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The strength properties of fibre glass dowels used for ground control in coal mines

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ABSTRACT
Glass-Reinforced Polymer (GRP) bolts, commonly known as Fibre Glass (FG) dowels or plastic dowels are increasingly applied for strata reinforcement in mines as well as in concrete reinforcement in civil engineering. The most popular dowels used in Australian coal mines are the 22 mm diameter fully threaded type. FG bolts are cuttable, easy to handle, lightweight and corrosion resistant. The tested dowels were all black in colour, which is a favoured colour in coal mines. A series of tests were undertaken to evaluate various strength properties of FG dowels. These tests include the tensile failure test by the double-embedment method, single guillotine shear test, double shear test both in steel frame and in concrete blocks, and finally the punch shear test. The study found that the tensile strength by pull testing of the 22 mm diameter fibre glass dowels was in the order of 27 t. The shear strength testing of dowels in both single guillotine and double shear steel frames were in agreement with each other. In general the shear strength values of dowels tested, using single shear guillotine testing, were around 20% of the axial strength in comparison with 70% in the same diameter steel rebar tests. The peak shear load values obtained from double shear tests in concrete blocks was influenced by the encapsulation grout type and the level of fibre glass axial pre-tension. The punch shear tests revealed that there was a more than threefold increase in the punch shear strength value of fibre glass dowels tested perpendicular as against parallel to the dowel axis.
KEYWORDS: Fibre glass dowels; rib support; tensile strength; single and double shear test; punch shear test

1. INTRODUCTION

Glass-Reinforced Polymer (GRP) bolts, commonly known as Fibre Glass (FG) dowels, are increasingly used in Australian coal mines as a means 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 thermoset 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 at 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).

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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 used and host medium properties. The current reporting 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 an undesirable test, unless the dowels are contained in very thick grout encapsulation sleeve. 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 for effective marketing strategy. 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.

2. TENSILE STRENGTH PROPERTIES

Six 1.2 m long 22 mm diameter black dowels were tested for tensile strength. Each sample was double embedded in 400 mm length steel tubes and pull-tested to failure. Oil based chemical bolt resin was used to install the dowel in steel tubes. Figure 1 shows a dowel with both embedded ends being encapsulated in the steel tubes. Figure 2 shows the sample being tested in 50 t Instron Universal Testing machine. Figure 3 shows the load displacement of four failed samples out of six tested samples. Figure 4 shows post-test dowels. Two samples did not fail

Figure1: Black dowel with ends encapsulated in 450 mm long tubes used for tensile strength testing.

Figure 2: Tensile testing of a dowel in 50 t Instron Universal Testing Machine and monitoring system.

because of poor encapsulation. The average peak failure load of four failed dowels is 273.36 kN, as shown in Table 1.

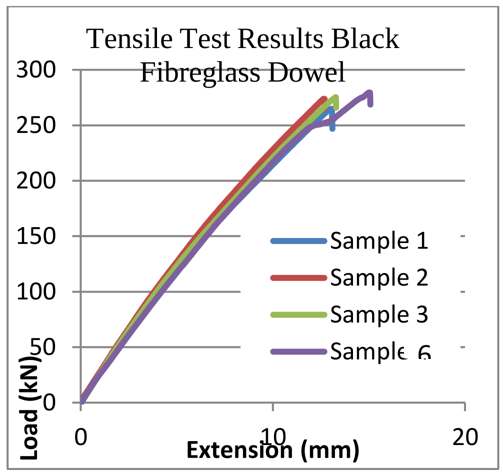


Figure 3: Load displacement profiles of four tested black dowel samples.

Figure 4: Tensile failure of four out of six tested samples.

Table 1: Average peak load for tested samples.

