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EMPA Materials Science & Technology

FiReP International AG
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Test Report No. 456497

Test assignment:	**Testing of Powerthread K60-25 and accessories**
Client:	FiReP International AG, Rapperswil, Switzerland
Test objects:	5 Bolts
	5 Bolts with Normal Nut & Plate (GRP)
	5 Bolts with Power Nut & Plate (GRP)
	5 Bolts with Domed Nut & Plate (GRP)
	5 Bolts with Steel Nut L=100 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:	25.01.2011 – 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:
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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	maximum force
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 on 4 types of glass fiber reinforced polymer (GRP) bolt and accessories under short term loading. These bolt systems are used in mining, tunneling and ground stabilization.

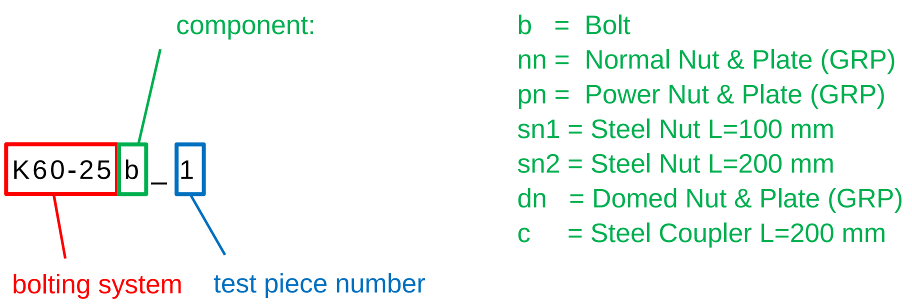
The test method is based on ISO 10406-1 standard.

This test report describes tensile tests and its test results for 5 specimens of Powerthread K60-25 (D=25 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	K60-25b_1…5	0.8
Normal Nut & Plate (GRP)	5	K60-25nn_1…5	0.9
Power Nut & Plate (GRP)	5	K60-25pn_1…5	0.9
Domed Nut & Plate (GRP)	5	K60-25dn_1…5	0.9
Steel Nut L= 100 mm	5	K60-25sn1_1…5	0.9
Steel Nut L= 200 mm	5	K60-25sn2_1…5	0.9
Steel Coupler L = 200 mm	5	K60-25c_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 bolt length was 1000 mm. Both ends of the 2000 mm long GRP bolt were glued into steel sleeves in the factory.

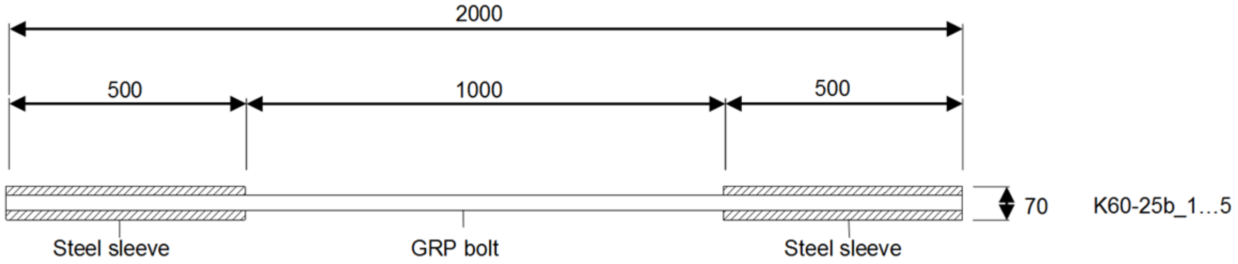


Figure 1: Test piece for the bolt tensile tests [mm].

2.3.2 Test set up

The test set up is shown in Figure 2, left. 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.

