Empa
Überlandstrasse 129
CH-8600 Dübendorf
T +41 58 765 11 11
F +41 58 765 62 44
www.empa.ch

Materials Science & Technology

FiReP International AG
Mr. Hamid Ahari Hashemi
Alte Jonastrasse 83
8640 Rapperswil

Test Report No. 456496

Test assignment:	**Testing of Powerthread K60-32 and accessories**
Client:	FiReP International AG, Rapperswil, Switzerland
Test objects:	5 Bolts
	5 Bolts with Normal Nut & Plate (GRP)
	5 Bolts with Steel Nut L=150 mm
	5 Bolts with Steel Nut L=200 mm
	5 Bolts with Steel Coupler L=200 mm
Client's ref:	Mr. H. Ahari Hashemi
Order dated of:	05.11.2010
Test performed:	27.01.2011 – 17.02.2011
Number of pages:	13
Attachments:	Appendix A and B

Empa, Swiss Federal Laboratories for Materials Science and Technology
Laboratory for Structural Engineering
Dübendorf, March 24, 2011

Expert:
Dr. Andrin Herwig

Head of Laboratory:
Prof. Dr. Masoud Motavalli

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Contents

0 Units and symbols

Units

area:	mm^2
deformation:	mm
displacement:	mm
force:	kN
length:	mm, cm, m
strain:	%
stress:	N/mm^2
temperature:	°C
time:	min.
volume:	mm^3
Young's modulus:	N/mm^2

Latin upper case symbols

A	cross section area
A_s	stress section area
D	diameter
D_s	stress section diameter
E	Young's modulus
F_u	breaking load
T_u	breaking torsional moment
L	length
L_m	length of the field for the image correlation measurements in bolt direction
N	number of samples

Latin lower case symbols

f_u	maximum stress
$\bar{x}$	mean value
x_i	sampling data

Greek upper case symbols

$\Delta\varepsilon$	difference between the strains at 50% and 20% of the maximum tensile force
ΔF	difference between the forces at 50% and 20% of the maximum tensile force

Greek lower case symbols

ε	strain
σ	standard deviation

1 Introduction

FiReP International AG (Switzerland) commissioned Empa to conduct tests with 4 types of glass reinforced polymer (GRP) bolts and accessories under short term loading. These bolt systems are used in mining, tunneling and ground stabilization.

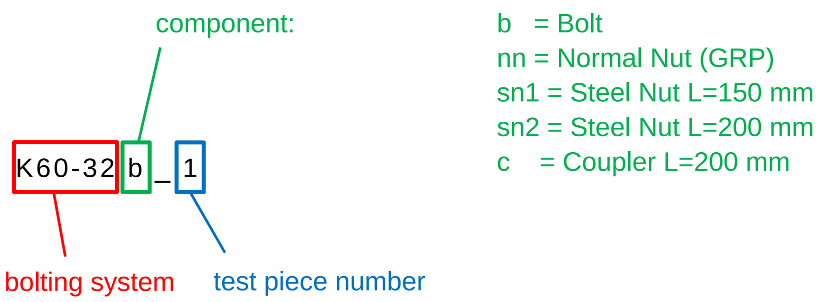
The test method is based on the ISO 10406-1 standard.

This test report describes tensile tests and its test results for 5 specimens of Powerthread K60-32 (D=32 mm, UP resin) and related accessories.

2 Tests

2.1 Test piece names

Using the following example the explanation is given on how the test piece name is built up.



2.2 Overview of the tests

The test pieces were delivered to Empa on January 24, 2011. All tested objects are listed in Table 1. The loading was applied with a 1000 kN machine (Log-No 60.220) cross head displacement controlled. The measurement uncertainty was smaller than 1% of the load over the 1000 kN measuring domain.

This machine allows for a maximum test piece length of 2.0 m.

The strain rate listed in the table corresponds to the constant cross head displacement velocity divided by the free length of the GRP bolt.

Table 1: Components to be tested for fracture load

Component to be tested	Number of test pieces	Test piece designation	GRP strain rate [% / min.]
Bolt: Fracture load and tensile modulus	5	K60-32b_1…5	0.8
Normal Nut (GRP)	5	K60-32nn_1…5	0.9
Steel Nut L= 150 mm	5	K60-32sn1_1…5	0.9
Steel Nut L= 200 mm	5	K60-32sn2_1…5	0.9
Steel Coupler L = 200 mm	5	K60-32c_1…5	0.9

The temperature was 20° C for all tests.

