ECCS TC7 – TWG 7.5

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BUILT-UP COLD-FORMED STEEL BEAMS WITH CORRUGATED WEB CONNECTED THROUGH SPOT WELDING OR MIG BRAZING

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CEMSIG
Centrul de cercetari pentru mecanica materialelor si siguranta structurilor

Objectives

To present new research developments on cold-formed steel beams of corrugated web (CWB)

IDEA

CEMSIG Research Centre of PU Timisoara

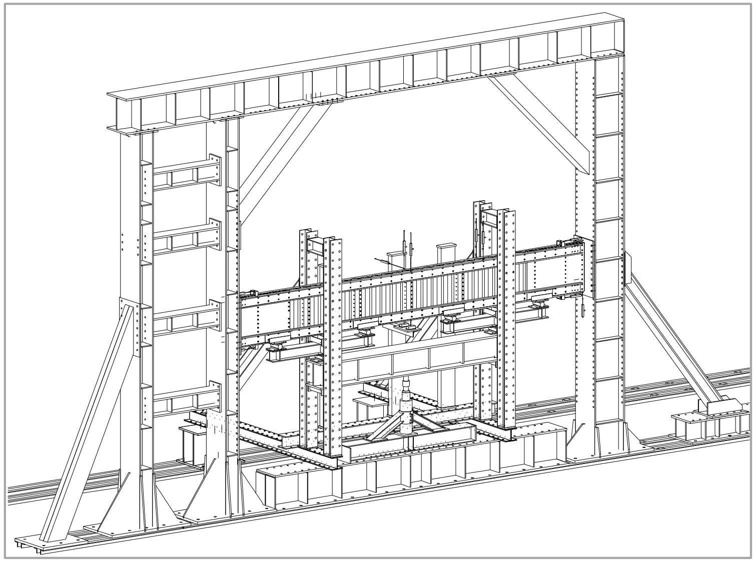
- is 100% composed of cold-formed steel elements, avoiding the combination of two types of products;
- high protection to corrosion due to the fact that all components are galvanized;
- to develop a structural system able to enable easy and/or automated prefabrication, reduced erection time, mass production and possibility of high-precision quality control.

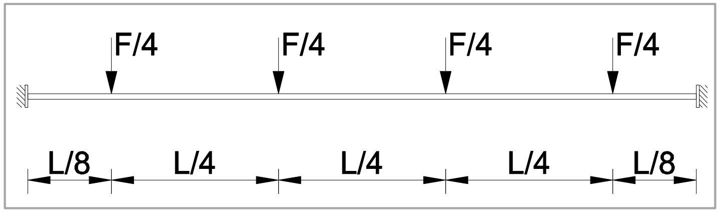
Actual solution : SCREWED !

EXPERIMENTAL PROGRAM ⇒ 5 SPECIMENS

CWB - 1	Standard solution: flange-to-web connection in every corrugations and uniformly distributed seam fasteners
CWB - 2	Standard solution + supplementary lipped channel sections C under the load application points
CWB - 3	Optimized solution by adapting the flange-to-web connections according to the distribution of shear stresses (connections at each second corrugations where the shear force decreases)
CWB - 4	Optimized solution by eliminating shear panels and doubling of corrugated webs in the zones with high shear forces
CWB - 5	Optimized solution by adapting both the flange-to-web connections and seam fasteners to the distribution of shear stresses

Actual solution : SCREWED !





