type, with average shear values obtained from FG dowels tested with grout TD80 being higher than test results with BU100 grout, despite the fact that BU100 grout has relatively superior strength in comparison with TD80 grout.
d) The shear value of each tested dowel was determined taking into consideration the shear strength contribution from 150 mm^2 concrete joint planes.

Figure 9: An assemble FG dowel with load cells for double shear testing in 50 t Instron testing machine

Table 3: Single and double shear test results with different grouts

a) Encapsulation Grout: BU100

Test	Initial ave axial load (kN)	Final ave axial load (kN)	Peak shear load (kN)	Peak double joint plane shear strength (MPa)	Peak shear per joint plane (MPa)	Contribution from concrete joint surface (%)	shear strength less joint surface shear (MPa)	Direct single shear test (guillotine) ave value from Table 2 (MPa)	Increase (%)
1	2.5	28.7	163.9	431.2	215.6	10	194	133.5	49
2	4.5	43.4	182.9	481.6	240.6	15	205	133.5	58
3	5	62.0	204.7	538.5	269.2	15	229	133.5	76
4	15	31.2	219.7	578.0	289.0	20	231	133.5	78
5	20	40.0	258.1	679.0	339.5	25	255	133.5	96
6*	25	66.2	191.8	504.6	252.3	30	177	133.5	36

* Sample 6 - twisted dowel

b) Encapsulation Grout: TD80

Test	Initial ave axial load (kN)	Final ave axial load (kN)	Peak shear load (kN)	Peak double joint plane shear strength (MPa)	Peak shear per joint plane (MPa)	Contribution from concrete joint surface (%)	shear strength less joint surface shear (MPa)	Direct single shear test (guillotine) ave value from Table 2 (MPa)	Increase (%)
7	2.5	26.9	206.3	542.6	271.3	10	244	133.5	88
8	7.5	49.2	178.5	469.6	234.8	15	200	133.5	54
9	10	20.6	266.6	701.2	350.6	15	298	133.5	229
10	22.5	50.2	296.1	779.0	389.5	15	331	133.5	255
11	25	53.7	172.4	453.5	226.8	25	170	133.5	31

