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WP 6 Final Report on BOLTED & SCREWED CONNECTIONS

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Results obtained per task

WP6: BOLTED & SCREWED CONNECTIONS

(Co-ordinated by IMT, with VTT)

Based on previous test programmes and Eurocode design requirements, a programme of lap shear connection tests was defined by VTT, including test specimen dimensions and instructions for measurements and reporting. The tests were performed at IMT.

6.1 Tests of bolted and screwed connections

The plan of tensile test specimens on bolted and screwed connections was prepared. The plates of 1.4509 steel were applied in thickness of 0.5 mm, 0.8 mm, 1.2 mm, 2.00 mm, 3.00 mm, 4.5 mm, 5.5 mm and plates of steel S355 in thickness of 5.00 mm and 10.00 mm.

Test samples for tensile tests of screwed and bolted connections were manufactured of sheet with different thicknesses by cutting on shears.

The samples for angle bar test were prepared by bending.

For bolted connections were applied:

- Austenitic stainless steel, fully threaded bolts A2, 70, M12 x 30, DIN 933
- Austenitic stainless steel nuts M12, DIN 934
- Austenitic stainless steel washers, M12, DIN 125
- Bolts M12 x 30, 8.8, DIN 933, fully threaded
- Nuts, M12, DIN 934.

The hole diameter $d_o = 13$ mm was used at all bolted connections.

The prehole with diameter $d_o = 4$ mm was used at all screwed connections.

The same plate thickness were used in single shear tests. For double shear tests the outer plate thickness was lower compared to the inner plate thickness.

The normal bolts of class 8.8 were used at comparative carbon steel S335 specimens.

For screwed connections two types of self drilling screws were applied:

- Self drilling screw A2, 5.5 x 19 mm, DIN 7504K
- Washers A6, DIN 125
- Self drilling screw A2TIIV, 5.5 x 25 mm, DIN 7504-K/POR

Specimen dimensions and the principle of single and double shear testing of bolted and screwed connections are shown in **Fig. 1**.

The width and the length of samples for bolted connections were: 42 x 470, 83 x 470, 208 x 470 mm, for screwed connections were: 50 x 320 mm and for angle bar test were: 42 x 42 x 470 mm.

Different connection types with position of holes Φ 13 mm for mechanical tests of bolted connections and expected failure modes are presented in **Fig. 2**.

In **Fig. 3** are presented predicted failure modes at tensile tests of different connection types.

The following tests were performed:

- Single and double shear test
- Bolted plate connections
- Bolted sheeting connections
- Angle bar tests
- Screwed sheeting connections
- Material tests.