Monotonic load - v_{test}=2mm/min

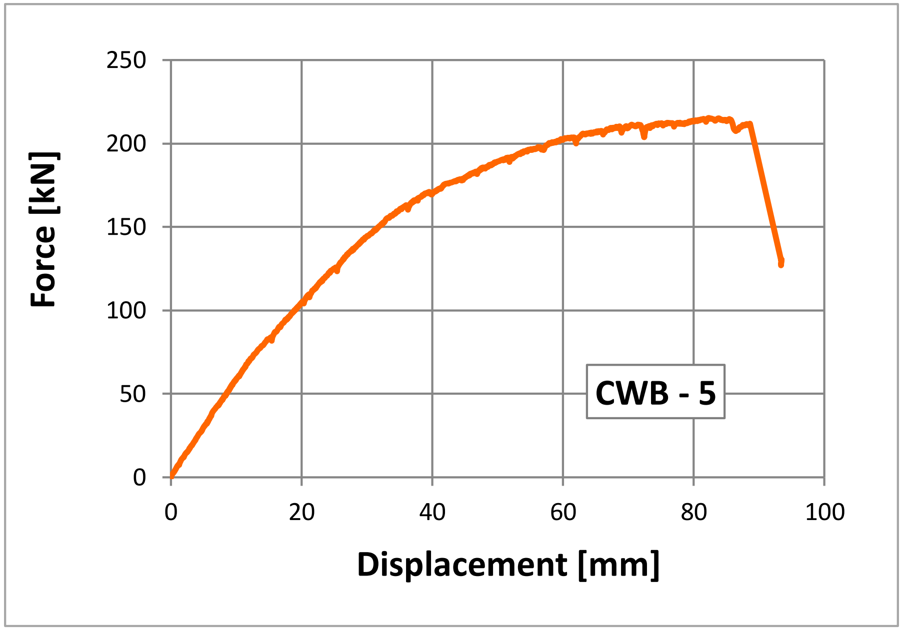
6 points bending test

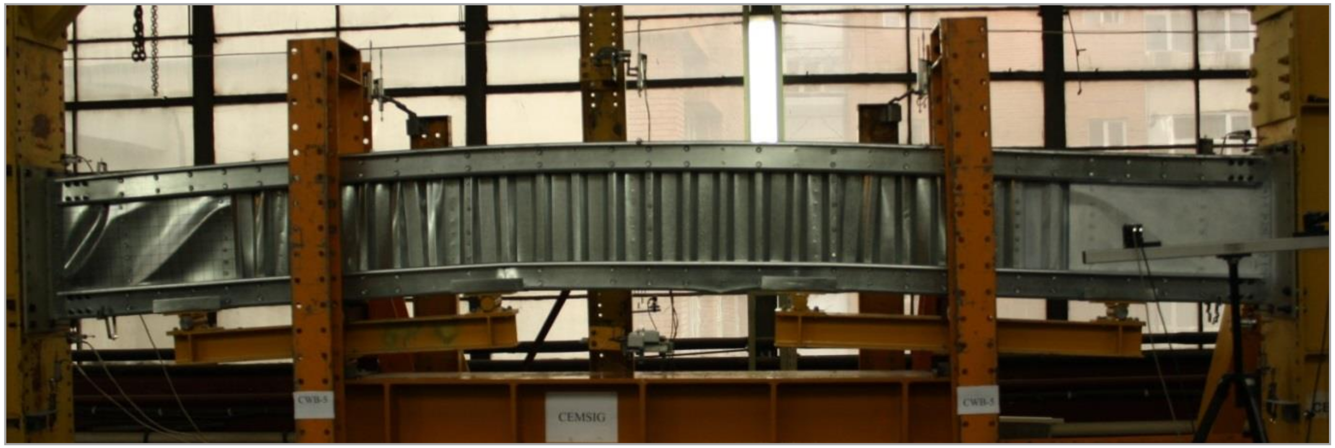
EXPERIMENTAL PROGRAM

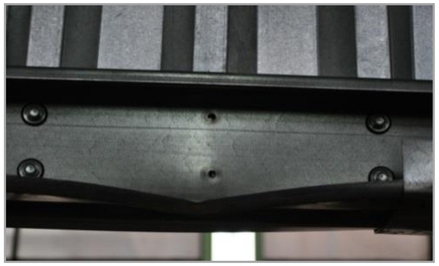
Beam CWB-5

- First deformation – distortion of corrugated web near support – 21mm
- $K_{0\text{-}Exp}$ =5516.23 N/mm
- F_{max}= 214.575 kN
- Collapse at 88mm displacement