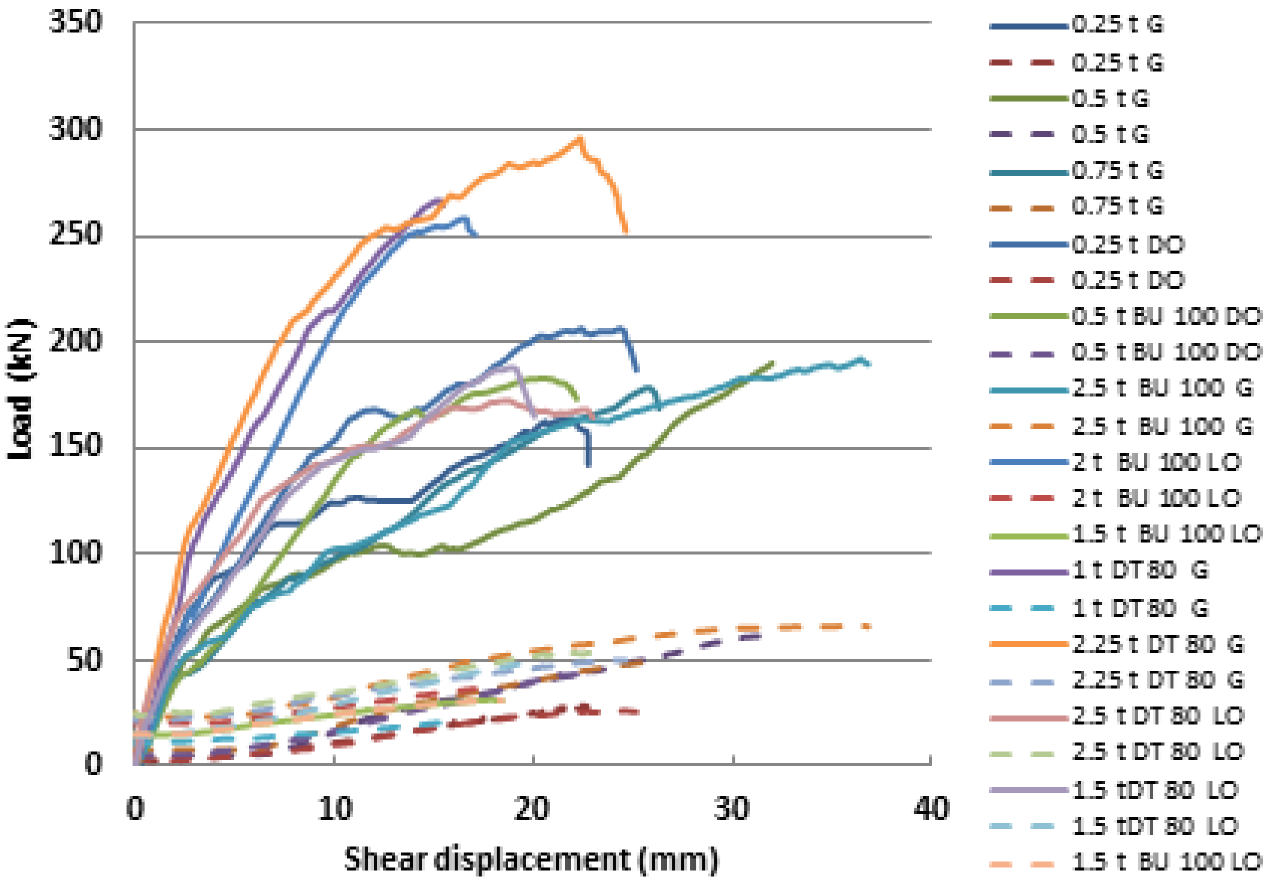


Figure 10- Shear pretention loads versus vertical displacement of double shear testing of 11 dowels

Impact of concrete strength

Further studies on the impact of the concrete strength on the double shear strength value of the dowel, a series of tests were undertaken in 40 MPa and 60 MPa concrete strength respectively. Four double shear tests were carried in 60 MPa strength concrete assemblies. Each double shear test was made in different pretension load of 2.5, 5, 10 and 15 kN respectively. Tests were made using 40 mm hexagonal nut with spherical ends. Another set if three tests were also made in 40 MPa concrete.

Table 4 shows initial axial loads, the peak axial loads, the peak shear loads and the equivalent single shear strength of four 22 mm dowels double shear tested in 60 MPa concrete blocks.
Figure 1 shows graphically the combined results from all four tests. The figure shows both the shear load and axial pretension loads for all samples. The shear strength values of the dowel appears to be influenced by the level of pretension loads, which is an expected variation and in agreement with various tests undertaken in both solid rebar and cable bolts. In general, the shear strength of the dowel was increased with increasing pretension loads.

Table 4: Double shear axial and shear loads of dowels tested in 60 MPa concrete

Sample	Initial Axial Load (kN)	Peak Axial Load 1 (kN)	Peak Axial Load 2 (kN)	Peak Shear Load (kN)	Shear Strength (MPa)
1B	2.5	15.91	13.64	220.74	290.34
2B	5	25.73	22.39	213.03	280.20
3B	10	22.60	27.79	242.70	319.23
4B	15	29.83	44.14	262.48	345.25