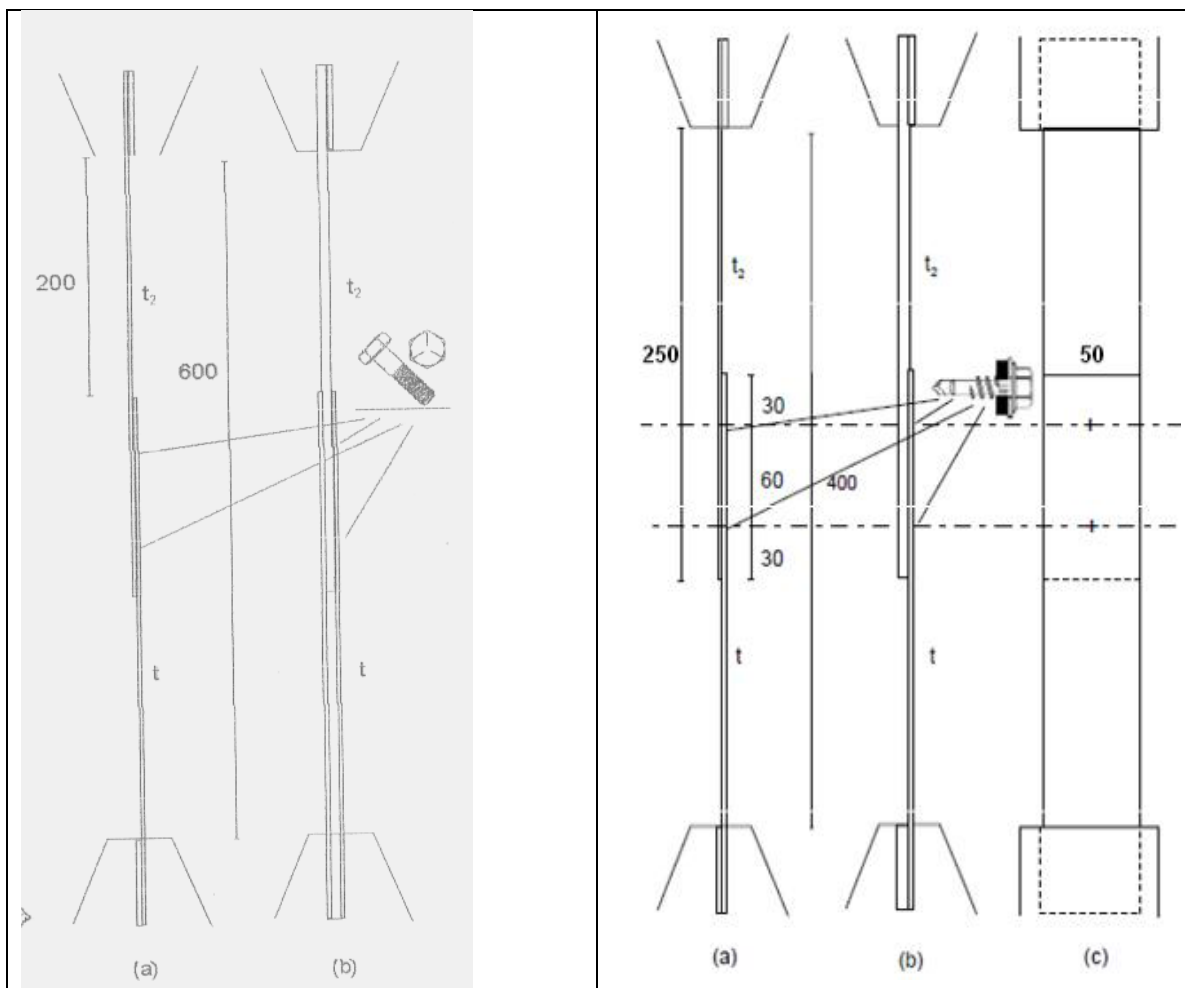


Figure 1: Dimensions of samples for bolted (left) and screwed (right) connections of single (a) and double (b) shear tests.

6.2 Predicted bolted connection failure modes

The predicted failure mode is bearing failure (hole elongation), except at combination with thickness 1.2 and 2 mm, where predicted failure mode is shear failure of the fastener.


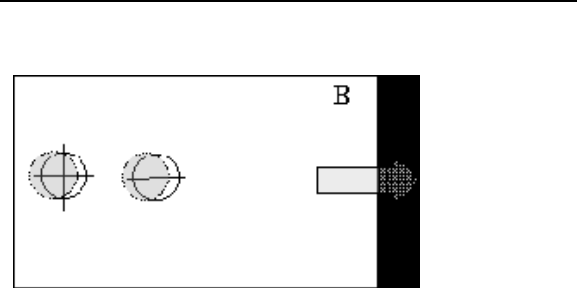
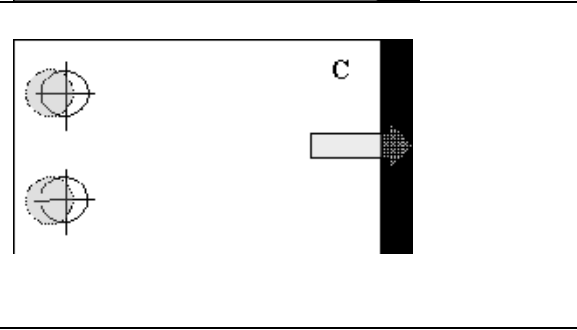
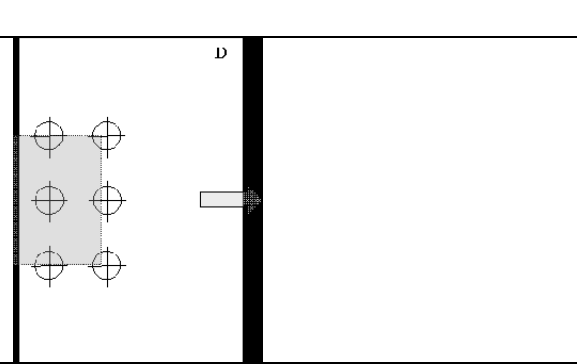
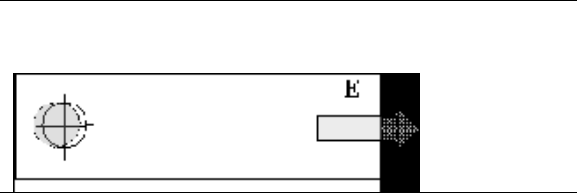
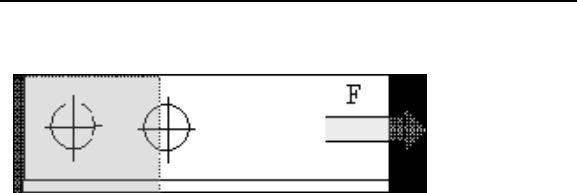
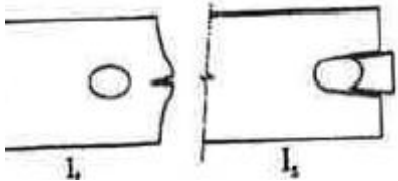
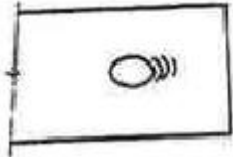
	A 1 -Net section failure
	B 1 -Bearing failure
	C 1 -Bearing failure
	D 1-Block tearing failure
	E 1 -Bearing failure of angle bar
	F 1 -Net section failure of angle bar