2.3 Tensile tests with bolts

2.3.1 Test piece

Figure 1 shows the test piece geometry. The free GRP length was 1000 mm. Both ends of the 2000 mm long GRP bolt were glued into steel sleeves in the factory.

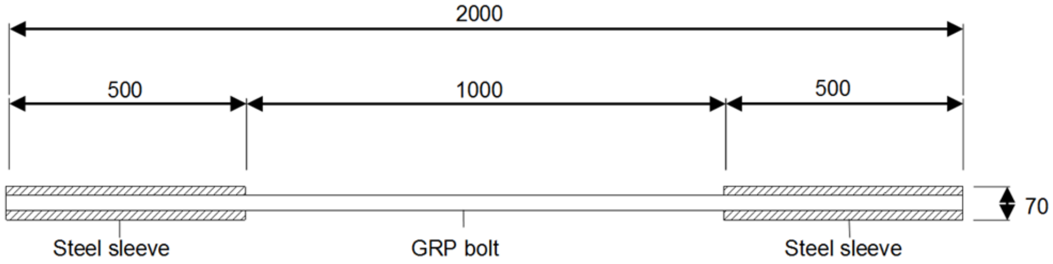


Figure 1: Test piece for the bolt tensile tests [mm].

2.3.2 Test set up

The test set up is shown in Figure 2. The cross head displacement and the force were measured. The measurement of the cross head displacement is subsequently designated as ‚test machine displacement reading'. The strain was measured contactless with an image correlation system within a field with a length of L_m = 300 mm. The image correlation system took pictures with a frequency of 0.4 Hz. The software calculated the surface profile and the displacements in three orthogonal directions. The accuracy of the measured displacements was ±0.005 mm. The strain was calculated using the relative displacement between two selected points along the bolt axis.

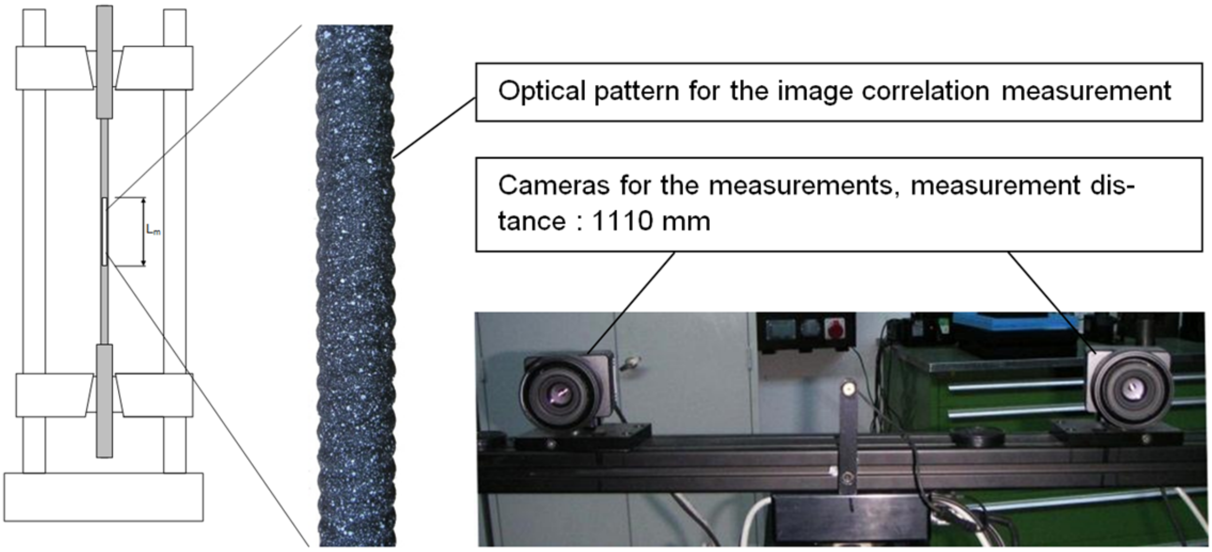


Figure 2: Test set up for the bolt tensile tests with image correlation system.

2.3.3 Test Results

Figure 3a shows the force-displacement relationships and Figure 3b the stress – strain relationships of the bolts. The stress – strain relations have a linear and coincident course.