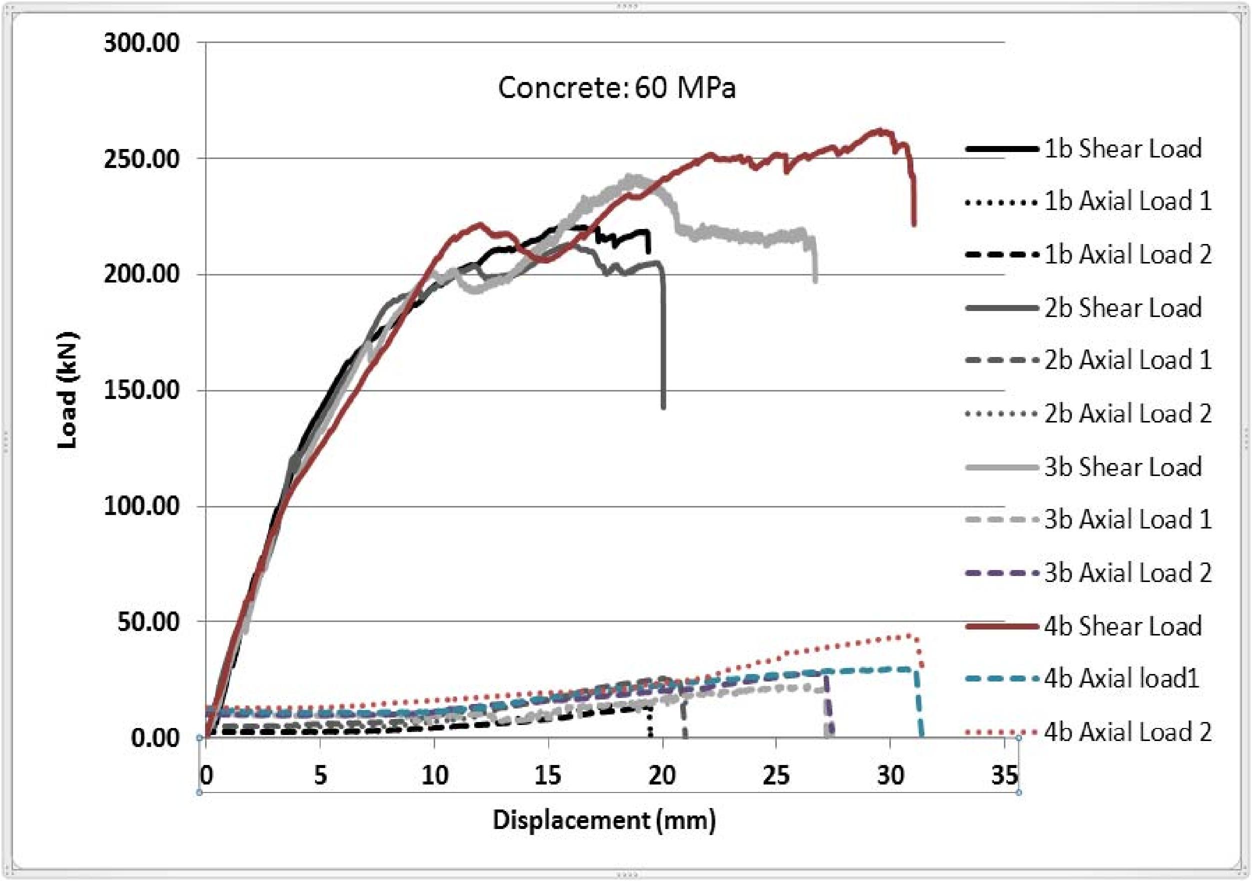


Figure 11: Double shear load–displacement profile of dowels axial and shear loads in 60 MPa concrete blocks

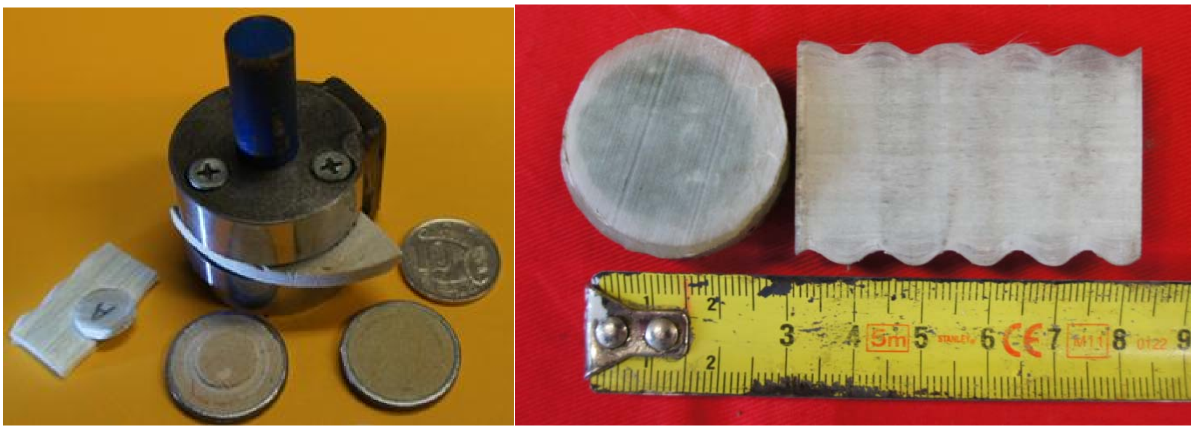
Punch shear test

Using the punch shear box, shown in Figure 12a, a series of punch shear tests were carried out on FG dowel samples to determine the shear strength of FG dowels. 3 mm thick discs were sliced perpendicular to the dowel axis to examine the shear strength properties of dowels parallel to the strands or FG elements lay, while 3 mm strips were cut parallel to the dowel axis to evaluate the shear strength of the FG elements bonding. Figure 12 b shows typical samples prepared for testing in punch shear apparatus. Tables 5 and 6 show results of punch shear tests. Values of the shear strength were determined by using the following equation;

$$\tau = \frac{F}{3.142 \, x \, T \, x \, D} \qquad (2)$$

where;