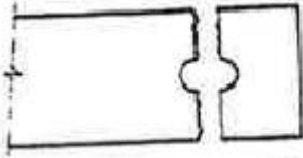
Figure 2: Connection types, position of holes in test samples and typical expected failures



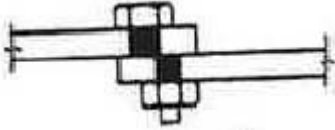
Mode I – end failure (tearing or shear)



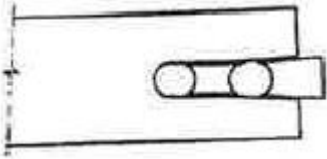
Mode II – bearing failure



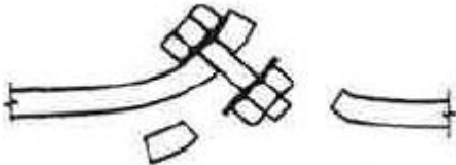
Mode III – net section failure



Mode IV – bolt failure



Mode V – block tear out (multibolt)



Mode VI – bolt pull - through

Figure 3: Predicted failure modes at bolted connections, real figures of failures are in Appendix.

Table 1: The quality and thickness of materials for mechanical tests at IMT

		Thickness (mm)	Delivered by
Grade	1.4509	0.5	Arcelor Mittal
		0.8	Arcelor Mittal
		1.2	Arcelor Mittal
		2	Arcelor Mittal
		3	Arcelor Mittal
		4.5	AcerInox
		5.5	AcerInox
Grade	S335	5	Purchased
		10	Purchased

6.3 Manufacturing of the specimens

The test specimens and material test pieces were taken in the rolling direction of the sheets. Holes were made by drilling with a drill of 13 mm diameter. The bolts were tightened so, that friction did not affect the results.

The bolts were provided with washers under the head and the nut.

Most of tensile tests of bolted and screwed connections were performed with INSTRON 8802 , 250 kN machine.

But tests of 208 mm wide samples were performed at ZAG with ZWICK, 2500 kN machine with open flat grips that are suitable for the wider test samples.

6.4 The tensile test of bolted connections – Test procedure

Dimensions of the specimens were checked and registered before the tensile tests. The force-displacement behavior of the connection was determined by tensile test. During the tensile test the data were measured and recorded for further use.

Loading rate was 10 % of the predicted ultimate load per minute up to 50 % of the predicted ultimate load. Thereafter the displacement rate was 0.5 mm/min up to deformation of 3 mm. After that the strain rate was duplicated at deformations of 6, 9 and 12 mm, till the final rupture.

In the Appendix are presented results of tensile tests as well as numerical data recorded during tensile tests.

Before the test the test samples were preloaded with 10 % of predicted maximum loads to fit well bolts with the holes and to make connection stable for tensile test.

The tests were performed by measuring the length before and after the tensile test and at material tests also with extensometer.

Material tests were performed under strain control, starting with a constant strain rate of 0.9%/min until $R_{p0.2}$. Thereafter the strain rate was 15%/min.

All data from load cells and strains were recorded in 0.2 second intervals for further use.

Values obtained by tensile tests for bolted and for screwed connections as well as for material tests are presented in **Tables 2 to 9**.

Samples after tensile tests with and without bolts or screws and drawings of holes after test are presented in Appendix.

6.5 Bolts

Two types of stainless steel bolts were applied at bolted connections: VIBO A2, 70, A2,70 and Zn-plated bolt CETIN, 8.8. All bolts were full threaded. The application of bolts is presented in Table 10.