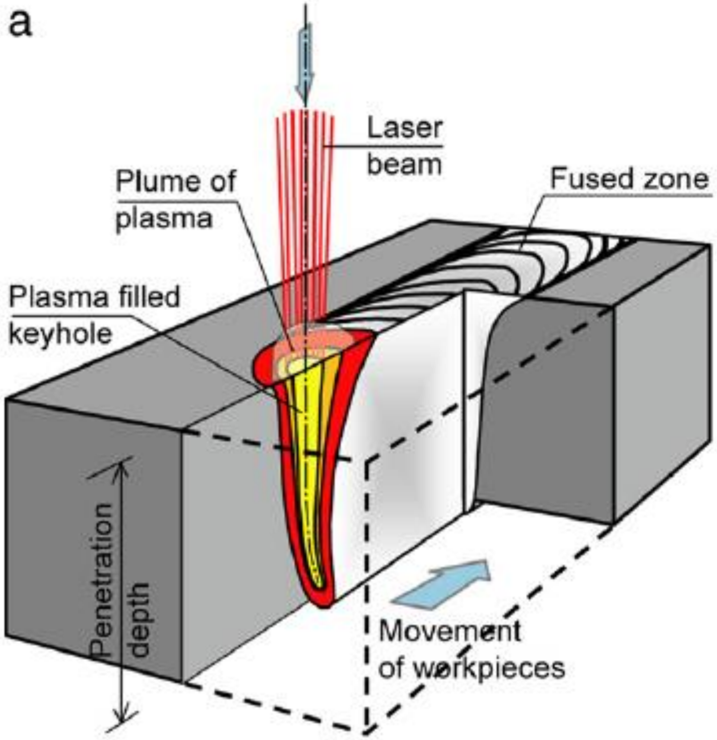
Actual solution : SCREWED !