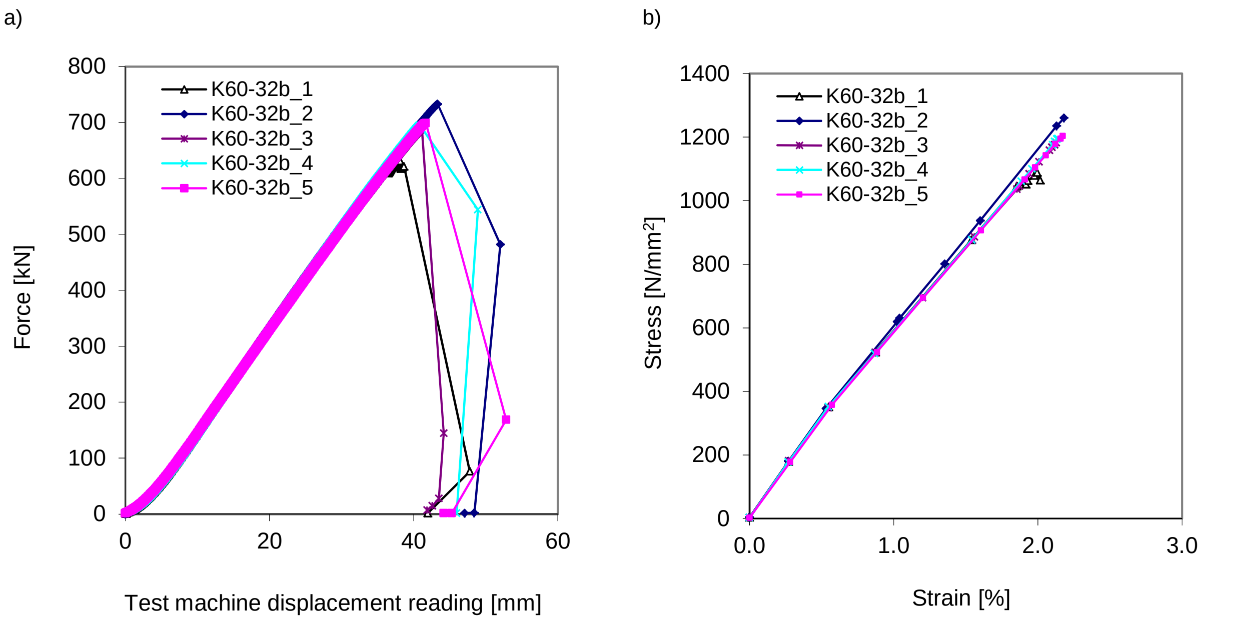


Figure 3: Relationships for a) force – machine displacement reading, b) stress – strain (from the image correlation system).

Figure 4 shows examples of the displacement and strain fields close to breaking load for K60-32b_2.

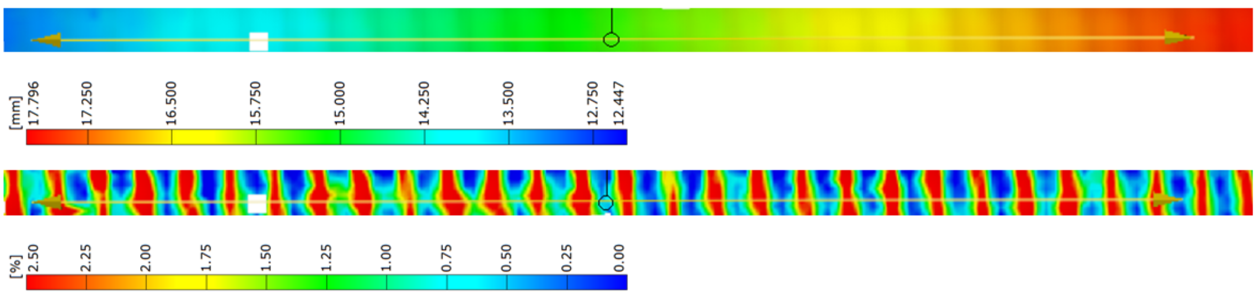


Figure 4: Displacement and strain fields of the image correlation measurement for K60-32b_2 close to breaking load. The arrow line represents the distance for the strain measurements.

Table 2 shows the results of the tensile tests and the Young's moduli. The maximum stress and the Young's modulus were calculated using the stress area shown. Explanations of this area are provided in Appendix 1.