Figure 4. Bolts and nuts applied in tests and destroyed bolts

6.6 Application of bolts and washers

TABLE 10: Application of bolts and washers

Type of bolt	Washer on both sides	Number of bolts	Remarks
A2-70 VIBO	S0808 A1, S0808 B1, S0808 C1, S0820 A1, S0820 B1, S0820 C1, S1220 A1, S1220 C1, S2020 A1, S2020 B1, S2020 C1, A1 33 1, A1 33 2, B1 33 1, B1 33 2, C1 33 1, C1 33 2, F1 33 1, F1 33 2	2	
A2-70 VIBO	S0808 D1, S0820 D1, S1220 D1, D1 33 1, D1 33 2	6	
A2-70	A1 55 1, A1 55 2, A2 36 1, A2 36 2, B1 55 1, B1 55 2, B2 36 1, B2 36 2, C1 55 1, C1 55 2, C2 36 1, C2 36 2,	2	
A2-70 + A2-70 VIBO	D1 55 1	6	2xA2-70+4xA2-70 VIBO
A2-70 + A2-70 VIBO	D1 55 2	6	2xA2-70+4xA2-70 VIBO
A2-70	D2 36 1	6	
A2-70	D2 36 2	6	
A2-70 VIBO	E1 33 1, E1 55, F1 55	1	
A2-70	E1 33 2	1	
Type of bolt	Without washer		Remarks
8.8	A2510S	2	
8.8	B2510S	2	
8.8	C2510S	2	
8.8	D2510S	6	
A2-70 + A2-70 VIBO	A2510	2	1x A2-70 + 1x A2-70 VIBO
A2-70 + A2-70 VIBO	B2510	2	1x A2-70 + 1x A2-70 VIBO
A2-70 VIBO	C2510	2	
A2-70 VIBO	D2510	6	6xA2-70 VIBO

Remark: There were two types of M12x30, full threaded A2-70 bolts applied (A2-70 and A2-70 VIBO), DIN 933, inox.

Nuts M12, A2, DIN 934, inox.

Washers M12, A2, DIN 125, inox.

For comparative carbon steel specimens normal bolts M12x30 of class 8.8 , DIN 933, ZN were applied.

Nuts M12, DIN 934, ZNS

6.7 Test samples where screws or bolts shear occurred

Samples where the bolts or screws shear was observed at tensile test are present in Table 11

TABLE 11: Test samples with shear of bolts or screws

Sample	Remark
B1 55 1	Shear of one bolt of two
B1 55 2	Shear of one bolt of two
C1 55 2	Fracture of both bolts below the head
E1 55	Shear of bolts
S1220 1a 1	Shear of screw
S1220 1 a 2	Shear of screw
S1220 2a 1	Shear of both screws
D2 510	Shear of all 6 bolts, grade A2, 70
D2 510 S	Shear of all 6 bolts, grade 8.8
B2 510 S	Shear of all 2 bolts, grade 8.8
C2 510	Shear of 1 bolt of two, grade A2, 70
C2 510 S	Shear of 1 bolt of two, grade 8.8

6.8 Self drilling screws

For screwed connections two types of self drilling screws were applied:

- Self drilling screw A2, 5.5 x 19 mm, DIN 7504K
- Washers A6, DIN 125
- Self drilling screw A2TIIV, 5.5 x 25 mm, DIN 7504-K/POR

The self drilling tests revealed that austenitic stainless steel self drilling screws A2, 5.5x19 mm are too soft to cut into the test samples., even at application of prehole. Damaged screws are presented in **Figure 5**.

For that reason most of tensile tests were performed with harder self drilling screws A2TIIV, 5.5x25 mm (**Figure 6**).

Due to the problems with the austenitic stainless steel self drilling screws the pre-drilled hole Φ 4 mm was applied at all samples..



Figure 5: Austenitic stainless steel self drilling crews, too soft to cut the thread.



Figure 6: Self drilling screw A2TiIV, 5.5 x 25 mm, DIN 7504-K/POR, able to cut the thread into predrilled hole.

6.9 Results of tensile tests of bolted and screwed connections

TABLE 2: Bolted connections, bolts M12, A2 70, hole Φ 13 mm

Specimen	Anvil height	Thickness	Width	Area	Final anvil height	Load at extension 3 mm	Load at extension 6 mm	Load at extension 9 mm	Load at extension 12 mm	Expected max. load	Maximum load
	(mm)	(mm)	(mm)	(mm ²)	(mm)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)
S 0808-A1	500.00	0.80	41.90	33.52	515.00	8.71	10.24	10.88	11.26	10	11.34
S 0808-B1	500.00	0.80	83.00	66.40	520.00	5.64	13.62	16.60	17.93	10	19.73
S 0808-C1	500.00	0.80	83.00	66.40	519.00	12.79	15.95	17.53	18.69	10	19.63
S 0808-D1		0.80/0.80	207.5/207.4			29.3	38.0	40.2	41.7	33	43.70
S 0820-A1	500.00	0.80	42.00	33.60	510.00	9.68	11.18	11.73	-	10	11.86
S 0820-B1	500.00	0.80	83.00	66.40	516.50	13.62	18.91	19.83	21.27	10	21.96
S 0820-C1	500.00	0.80	83.00	66.40	510.50	16.33	18.56	17.91	-	10	18.77
S 0820-D1		0.80/1.99	207.5/207.5			33.40	42.5	40.20	-	33	44.00
S 1220-A1	500.00	1.20	42.10	50.52	509.00	15.78	17.10	17.01	-	15	17.48
S 1220-B1	500.00	1.20	82.90	99.48	517.00	23.26	28.05	30.47	31.59	17	32.38
S 1220-C1	500.00	1.20	82.90	99.48	511.50	25.34	28.59	28.63	-	17	29.32
S 1220-D1		1.19/1.97	207.2/207.7			48.8	61.6	65.9	-	50	66.70
S 2020-A1	500.00	2.00	42.00	84.00	510.00	23.87	26.77	28.01	-	26	28.36
S 2020-B1	500.00	2.00	83.00	166.00	522.00	33.56	41.04	44.90	46.72	30	47.64
S 2020-C1	500.00	1.90	82.80	157.32	521.00	32.28	38.23	41.25	43.24	30	45.24
S 2020-D1		1.98/1.98	207.7/207.6			64.30	93.00	101.60	106.90	80	111.00