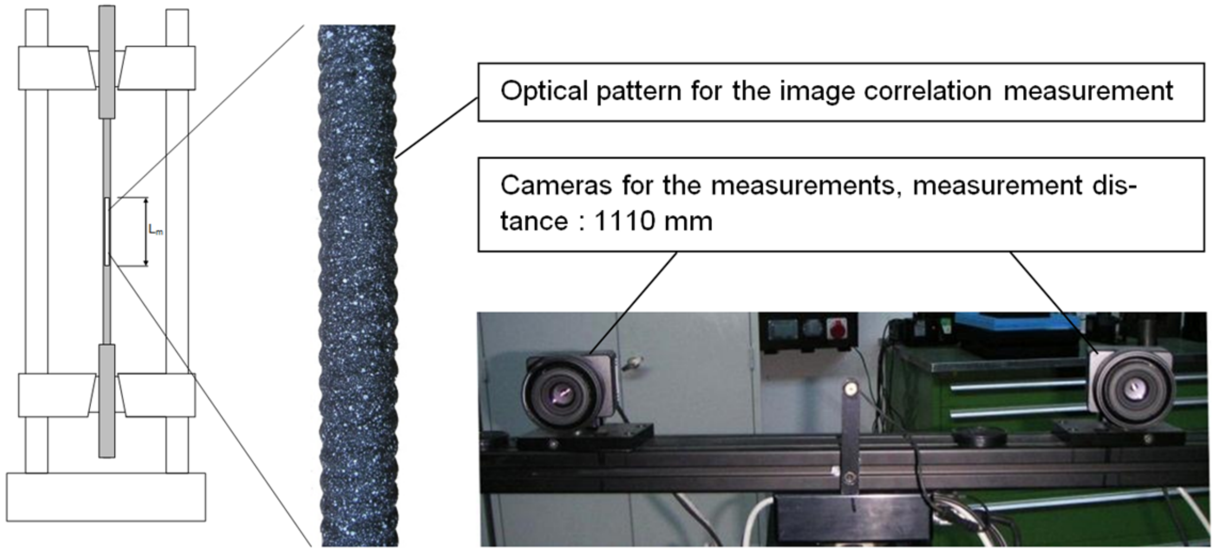


Figure 2: Test set up for the bolt tensile tests with image correlation system.

2.3.3 Test results

Figure 3a) shows the force-displacement relationships and Figure 3b) the stress – strain relationships of the bolts. The stresses were calculated using the stress area A_s given in Table 2. The stress – strain relations have a linear and well coincident course.

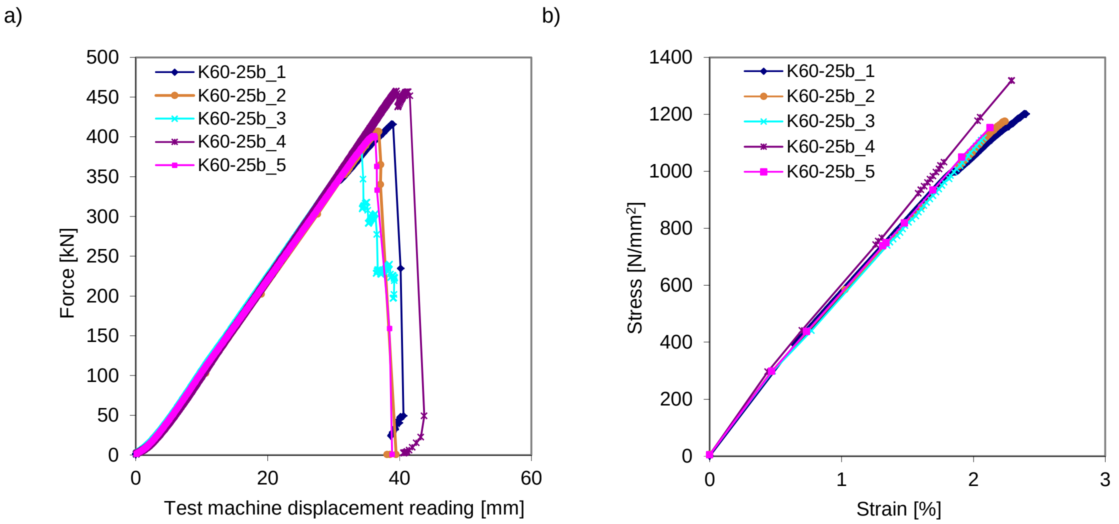


Figure 3: Relationships for a) force – machine displacement reading, b) stress – strain (from the image correlation system).

Figure 4 shows examples of the displacement and strain fields close to maximum force for K60-25b_5.