Table 2: Test results for the bolt. Test date: 17.02.2011

Name	Stress area A_s *) [mm²]	Maximum force F_u [kN]	Maximum stress f_u [N/mm²]	Strain ε @ F_u [%]	Strain ε @ 20 % F_u [%]	Strain ε @ 50 % F_u [%]	Young's modulus [N/mm²]
K60-32b_1	580	633.0	1,091	2.00	0.33	0.91	56,411
K60-32b_2		732.9	1,264	2.18	0.38	1.04	57,438
K60-32b_3		688.5	1,187	2.13	0.37	1.01	55,468
K60-32b_4		694.9	1,198	2.14	0.37	1.02	55,385
K60-32b_5		698.5	1,204	2.17	0.38	1.03	55,794
Mean value: $\bar{x}$		**698.6**	**1,189**	**2.12**	**0.37**	**1.00**	**56,099**
Standard dev.: σ		**32.2**					

*) Stress area specified by the client. See also explanations in Appendix 1.

The maximum stress is calculated according to Equation (1)

$$f_u = \frac{F_u}{A_s}. \tag{1}$$

The mean values were calculated according to Equation (2):

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \tag{2}$$

where N is the number of test pieces and x_i are the sampling data. The standard deviation is defined as given in Equation (3):

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2}. \tag{3}$$

The Young's modulus was calculated according to [ISO 10406-1, 2008] by dividing the difference between the stresses by the difference between the strains at 50% and 20% of the maximum tensile force. The Young's modulus was calculated according to Equation (4).

$$E = \frac{\Delta F}{\Delta\varepsilon \cdot A_s}. \tag{4}$$

Figure 5 shows the bolts after the tests.

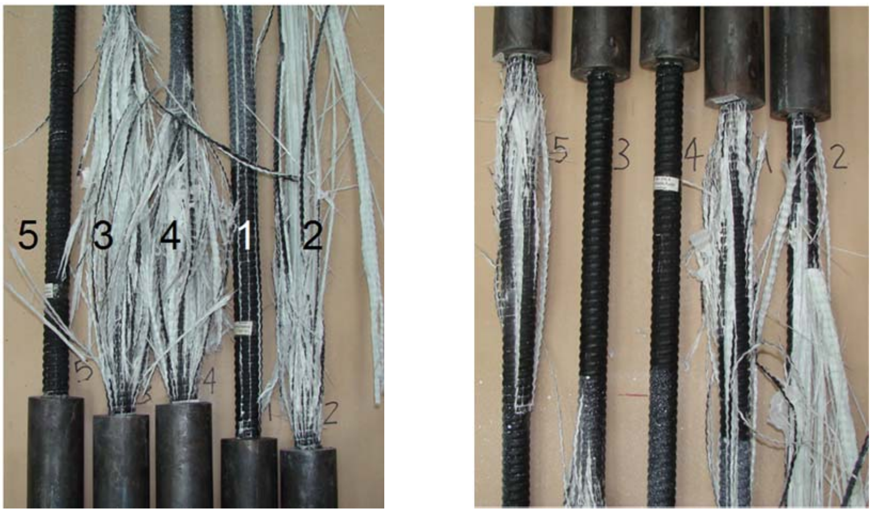


Figure 5: Bolts after the tests. The bolts have not been completely separated by the fracture.

2.3.4 Failure mechanism and fracture pattern

Failure occurred in a brittle manner with a sequence of loud banging noises. The bolts were not completely separated since the machine was immediately stopped after the distinct force drop. The bolts experienced a fibrous fracture pattern (Figure 5). A core-like part of the bolt had been pulled through one of the two the sleeves and a tube-like body remained in the sleeve.

2.4 Tensile tests with nuts

2.4.1 Test pieces

Figures 6 and 7 show the geometry of the test pieces for the tests with the nuts. One end of the test piece was glued into a steel sleeve in the factory and the other end was equipped with either (1) a GRP nut plus a GRP plate (Figure 6) or (2) a steel nut (Figure 7). The free end of the bolt had a length of 40 mm.

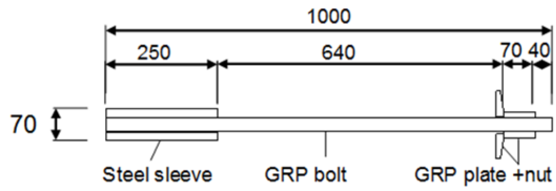


Figure 6: Test piece for the tests with GRP Nuts [mm].