TABLE 3: Bolted connections, bolts M12, A2 70, hole Φ 13 mm

Specimen	Anvil height	Thickness	Width	Area	Final anvil height	Load at extension 3 mm	Load at extension 6 mm	Load at extension 9 mm	Load at extension 12 mm	Expected max. load	Maximum load
	(mm)	(mm)	(mm)	(mm ²)	(mm)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)
A1 - 33 1	500.00	3.00	42.20	126.60	619.00	25.26	34.48	37.8	39.39	40	40.44
A1 - 33 2	500.00	2.90	42.20	122.38	519.00	31.26	36.10	38.57	39.96	40	40.86
B1 - 33 1	500.00	3.00	83.20	249.60	529.00	43.39	53.91	59.59	64.38	50	71.24
B1 - 33 2	500.00	2.90	83.30	241.57	523.50	43.36	54.11	58.13	62.44	50	72.01
C1 - 33 1	500.00	3.00	83.20	249.60	520.00	38.27	50.34	56.21	61.00	40	66.87
C1 - 33 2	500.00	2.90	83.30	241.57	520.00	41.65	51.84	56.93	61.33	40	67.50
D1 - 33 1		2.95/2.95	208.1/208.0			62.70	115.40	133.00	142.70	120	159.50
D1 - 33 2		2.94/2.96	207.9/208.0			62.30	116.40	133.70	143.80	120	159.50
A1 - 55 1	500.00	4.50	42.50	191.25	515.00	38.38	59.03	64.57	66.89	60	66.96
A1 - 55 2	500.00	4.50	42.40	190.80	516.00	18.13	56.11	63.64	66.27	60	67.50
B1 - 55 1	500.00	4.50	83.50	375.75	516.00	13.61	70.44	89.19	97.97	75	103,81
B1 - 55 2	500.00	4.50	83.50	375.75	512.40	66.23	88.43	96.00	101.61	75	103.42
C1 - 55 1	500.00	4.50	83.80	377.10	513.70	57.55	80.54	91.54	98.95	60	100.64
C1 - 55 2	500.00	4.50	83.30	374.85	513.00	58.63	80.27	91.21	97.01	60	98.68
D1 - 55 1		4.50/4.50	208.4/208.4			152.00	209.10	230.90	242.00	180	248.80
D1 - 55 2		4.50/4.50	208.4/208.4			156.60	211.30	232.40	243.00	180	248.90

TABLE 4: Bolted connections, bolts M12, A2 70, hole Φ 13 mm

Specimen	Anvil height	Thickness	Width	Area	Final anvil height	Load at extension 3 mm	Load at extension 6 mm	Load at extension 9 mm	Load at extension 12 mm	Expected max. load	Maximum load
	(mm)	(mm)	(mm)	(mm ²)	(mm)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)
A2 - 36 1	500.00	2.90/5.35/2.90	42.20/42.20/42.20		514.50	58.13	71.74	76.78	79.08	70	79.17
A2 -36 2	500.00	3.00/5.35/3.00	42.10/42.10/42.10		515.00	59.48	72.68	77.35	79.48	70	79.50
B2 - 36 1	500.00	2.90/5.35/2.90	83.20/83.20/83.20		519.00	79.39	105.12	116.19	121.38	95	122.09
B2 - 36 2	500.00	2.90/5.35/2.90	83.10/83.10/83.10		518.50	73.86	103.08	114.74	120.38	95	120.93
C2 - 36 1	500.00	2.90/5.35/2.90	83.00/83.10/83.10		523.00	79.46	103.06	114.06	120.98	75	126.45
C2 - 36 2	500.00	3.10/5.35/3.10	83.10/83.10/83.10		520.50	73.89	100.08	112.19	119.46	75	123.13
D2 - 36 1		2.95/5.35/2.96	208.1/208.3/208.0			144.60	239.30	271.00	288.10	220	299.60
D2 - 36 2		2.96/5.35/2.95	207.9/208.3/208.1			127.40	236.10	270.20	288.10	220	300.40
E1 - 33 1	500,00	2.90	41.60	120.64	526.50	20.86	26.60	29.41	31.40	20	37.45
E1 - 33 2	500.00	2.90	41.80	121.22	520.00	22.18	27.74	31.00	33.12	20	37.25
E1 - 55	500.00	4.50	42.50	191.25	518,00	19.50	38.81	44.20	47.10	30	50.44
F1- 33 1	500,00	2.90	41.20	119.48	521,00	33.34	46.92	53.13	57.07	45	62.13
F1 - 33 2	500,00	2.90	41.00	118.90	518.00	36.08	48.13	53.73	57.37	45	60.93
F1 - 55	500.00	4.50	42.50	191.25	518.00	51.22	71.36	79.85	84.06	70	84,69