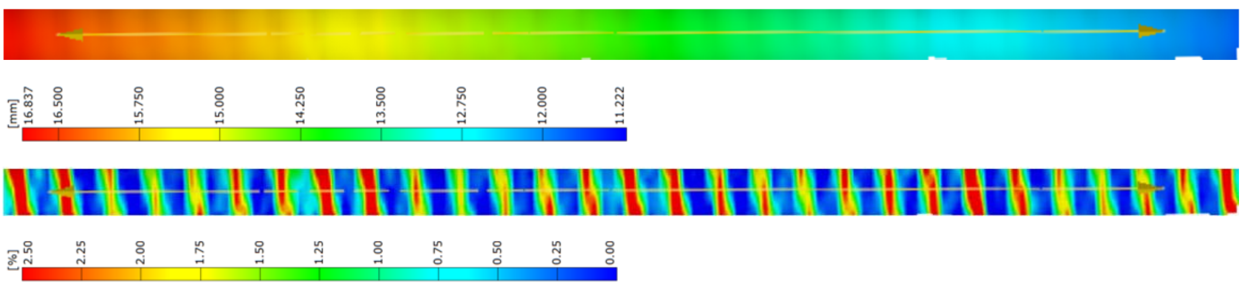


Figure 4: Displacement and strain fields of the image correlation measurement for K60-25b_5 close to maximum force. The arrow line represents the distance for the strain measurements.

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 *) [mm^2]	Maximum force F_u [kN]	Maximum stress f_u [N/mm^2]	Strain ε @ F_u [%]	Strain ε @ 20 % F_u [%]	Strain ε @ 50 % F_u [%]	Young's modulus [N/mm^2]
K60-25b_1	346	415.9	1,202	2.51	0.40	1.06	54,563
K60-25b_2		406.7	1,176	2.24	0.37	1.03	53,002
K60-25b_3		388.1	1,122	2.08	0.36	1.00	52,060
K60-25b_4		457.7	1,323	2.29	0.39	1.11	55,334
K60-25b_5		401.5	1,160	2.13	0.37	1.01	53,977
Mean value: $\bar{x}$		**414.0**	**1,197**	**2.25**	**0.38**	**1.04**	**53,787**
Standard dev.: σ		**23.7**					

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

The maximum stress was calculated according to Equation (1)

$$f_u = \frac{F_u}{A_s}. \quad (1)$$

The mean value was calculated according to Equation (2):

$$\overline{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \quad (2)$$

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):

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

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).

$$E = \frac{\Delta F}{\Delta\varepsilon \cdot A_s}. \quad (4)$$

Figure 5 shows the Bolts after the tests.

Figure 5: Photograph of failure patterns.

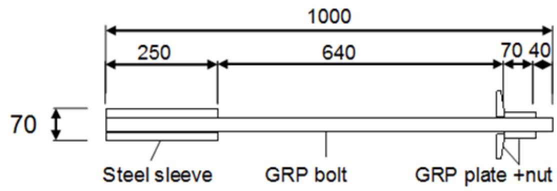
2.3.4 Failure mechanism and fracture pattern

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).

2.4 Tensile tests with nuts

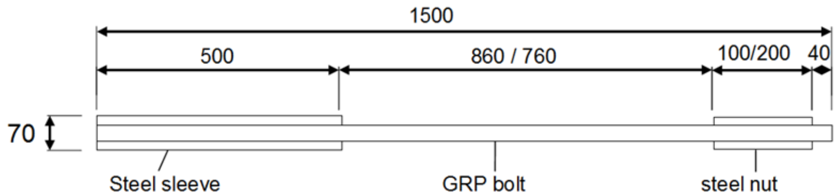
2.4.1 Test pieces

Figures 6 and 7 show the geometry of the test pieces for the tests on the nuts. One end of the test piece was glued into a 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.



K60-25nn_1…5, K60-25pn_1…5, K60-25dn_1…5

Figure 6: Test piece for the tests with GRP nuts and GRP plates [mm].