Laser welding



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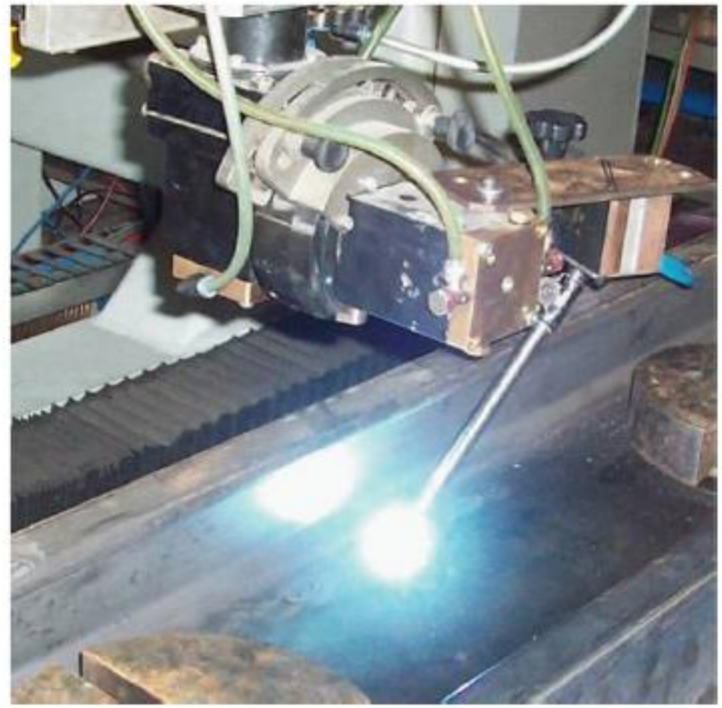
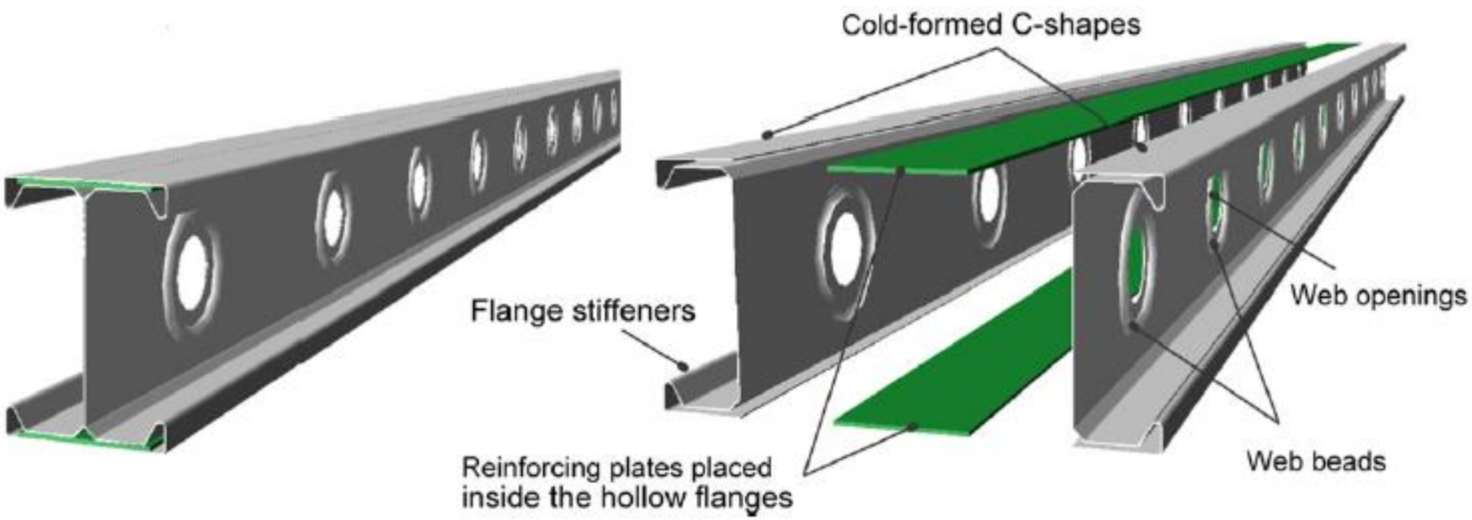
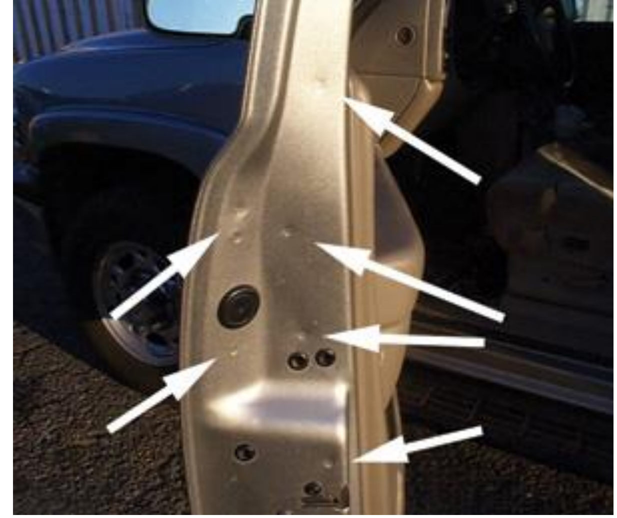
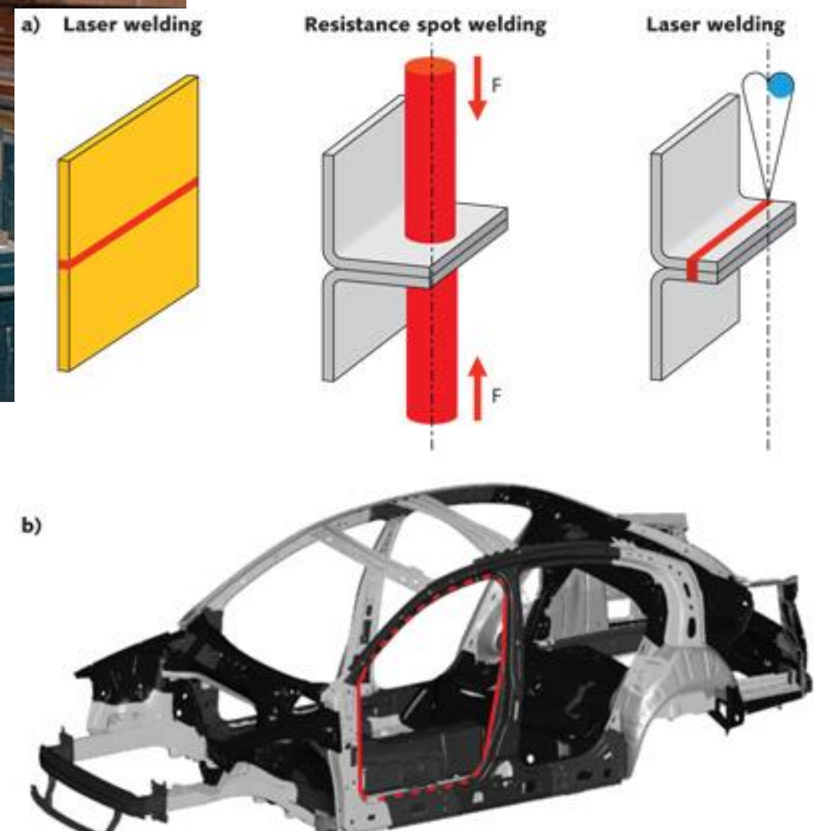