TABLE 5: Bolted connections, bolts M12, A2 70, bolts M12, 8.8, hole Φ 13 mm

Specimen	Anvil height	Thickness	Width	Area	Final anvil height	Load at extension 3 mm	Load at extension 6 mm	Load at extension 9 mm	Load at extension 12 mm	Expected max. load	Max. load
	(mm)	(mm)	(mm)	(mm ²)	(mm)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)
A2 – 5 10		4.53/9.90/4.53	42.40/42.83/42.40			95.7	118.5	107.7	-	115	120.9
B2 – 5 10		4.53/9.97/4.53	83.38/83.51/83.38			123.3	164.9	173.5	-	155	177.4
C2 – 5 10		4.53/10.02/4.53	83.16/83.28/83.16			128.1	156.5	168.2		120	168.7
E2 – 5 10		4.53/10.03/4.53	208.0/205.0/208.00			266.9	438.0	486.9	509.7	370	510.2
A2-5 10 S*		5.03/9.98/5.03	42.08/41.17/42.08			105.4	130.9	132.6	-	115	135.9
B2– 5 10 S*		5.05/9.96/5.05	82.77/83.11/82.77			129.3	166.9	-	-	180	167.4
C2– 5 10 S*		5.05/10.02/5.05	82.95/83.22/82.95			119.1	162.1	-	-	140	162.2
D2– 5 10 S*		5.03/10.03/5.03	207.03/208.0/207.03			212.8	454.2	452.5	-	410	497.9

*S – bolts M12 x 30, 8.8

TABLE 6: Screwed connections

Specimen	Anvil height	Thickness	Width	Area	Final anvil height	Load at extension 3 mm	Load at extension 6 mm	Load at extension 9 mm	Load at extension 12 mm	Expected max. load	Maximum load
	(mm)	(mm)	(mm)	(mm ²)	(mm)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)
S0505 -1a 1*	300.00	0.50	50.00	25.00	301.20	-	-	-	-	1.3	1.58
S0505 -1a 2*	300.00	0.50	50.00	25.00	303.00	1.70	-	-	-	1.3	2.00
S0505 -1a 3*	300.00	0.50	50.00	25.00	301.20	-	-	-	-	1.3	1.80
S0505 -1b 1*	300.00	0.50	50.00	25.00	301.00	-	-	-	-	1.3	1.34
S0505 -1b 2*	300.00	0.50	50.00	25.00	301.10	-	-	-	-	1.3	1.71
S0505 -1b 3*	300.00	0.50	50.00	25.00	302.10	1.54	-	-	-	1.3	2.29
S0505 - 2a 1*	300.00	0.50	50.00	25.00	302.30	3.47	-	-	-	2.7	3.64
S0505 - 2a 2*	300.00	0.50	50.00	25.00	301.20	-	-	-	-	2.7	3.21
S0505 - 2a 3*	300.00	0.50	50.00	25.00	301.50	-	-	-	-	2.7	3.45
S0520 - 1a 1	300.00	0.50	50.00	25.00	304.50	2.69	-	-	-	1.3	3.08
S0520 - 1a 2	300.00	0.50	50.00	25.00	304.50	2.94	-	-	-	1.3	3.12
S0520 - 1a 3	300.00	0.50	50.00	25.00	305.00	2.85	3.09	-	-	1.3	3.20
S0520 - 1b 1	300.00	0.50	50.00	25.00	305.00	3.06	-	-	-	1.3	3.43
S0520 - 1b 2	300.00	0.50	50.00	25.00	305.00	2.97	3.33	-	-	1.3	3.41
S0520 - 1b 3	300.00	0.50	50.00	25.00	305.00	2.85	3.07	-	-	1.3	3.30
S0520 - 2a 1	300.00	0.50	50.00	25.00	304.00	5.86	6.06	-	-	2.7	6.41
S0520 - 2a 2	300.00	0.50	50.00	25.00	305.50	5.76	6.34	-	-	2.7	6.63
S0520 - 2a 3	300.00	0.50	50.00	25.00	303.00	5.76	-	-	-	2.7	5.93
S0808 - 1a 1	300.00	0.80	50.00	25.00	303.50	2.88	-	-	-	2.7	2.97
S0808 - 1a 2	300.00	0.80	50.00	40.00	303.50	2.98	-	-	-	2.7	3.16
S0808 - 1a 3	300.00	0.80	50.00	40.00	302.50	2.58	-	-	-	2.7	2.72

Remark: * -Connections done with self drilling screws A2 5.5x19 mm, the other connections done by harder A2 TIIV 5.5x 25 mm self drilling screws. All connections were made with prehole Φ 4 mm.