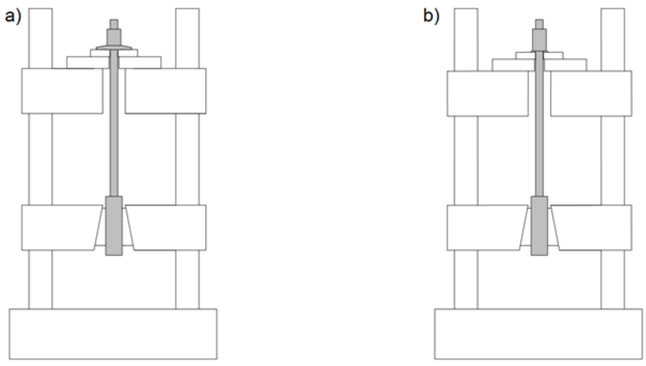


K60-25sn1_1…5, K60-25sn2_1…5

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 27 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.



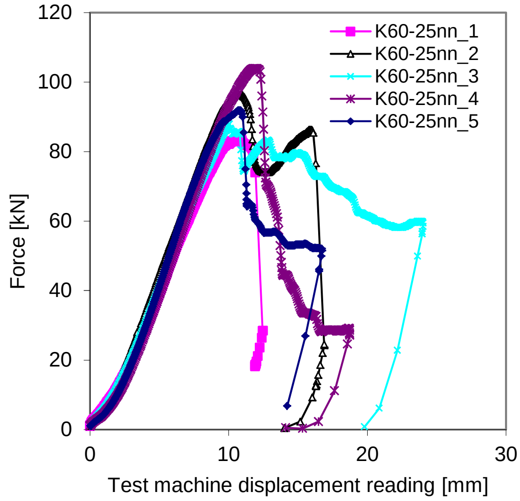
K60-25nn_1…5, K60-25pn_1…5, K60-25dn_1…5 K60-25sn1_1…5, K60-25sn2_1…5

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

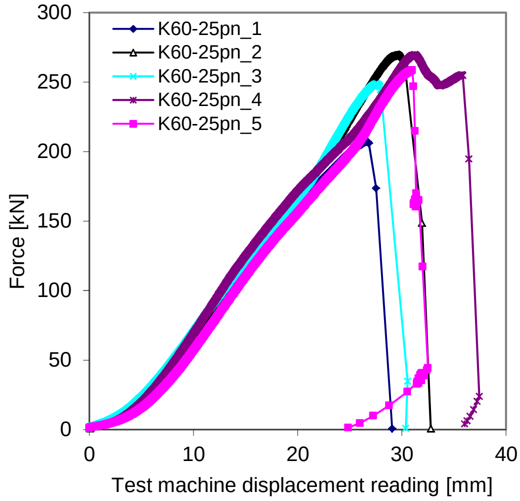
2.4.3 Test results

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

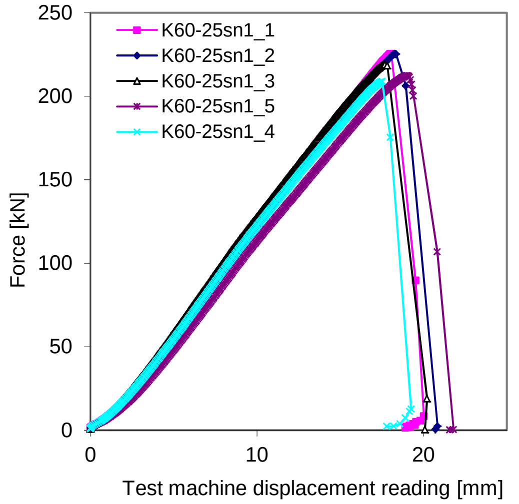
a) Normal Nut & Plate (GRP)



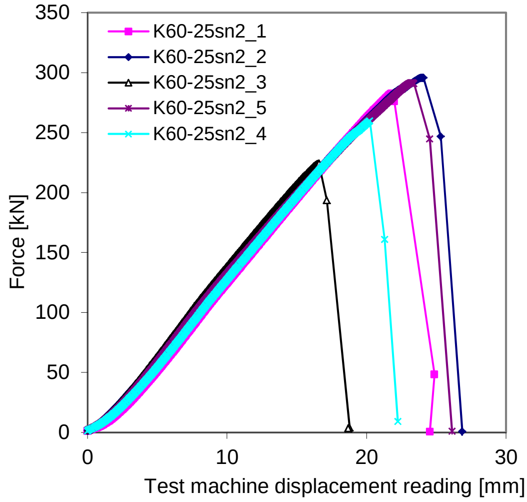
b) Power Nut & Plate (GRP)



c) Steel Nut L = 100 mm



d) Steel Nut L = 200 mm



e) Domed Nut & Plate (GRP)