F = applied load, τ = shear strength, T = Sample thickness and D = Punch diameter



(a) Punch shear apparatus **(b) FG dowel samples perpendicular and parallel dowel axis**

Figure 12: (a) Punch shear apparatus and (b) 33 samples FG strip cut out (i) perpendicular and (ii) parallel to dowel axis, for shear testing

From Table 5, the average shear strength value of six samples punch tested parallel to the direction of the dowel is shown to be 22.35 MPa, and the average shear strength value of testing three samples perpendicular to the direction of the dowel axis as shown in Table 6 is 104.01 MPa. It is clear that there is an obvious difference in shear strength in the ration of 4.7:1 in favour of perpendicular to dowel axis or dowel strands compared with parallel to dowel axis. The low shear strength values parallel to the dowel axis may be due to the resin strength holding the fibres together, which is resisting the shear force. The average shear strength value shown in Table 5 strikingly similar to the average shear strength value of 21 days old standard oil based bolting as reported by Gilbert (2014)

Table 5: Punch test results of samples cut parallel to dowel axis

Sample	MN	T (m)	D (m)	τ (MPa)
A	0.0021	0.00249	0.0127	21.12
B	0.0022	0.00253	0.0128	21.70
C	0.0023	0.00279	0.0126	20.64
D	0.0028	0.00336	0.0126	20.98
E	0.0040	0.00363	0.0127	27.97
F	0.0011	0.00178	0.0127	15.38
G	0.0039	0.00342	0.0127	28.67
			Average	**22.35**

Table 6: Punch test results of samples cut perpendicular to dowel axis

Sample	Punch load (MN)	T (m)	D (m)	τ (MPa)
A	0.012	0.00297	0.0128	102.22
B	0.012	0.00302	0.0127	102.30
C	0.013	0.00302	0.0129	107.50
			Average	**104.01**

CONCLUSIONS

This study demonstrated that the guillotine method of testing dowels yields lower shear values than results obtained from testing dowels by double shear testing in concrete. Double shear testing in concrete represent a realistic way of simulating the strength property of the composite material in rock and *in situ*. The study also found that:

a) Shear strength values of the FG dowels were higher with higher pretension loads.
b) Increased pretension loads greater than 22.5 kN caused dowel ends to twist, affecting double shear strength values.
c) Shear load values of dowels are affected by the grout type, with average shear values obtained from testing FG dowels tested with grout TD80 was higher than test results with BU100 grout, despite the fact that BU100 grout has relatively superior strength in comparison with TD80 grout.
d) Low shear strength results of testing dowel parallel to the dowel axis in comparison to the shear values perpendicular to FG strands lay may be indicative of the resin strength holding the fibres together and resisting the shear force. Shear strength values shown in Table 3 are comparable to the shear strength of a typical oil based standard chemical resin used for bolting installation.

REFERENCES

Lowenstein, K.L. 1973, *The Manufacturing Technology of Continuous Glass Fibers*. New York: Elsevier Scientific. pp. 2–94. ISBN 0-444-41109-7.

American Standard for Testing Materials (ASTM. C-759). 1991, Standard test method for compressive strength of chemical –resistant mortar, grouts, monolithic surfacings and polymer concretes.

British Standard BS 7861- Parts 1 and 2. 2009, Strata Reinforcement support system components used in Coal Mines-Part 1. Specification for rock bolting and Part 2: Specification for Flexible systems for roof reinforcement.

International Standard ISO 10406-1. 2008, Fibre-reinforced polymer (FRP) reinforcement if concrete – test methods, part 1: FRP bars and grits, First edition, 40 p.

South African Standard SANS1534. 2004, Resin capsules for use with tendon based support systems, published by *Standards South Africa*.

Gibert, D. 2014, Study of fibre glass strength properties, undergraduate thesis, *University of Wollongong*.