Sample	Peak Load (kN)
1	264.83
2	273.79
3	275.34
6	279.48
Average	273.36

3. SHEAR TESTING OF DOWELS

3.1 Single shear guillotine test

Figure 5 shows the single shear apparatus used for shear testing of FG dowels. Commonly known as the “guillotine test”, the instrument allows direct shearing of dowels and steel rock bolts to failure. Figure 6 shows typical tested samples. Figure 7 shows typical graphs of single shearing tests of nine, 300 mm long black dowel sections. Details of the test results are also shown in Table 2. The average value of the shear strength was 150.45 MPa. The cut face surface of all ten tested dowels was identically stepped at mid-face as is obvious in Figure 6. This may be attributed to the fact that dowel sections were not grouted in the frame and the guillotining effect may have caused a slight bending and incremental elongation of the uncut half FG elements. Also it should be noted that the slight displacement at the early stage of testing, as indicated in the circled section of the graphs in Figure 7, may be attributed to the early crushing of the dowel rifle profiles.

Figure 5: Single shear testing of black dowel.

Figure 6: Sheared dowel face with stepped cut.

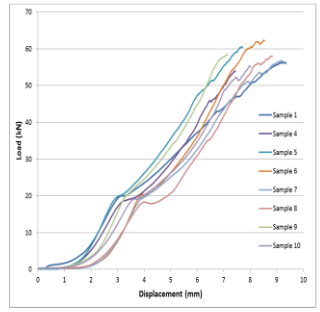


Figure 7: Single shear test results of 22 mm diameter dowels tested for single shear.

Table 2: Single shear test data for nine dowels.

Sample	Peak Load (kN)	Shear Strength (MPa)
1	56.33	148.19
2	52.78	138.86
3	53.98	141.99
4	60.63	159.49
5	62.35	164.01
6	56.75	149.29
7	58.04	152.68
8	58.43	153.71
9	55.42	145.80
Average	57.19	150.45

3.2 Double shear test method - in steel frame

The purpose of this section was to compare the single shear strength capacity of FG dowels using a double shear guillotine testing apparatus. Like the single shear test, this test does not represent the shearing action encountered in underground conditions. The test produces steel on dowel interaction whereas in underground it would be the strata on grout on dowel interaction. However, this test was carried out to compare with the single shear strength result observed using the single shear method. Each dowel was machine cut into 300 mm specimen lengths. Four samples were tested.

Figure 8 shows the double shear test apparatus that was 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. Figure 9 shows the load-displacement and failure of tested dowel sections. Figure 10 shows sheared samples.

Table 3 shows peak failure load and shear strength of the dowel. The average value of the shear strength is 157.62 MPa. This value is in reasonable agreement with the results of the single tests shown in Table 2. By taking a biased average of four tests as shown in the right column Table (blue writing), it is clear the results of single shear concur favourably with the results of double shear tests. Also the failure pattern in double shear test is similar to that of single shear test, with step cuts as shown in Figure 10.

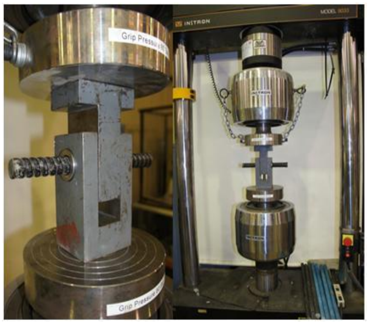


Figure 8: Double shear guillotine apparatus set up.

The shear strength of the dowel was determined using:

$$\tau(MPa) = \frac{F}{A} = \frac{N}{mm^2} = \frac{Peak\ Load\ (kN) \times 1000}{\pi 22^2/_4}$$

Where:

τ = shear strength in mega-Pascals
F = Peak load at failure in Newtons
A = dowel cross sectional area in millimetres squared

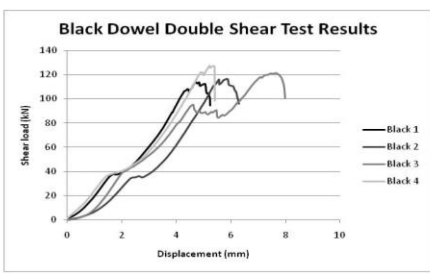


Figure 9: load displacement profiles of four double shear tests in steel frame.