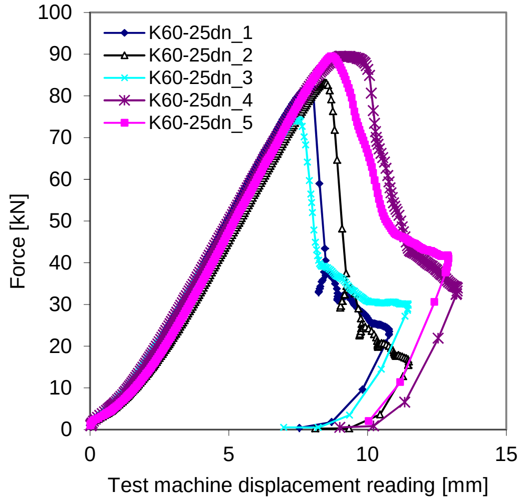


Figure 9: Relations force – test machine displacement reading for the nuts.

The maximum forces of the Normal Nuts and the Power Nuts are listed in Tables 3a) and b). Figure 10 a) and b) show the anchorage heads after the tests.

Table 3: Maximum forces of a) Normal Nuts & Plates (GRP) and b) Power Nuts & Plates (GRP).

a)

Normal Nut/Plate	Maximum force [kN]
K60-25nn_1	84.0
K60-25nn_2	96.6
K60-25nn_3	87.9
K60-25nn_4	103.8
K60-25nn_5	91.9
Mean value $\overline{x}$	**92.8**
Standard deviation σ	**6.9**
Test date	31.01.2011

b)

Power Nut/Plate	Maximum force [kN]
K60-25pn_1	207.1
K60-25pn_2	269.6
K60-25pn_3	248.7
K60-25pn_4	269.6
K60-25pn_5	258.6
Mean value $\overline{x}$	**250.7**
Standard deviation σ	**23.2**
Test date	01.02.2011

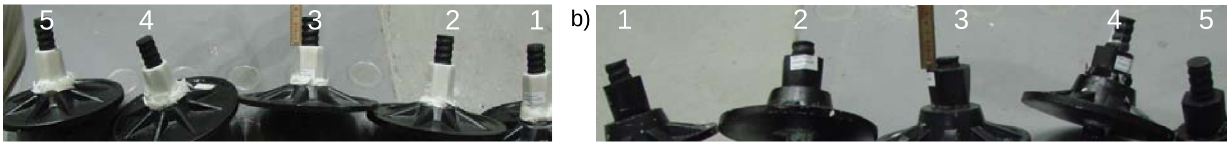
a)


Figure 10: a) Normal Nuts & Plate (GRP) and b) Power Nuts & Plate (GRP) after the test. Since the nuts could not be loosened, the bolts were cut after the tests.

The maximum forces for the Domed Nuts & Plates are listed in Table 4. Figure 11 shows the anchorage heads after the tests.

Table 4: Maximum forces of the Domed Nuts & Plates (GRP).

Domed Nut	Maximum force [kN]
K60-25dn_1	82.6
K60-25dn_2	83.2
K60-25dn_3	74.3
K60-25dn_4	89.5
K60-25dn_5	89.4
mean value: $\overline{x}$	**83.8**
standard deviation : σ	**5.6**
test date	31.01.2011

Figure 11: Domed Nuts after the tests. Since the nuts could not be loosened, the bolts were cut after the tests.

The maximum forces for the Steel Nuts are listed in Tables 5a) and b). Figure 12a) and b) show the test pieces after the tests.

Table 5: Maximum forces for the Steel Nuts, a) L = 100 and b) L = 200 mm.