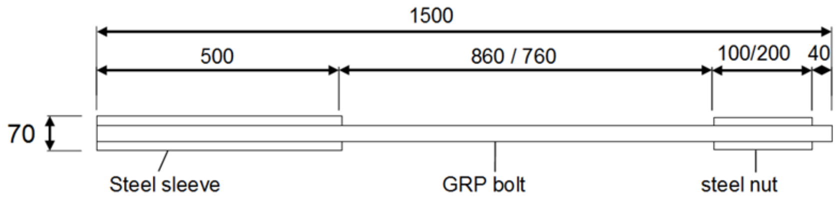


Figure 7: Test piece for the tests with Steel Nuts [mm].

2.4.2 Test set up

Figure 8 shows the test set up. To prevent eccentric loads from acting on the test pieces a steel plate with a hole diameter of 34 mm was placed underneath the nuts. This plate was protected by a washer in the case where steel nuts were tested. The steel sleeve at the other end was clamped.

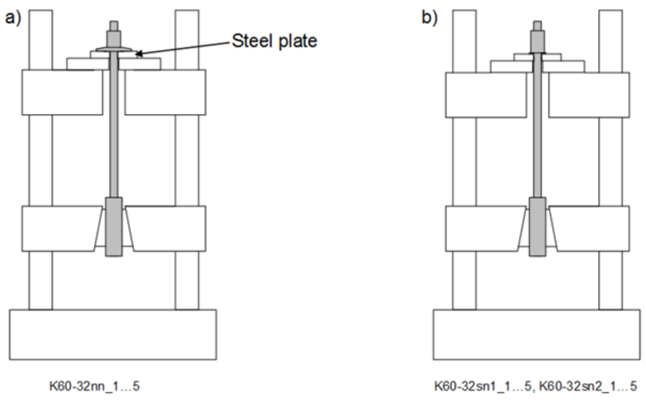


Figure 8: Test set up for the tensile tests a) with GRP Nuts & Plates, b) with Steel Nuts.

2.4.3 Test results

Figure 9 shows the force – test machine displacement relationships for the tests with nuts.