TABLE 7: Screwed connections

Specimen	Anvil height	Thickness	Width	Area	Final anvil height	Load at extension 3 mm	Load at extension 6 mm	Load at extension 9 mm	Load at extension 12 mm	Expected max. load	Maximum load
	(mm)	(mm)	(mm)	(mm ²)	(mm)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)
S0808 -1b 1	400.00	0.80	50.00	40.00	403.50	2.68	-	-	-	2.7	2.80
S0808 -1b 2	400.00	0.80	50.00	40.00	403.50	2.53	-	-	-	2.7	2.63
S0808 -1b 3	400.00	0.80	50.00	40.00	403.00	2.96	-	-	-	2.7	2.99
S0808 - 2a 1	300.00	0.80	50.00	40.00	309.00	6.17	6.30	4.19	-	5.4	6.41
S0808 - 2a 2	300.00	0.80	50.00	40.00	310.00	5.86	6.49	5.08	-	5.4	6.85
S0808 - 2a 3	300.00	0.80	50.00	40.00	308.50	5.45	5.68	-	-	5.4	5.80
S0820 -1a 1*	400.00	0.80	50.00	40.00	406.50	4.79	6.67	5.19	-	2.7	7.08
S0820 -1a 2	400.00	0.80	50.00	40.00	407.00	5.47	7.21	4.94	-	2.7	7.41
S0820 -1a 3	400.00	0.80	50.00	40.00	407.00	5.18	6.48	-	-	2.7	7.45
S0820 -1b 1	400.00	0.75	50.00	37.50	410.50	5.28	6.30	5.58	-	2.7	6.52
S0820 -1b 2	400.00	0.80	50.00	40.00	411.00	5.36	6.58	5.95	-	2.7	6.82
S0820 -1b 3	400.00	0.80	50.00	40.00	411.50	5.53	6.69	5.87	-	2.7	6.84
S0820 -2a 1*	300.00	0.80	50.00	40.00	306.50	7.27	10.73	-	-	5.4	10.94
S0820 -2a 2	300.00	0.80	50.00	40.00	316.50	8.72	10.82	11.72	13.46	5.4	14.73
S0820 -2a 3	300.00	0.80	50.00	40.00	313.50	9.31	12.81	13.81	14.64	5.4	14.75
S1212 -1a 1*	300.00	1.20	50.00	60.00	305.00	5.50	-	-	-	4.9	6.56
S1212 -1a 2*	300.00	1.20	50.00	60.00	306.50	4.43	5.54	-	-	4.9	6.09
S1212 -1a 3*	300.00	1.20	50.00	60.00	302.50	4.94	-	-	-	4.9	5.30
S1212 -1b 1*	300.00	1.20	50.00	60.00	305.20	5.72	-	-	-	4.9	6.28
S1212 -1b 2*	300.00	1.20	50.00	60.00	305.00	5.72	-	-	-	4.9	5.91
S1212 -1b 3*	300.00	1.20	50.00	60.00	304.40	5.11	-	-	-	4.9	5.30

Remark: * -Connections done with self drilling screws A2 5.5x19 mm, the other connections done by harder A2 TIV 5.5x 25 mm self drilling screws. All connections were made with prehole of Φ 4 mm.

TABLE 8: Screwed connections

Specimen	Anvil height	Thickness	Width	Area	Final anvil height	Load at extension 3 mm	Load at extension 6 mm	Load at extension 9 mm	Load at extension 12 mm	Expected max. load	Maximum load
	(mm)	(mm)	(mm)	(mm ²)	(mm)	(kN)	(kN)	(kN)	(kN)	(kN)	(kN)
S1212-2a 1	300.00	1.20	50.00	60.00	309.00	8.38	11.66	6.89	-	9.9	12.68
S1212-2a 2	300.00	1.20	50.00	60.00	308.00	9.89	12.50	-	-	9.9	12.90
S1212-2a 3	300.00	1.20	50.00	60.00	308.00	8.99	11.44	-	-	9.9	12.13
S1220-1a 1	400.00	1.20	50.00	60.00	405.00	6.77	-	-	-	5.5	7.97
S1220-1a 2	400.00	1.20	50.00	60.00	407.50	5.58	8.16	-	-	5.5	8.87
S1220-1a 3	400.00	1.20	50.00	60.00	404.50	6.24	-	-	-	5.5	7.52
S1220-1b 1	400.00	1.20	50.00	60.00	411.00	5.85	8.06	7.30	-	5.5	8.67
S1220-1b 2	400.00	1.20	50.00	60.00	414.00	4.88	7.81	9.76	9.20	5.5	9.83
S1220-1b 3	400.00	1.20	50.00	60.00	409.00	4.90	8.25	4.21	-	5.5	9.37
S1220-2a 1	300.00	1.20	50.00	60.00	309.00	9.32	14.26	17.53	-	11	18.55
S1220-2a 2	300.00	1.20	50.00	60.00	306.50	11.05	15.65	-	-	11	15.85
S1220-2a 3	300.00	1.20	50.00	60.00	306.50	11.13	16.62	-	-	11	17.06