Figure 10: Failure pattern of samples in steel double shared apparatus.

Table 3 shows 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 2. The pattern of the shear failures shown in Figure 10 is similar to the single shear test results, but less pronounced as is shown in Figure 6.

Table 3: Double shear guillotine test results.

Sample	Peak shear Load (kN)	Single face peak load (kN)	Shear Stress (single face) (MPa)
1	107.33	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

3.3 Double shear tests in concrete

The 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. Recently the process of mechanical reaming of 20 mm central hole was disbanded in favour of casting of profile holes using double core 3 mm thick electric wire wrapped around the central steel bar. The central steel bar and the wrapped wire were later removed during semi-hardened stage of cast concrete. 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)
(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 20 kg bag. The FG concrete assembly was left to cure 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 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 11. A 50 t capacity Instron universal testing machine was used for shearing study. Clearly there were variations to the shear strength properties of the FG dowels based on the level of pretension loads and grout type as shown in Table 4 and Figure 12. It 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 were affected by the grout type, with average shear values obtained for 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, which is surprising, Further tests will be carried out to verify theses findings
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 11: A double shear assembly mounted in the 500 kN Instron testing machine.

Table 4: 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

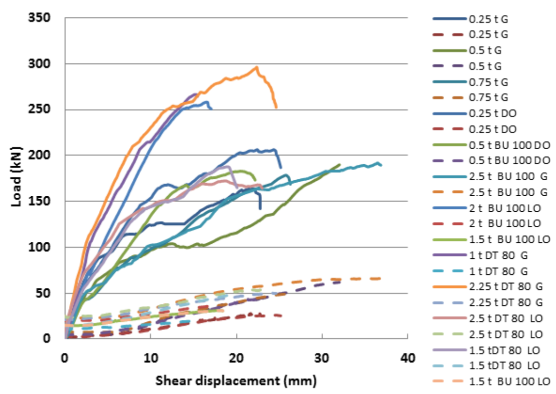


Figure 12- Shear pretention loads versus vertical displacement of double shear testing of 11 dowels.

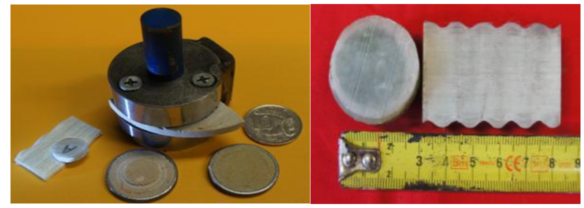
3.4 Punch Shear Test

Using the punch shear box, shown in Figure 13a, 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. These two types of cuts are shown in Figure 13b. Tables 5 and 6 show results of punch shear tests. Values of the shear strength were determined by using the following equation;

$$\tau = \frac{F}{3.142 \times T \times D}$$

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

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 ratio 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 shear strength holding the fibres together, being lower than the strength of the fibre glass. The average shear strength value shown in Table 5 strikingly similar to the average shear strength value of 21 days old standard oil based resin used for bolting encapsulation bolting as reported by Gilbert (2014).



(a) (b)

Figure 13a: Punch shear apparatus, Figure 13b: Punch shear apparatus.

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

4. 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 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 thus affecting double shear strength values, and this is evident from the lower value dowels double shear load pre-tensioned to 25 kN.
c) The Shear load values of dowels were 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, which is surprising. Further studies is planned to confirm this finding.

d) Low shear strength results of testing dowel parallel to the dowel axis and thus to FG strands may be due to the resin strength holding the fibres together and resisting the shear force being lower than the shear strength of fibre glass elements. The shear strength values shown in Tables 5 are comparable to the shear strength of a typical oil based standard chemical resin used for bolting installation.

5. ACKNOWLEDGEMENT

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