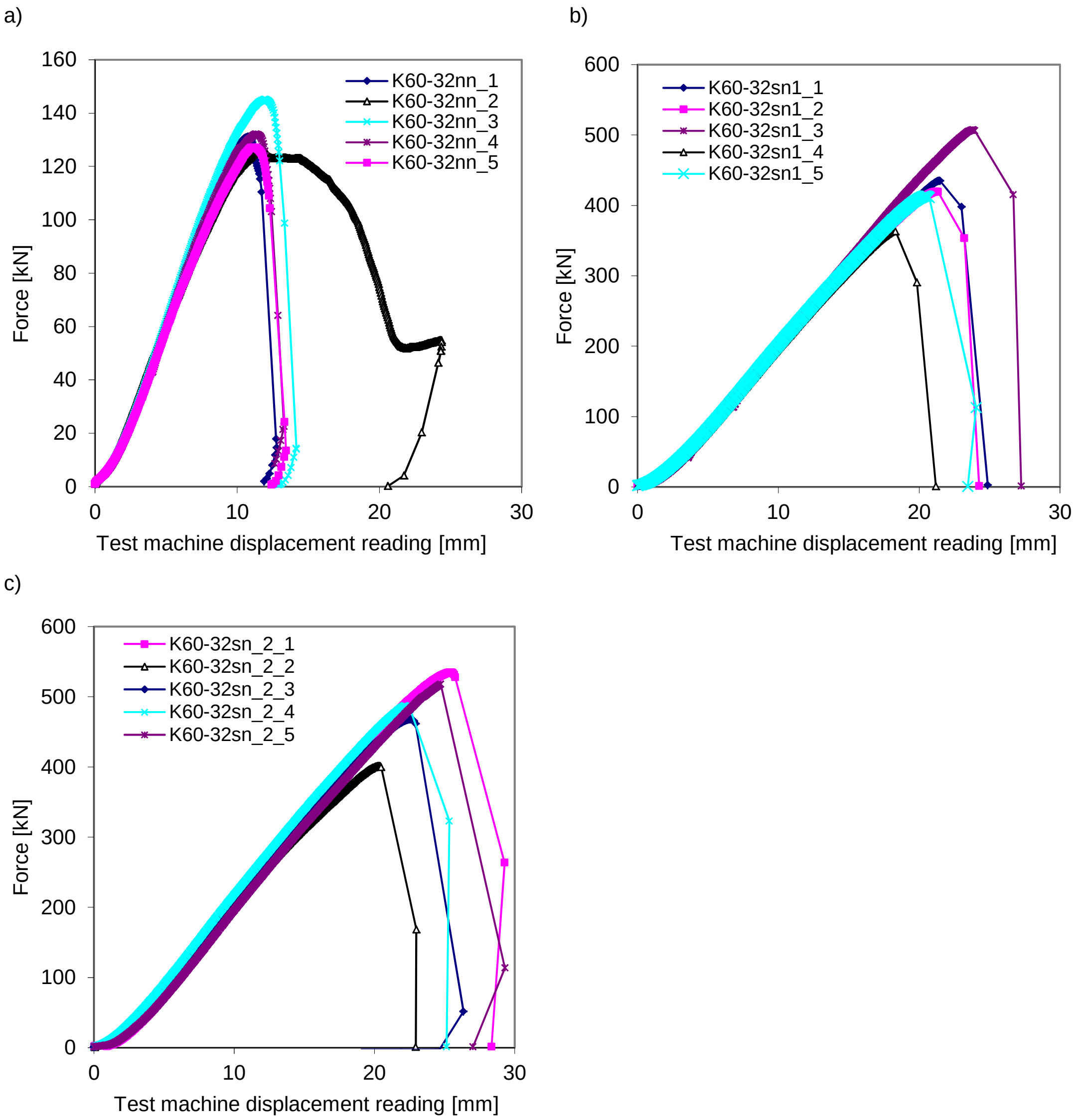


Figure 9: Force – displacement relation for a) Normal Nuts & Plates, b) Steel Nuts L=150 mm and c) Steel Nuts L=200mm.

The breaking loads of the Normal Nuts & Plates are listed in Table 3. Figure 10 shows the anchorage heads after the tests.

Table 3: Breaking loads of the Normal Nuts & Plates.

Normal Nut/Plate (GRP)	Breaking load [kN]
K60-32nn_1	131.2
K60-32nn_2	125.8
K60-32nn_3	145.2
K60-32nn_4	132.1
K60-32nn_5	127.0
mean value $\overline{x}$	**132.3**
standard deviation σ	**6.9**
test date	01.02.2011

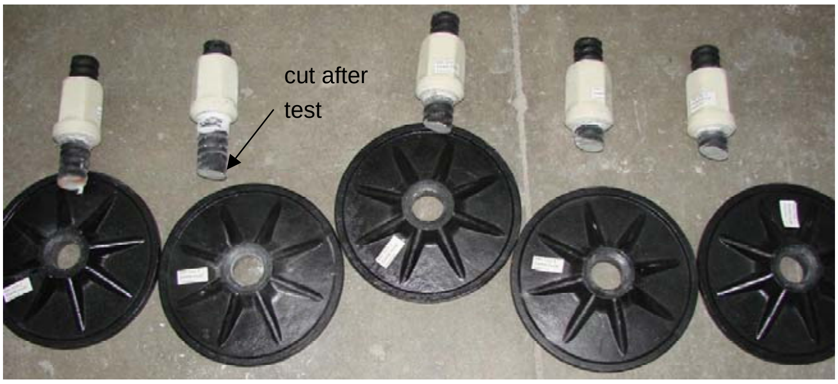


Figure 10: Normal Nuts & Plates after the test. Since the nuts could not be loosened, the bolts were cut after the tests.

The breaking loads for the Steel Nuts are listed in Tables 4a) and b). The Figures 11a) and b) show the anchorage heads after the tests.

Table 4: Breaking loads of the Steel Nuts, a) L=150 mm and b) L=200 mm.

a)

Steel Nut L= 150 mm	Breaking load [kN]
K60-32sn1_1	435.2
K60-32sn1_2	419.4
K60-32sn1_3	507.4
K60-32sn1_4	363.8
K60-32sn1_5	413.2
Mean value: $\bar{x}$	**427.8**
Standard deviation: σ	**46.4**
Test date	27.01.2011

b)

Steel Nut L= 200 mm	Breaking load [kN]
K60-32sn2_1	534.7
K60-32sn2_2	401.6
K60-32sn2_3	468.0
K60-32sn2_4	487.0
K60-32sn2_5	517.7
Mean value: $\bar{x}$	**481.8**
Standard deviation: σ	**46.3**
Test date	28.01.2011

a)

b)

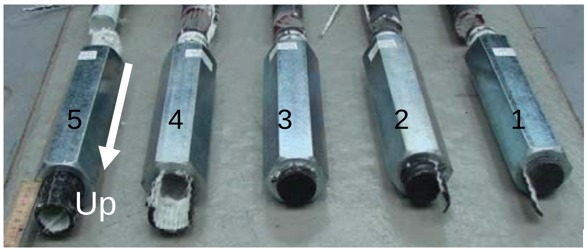


Figure 11: Steel Nuts after the tests. a) L = 150 and b) L = 200 mm. Since the nuts could not be loosened, the bolts were cut after the tests.