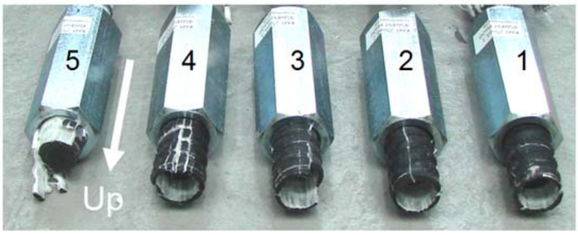
a)

Steel Nut L=100 mm	Maximum force [kN]
K60-25sn1_1	225.4
K60-25sn1_2	225.3
K60-25sn1_3	218.9
K60-25sn1_4	208.8
K60-25sn1_5	212.3
Mean value: $\bar{x}$	**218.1**
Standard deviation: σ	**6.7**
Test date	26.01.2011

b)

Steel Nut L=200 mm	Maximum force [kN]
K60-25sn2_1	282.5
K60-25sn2_2	295.8
K60-25sn2_3	224.3
K60-25sn2_4	259.6
K60-25sn2_5	291.6
Mean value: $\bar{x}$	**270.8**
Standard deviation: σ	**26.4**
Test date	26.01.2011

a)



b)

Figure 12: Steel Nuts after the tests. a) L = 100 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, a pronounced softening behavior could be observed (Figure 9 top right).

The Normal Nut was crushed and there was no displacement between bolt and nut (Figure 10a).

The other test pieces failed in a brittle manner accompanied by a banging noise. With the Power Nut, the bolt was pulled through the nut (Figure 10b). With the Domed Nut, a ring shaped portion of the nut was sheared off (Figure 11). The Steel Nuts remained intact but a core of the bolt was pulled in the direction of the force so that a tube-like body remained in the nut (Figures 12a) and b).

2.5 Tensile tests with Steel Couplers

2.5.1 Test piece

Figure 13 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.

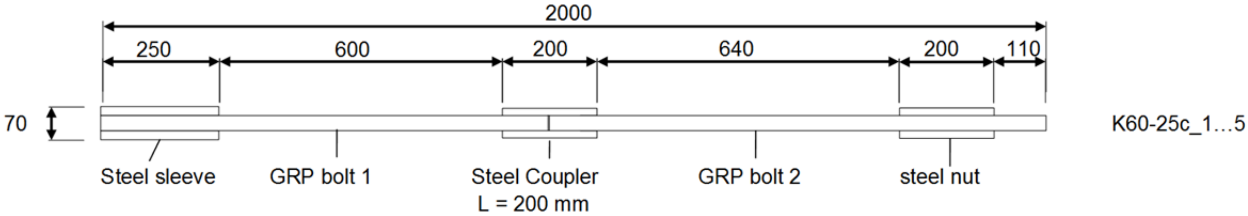


Figure 13: Test piece for the coupler tests [mm].

2.5.2 Test set up

Figure 14 shows the test set up. To prevent eccentric loads from acting on the test pieces a steel plate with a hole diameter of 27 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.

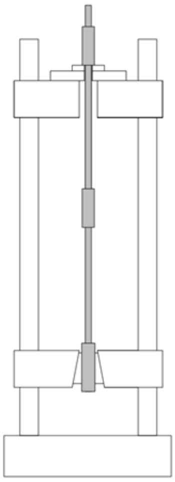


Figure 14: Test set up for the couplers.

2.5.3 Test results

Figure 15 shows the force – displacement relationships for the tests with the Steel Couplers.

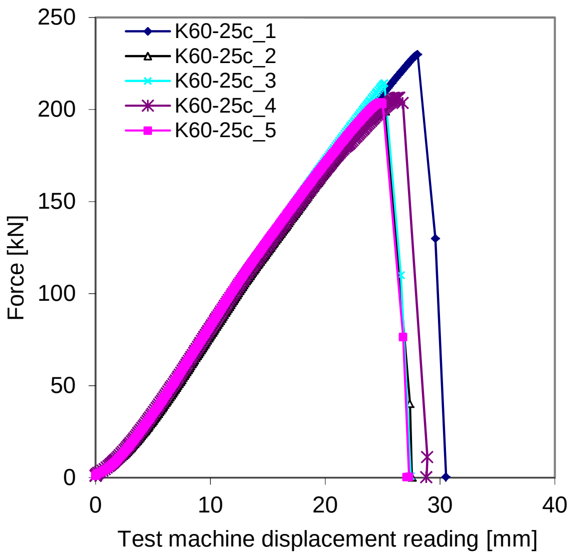


Figure 15: Force – displacement relationships for the tests with couplers.