Remark: all connections done with self drilling screws A2 TiIV, 5.5 x 25 mm, prehole Φ 4 mm

6.10 Material tests

TABLE 9: Materials test

ID- identification code b – width of test piece a – thickness S _o – cross sectional area				E – modulus of elasticity R _{p0.2} – 0.2 proof stress R _m – tensile strength			L _o – original length L _u – length after fracture A _{LO} – elongation after fracture		
ID	b (mm)	a (mm)	S _o (mm ²)	E (Gpa)	R _{p0.2} (Mpa)	R _m (Mpa)	L _o (mm)	L _u (mm)	A _{LO} (%)
S05 - 1	19.92	0.52	10.36	197	274	454	80.00	107.25	34.1
S05 - 2	19.93	0.52	10.36	178	274	454	80.00	104.43	30.5
S05 - 3	19.98	0.51	10.19	181	280	461	80.00	104.72	30.9
Mean	19.94	0.52	10.30	185.3	276	457	80.00	105.47	31.8
S08 – 1	20.00	0,80	16.00	202	326	479	80.00	104.00	30.0
S08 - 2	20.00	0.80	16.00	199	329	478	80.00	103.50	29.4
S08 - 3	20.00	0.80	16.00	200	327	477	80.00	105.00	31.3
Mean	20.00	0.80	16.00	200.3	327	478	80.00	104.16	30.2
S12 - 1	19.94	1.20	23.93	193	308	454	80.00	106.49	33.1
S12 - 2	19.96	1.21	24.15	122	311	454	80.00	106.02	32.5
S12 - 3	19.93	1.20	23.92	193	314	460	80.00	105.01	32.3
Mean	19.94	1.20	24.00	169.3	311	456	80.00	106.11	32.6
S20 – 1	19.94	1.96	39.08	158	335	464	80.00	106.88	33.6
S20 - 2	19.96	1.97	39.32	188	337	463	80.00	106.52	33.2
S20 - 3	19.95	1.97	39.30	198	331	462	80.00	107.85	34.8
Mean	19.95	1.97	39.24	181.3	334	463	80.00	107,08	33.9
M-3a	19.93	2.96	58.99	162	292	444	80.00	108.70	35.9
M-3b	19.98	2.91	58.14	123	298	449	80.00	108.53	35.7
M-3c	19.97	2.93	58.51	144	294	448	80.00	108.66	35.8

Mean	19.96	2.93	58.55	143	295	447	80.00	108.63	35.8
M-5a	4.50	20.10	90.45	190	349	477	80.00	103.50	29.3
M-5b	4.50	19.92	89.64	212	342	477	80.00	104.20	20.5
M-5c	4.50	19.65	88.43	200	369	482	80.00	105.50	21.5
Mean	4.50	19.89	89.50	200.6	353	478	80.00	104.40	23.7
M-6a	5.50	20.00	110.00	182	339	451	80.00	108.00	35.0
M-6b	5.50	20.00	110.00	179	346	449	80.00	105.00	31.3
M-6c	5.50	20.00	110.00	185	350	452	80.00	104.00	30.0
Mean	5.50	20.00	110.00	182	345	451	80.00	105.67	32.1
S-3a	19.85	4.97	98.65	202	395	527	80.00	100.63	25.8
S-3b	19.86	4.97	98.70	193	399	526	80.00	100.61	25.8
S-3c	19.86	4.98	98.90	213	392	525	80.00	100.73	25.9
Mean	19.86	4.97	98.75	202.6	395	526	80.00	100.66	25.8
S-5a	19.82	9.95	197.21	181	396	543	80.00	101.80	27.3
S-5b	19.85	9.96	197.71	184	407	551	80.00	100.97	26.2
S-5c	19.82	9.96	197.41	175	398	542	80.00	102.77	28.5
Mean	19.83	9.96	197.44	180	400	545	80.00	101.85	27.3

Some samples S08-1-2-3 and M5-a,b,c, fractured out of extensometer region.

Appendix – Database: Figures of all tensile test samples before and after tensile test

Appendix – Database: Figures of holes of bolted connections without bolts

Appendix – Database: Figures of holes of screwed connections without screws

Appendix – Drawings of holes of bolted connections after tensile tests.

Appendix – Tensile test data – diagrams and numerical records of tests

Appendix – Figures material tests