2.4.4 Failure mechanism and fracture pattern

With the Normal Nut, the force – displacement relation shows a rounded shape before and after the maximum value for the force (Figure 9a). The free bolt length above the nut was distinctly smaller than the initial 4 cm (Figure 10). The nut itself was a little crushed.

The test pieces with the Steel Nuts failed in a brittle manner accompanied by a banging noise. The bolts were pulled through the nuts (Figure 11).

2.5 Tensile tests with Steel Couplers

2.5.1 Test piece

Figure 12 shows the geometry of the test pieces with couplers. One end was equipped with an over-the-bolt glued steel sleeve and the other end with a steel nut. The free end of the GRP bolt 2 had a length of 110 mm. The two GRP bolts (bolt 1 and bolt 2) were joined with the Steel Coupler, which was centrically attached to both bolt ends with the ends touching each other.

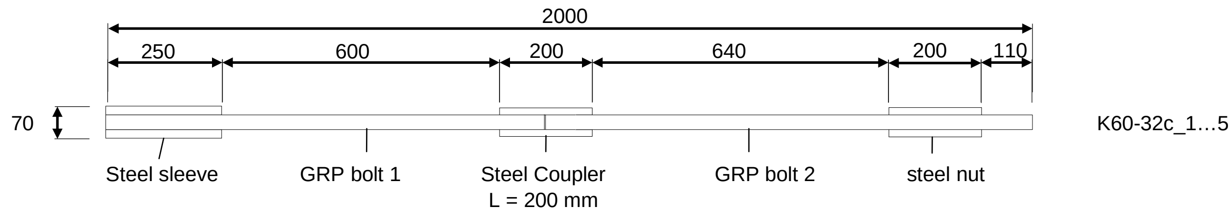


Figure 12: Test piece for the coupler tests [mm].

2.5.2 Test set up

Figure 13 shows the test set up, which shows that the mounting was similar to that described in Section 2.4.2.

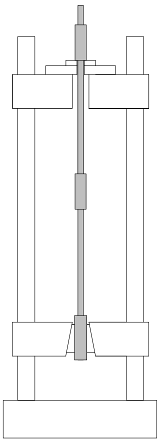


Figure 13: Test set up for the couplers.

2.5.3 Test results

Figure 14 shows the force – displacement relationships for the tests with the Steel Couplers.

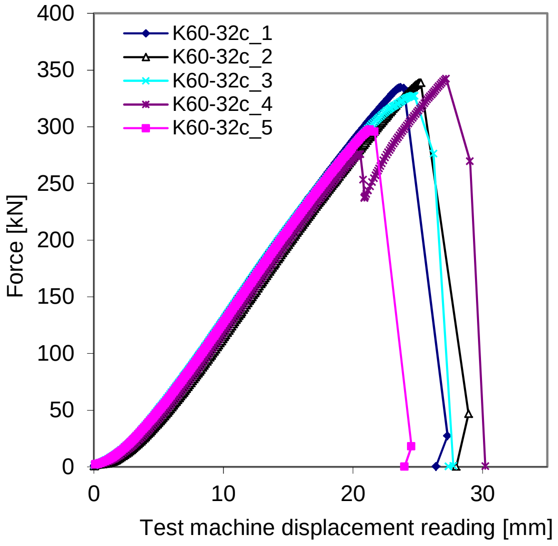


Figure 14: Force – displacement relationships for the tests with couplers.

The breaking loads are listed in Table 5.

Table 5: Breaking loads of the Steel Couplers.

Name	Breaking load [kN]
K60-32c_1	334.8
K60-32c_2	338.8
K60-32c_3	327.3
K60-32c_4	342.3
K60-32c_5	297.6
mean value $\bar{x}$	**328.1**
standard deviation σ	**16.1**
test date	02.02.2011

Figure 15 shows the Steel Couplers after the tests.