The maximum forces are listed in Table 6.

Table 6: Maximum forces for the Steel Couplers L = 200 mm

Name	Maximum force [kN]
K60-25c_1	229.9
K60-25c_2	199.3
K60-25c_3	214.3
K60-25c_4	206.4
K60-25c_5	203.6
Mean value: $\bar{x}$	**210.7**
Standard deviation: σ	**10.8**
Test date	01.02.2011

Figure 16 shows the Steel Couplers after the test.

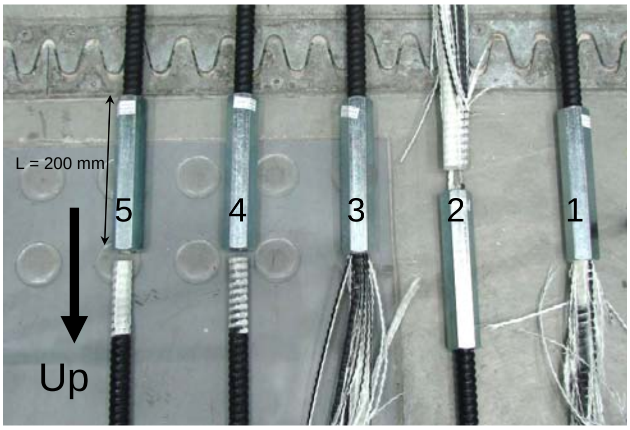


Figure 16: Couplers (L = 200 mm) with pulled out bolts.

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 maximum forces

The mean maximum forces of all tested components are listed in Table 7.

Table 7: Mean maximum forces for K60-25 components.

Component	Mean maximum force [kN]
Powerthread K60-25	414
Normal Nut & Plate (FRP)	93
Power Nut & Plate (FRP)	251
Domed Nut & Plate (FRP)	84
Steel Nut L= 100 mm	218
Steel Nut L= 200 mm	271
Steel Coupler L = 200 mm	211

4 Reference

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

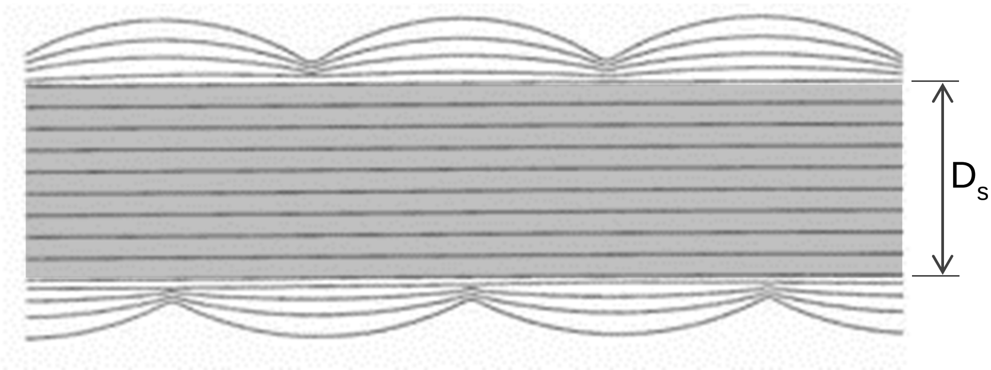
Appendix 1

Explanations for the stress area

Figure 17 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 17: Schematic longitudinal section of a GRP bolt.

Appendix 2

Mean bolt cross sectional area

3 bolt test pieces (K60-25A_1, K60-25A_2 and K60-25A_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 8 shows the measured water volumes and the calculated cross sectional areas.

Table 8: Measured water volumes and the calculated cross sectional areas.

Date			31.01.2011
pure water volume	[mm^3]	Vw	150'000
water + test piece volume	[mm^3]	Vtot_1	240'000
		Vtot_2	238'000
		Vtot_3	238'000
test piece volume (V = Vtot - Vw)	[mm^3]	V_1	90'000
		V_2	88'000
		V_3	88'000
test piece length	[mm]	L_1	200.1
		L_2	200.2
		L_3	200.0
cross section area	[mm^2]	A_1	449.8
		A_2	439.6
		A_3	440.0
mean section area	**[mm^2]**	**A_mean**	**443.1**