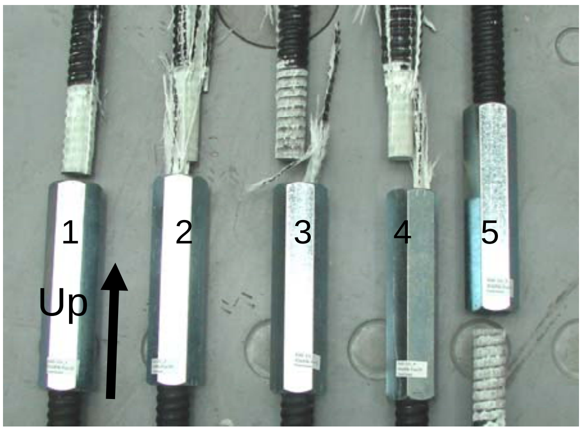


Figure 15: Couplers (L = 200 mm) with pulled out bolts.

2.5.4 Failure mechanism and fracture pattern

The test pieces failed in a brittle manner accompanied by a banging noise. The bolts were pulled out of the couplers.

3 Summary of the breaking loads

The mean breaking loads of all tested components are listed in Table 6.

Table 6: Mean breaking loads for K60-32 components.

Component	Mean breaking load [kN]
Powerthread K60-32	690
Normal Nut & Plate	132
Steel Nut L= 150 mm	428
Steel Nut L= 200 mm	482
Steel Coupler L = 200 mm	328

4 Reference

ISO 10406-1 (2008) Fibre reinforced polymer (FRP) reinforcement of concrete – Test methods, Part 1: FRP bars and grids, International Standard.

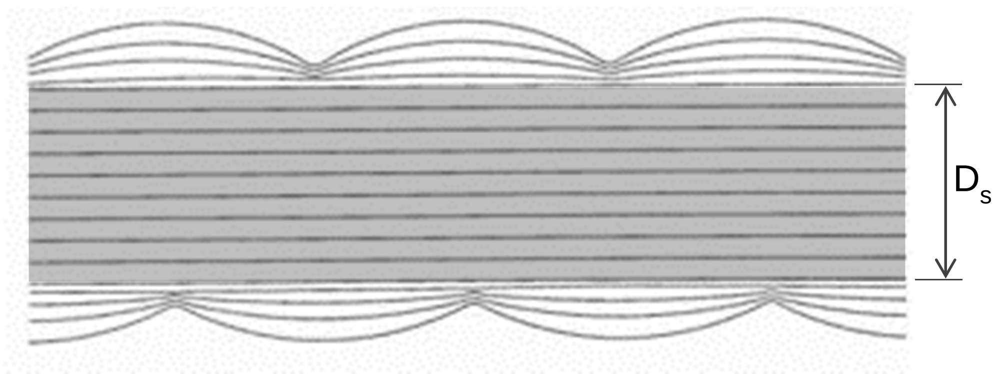
Appendix 1

Explanations for the stress area

Figure 16 schematically shows a longitudinal section of the GRP bolt. The cross section of the anisotropic GRP bolt is composed of a portion of unidirectional fibers within the core cross section, plus a portion of undulated fibers in the outer layer.

The stress section A_s is related to the core cross section with unidirectional fibers.

The stress section in the figure lies within the grey highlighted area of the height D_s.



D_s: Relevant diameter for the determination of the stress section A_s

Figure 16: Schematic longitudinal section of a GRP bolt.

Appendix 2

Mean bolt cross sectional area

3 bolt test pieces (K60-32A_1, K60-32A_2 and K60-32A_3) were trimmed to the length of about 200 mm for the determination of the mean cross sectional area. Subsequently, the lengths were exactly measured and the volume of water displaced was measured using a 250 ml measuring cup. No air bullets were observed at the test piece surface.

The cross sectional area was calculated by dividing the displaced volume of water by the test piece length. Table 7 shows the measured water volumes and the calculated cross sectional areas.

Table 7: Measured water volumes and the calculated cross sectional areas.

Date			31.01.2011
pure water volume	[mm^3]	Vw	90'000
water + test piece volume	[mm^3]	Vtot_1	241'000
		Vtot_2	243'000
		Vtot_3	243'000
test piece volume (V = Vtot - Vw)	[mm^3]	V_1	151'000
		V_2	153'000
		V_3	153'000
test piece length	[mm]	L_1	200.1
		L_2	200.3
		L_3	200.2
cross section area	[mm^2]	A_1	754.6
		A_2	763.9
		A_3	764.2
mean section area	**[mm^2]**	**A_mean**	**760.9**