Spot welding





PN-III-P2-2.1-PED-2016-1684

Fast welding cold-formed steel beams of corrugated sheet web

WELLFORMED

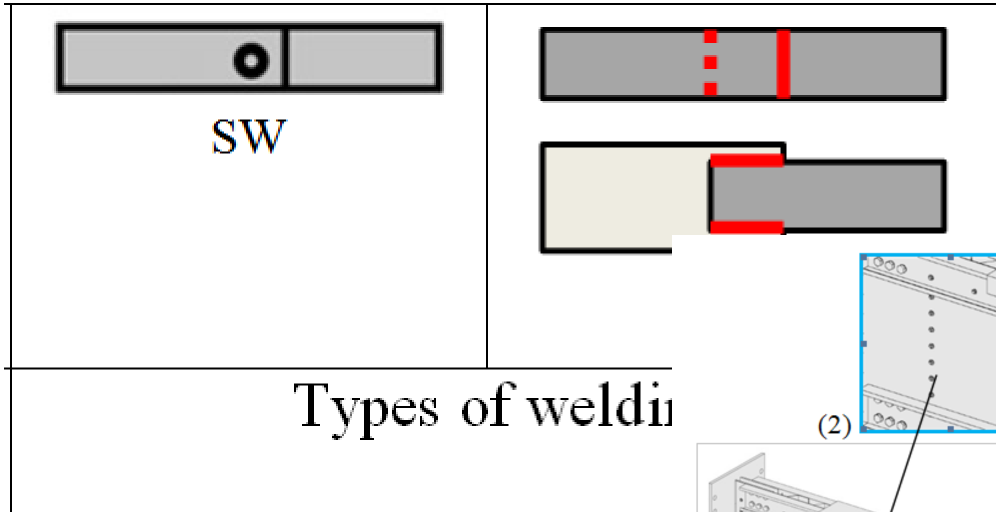
The main objectives of the project:

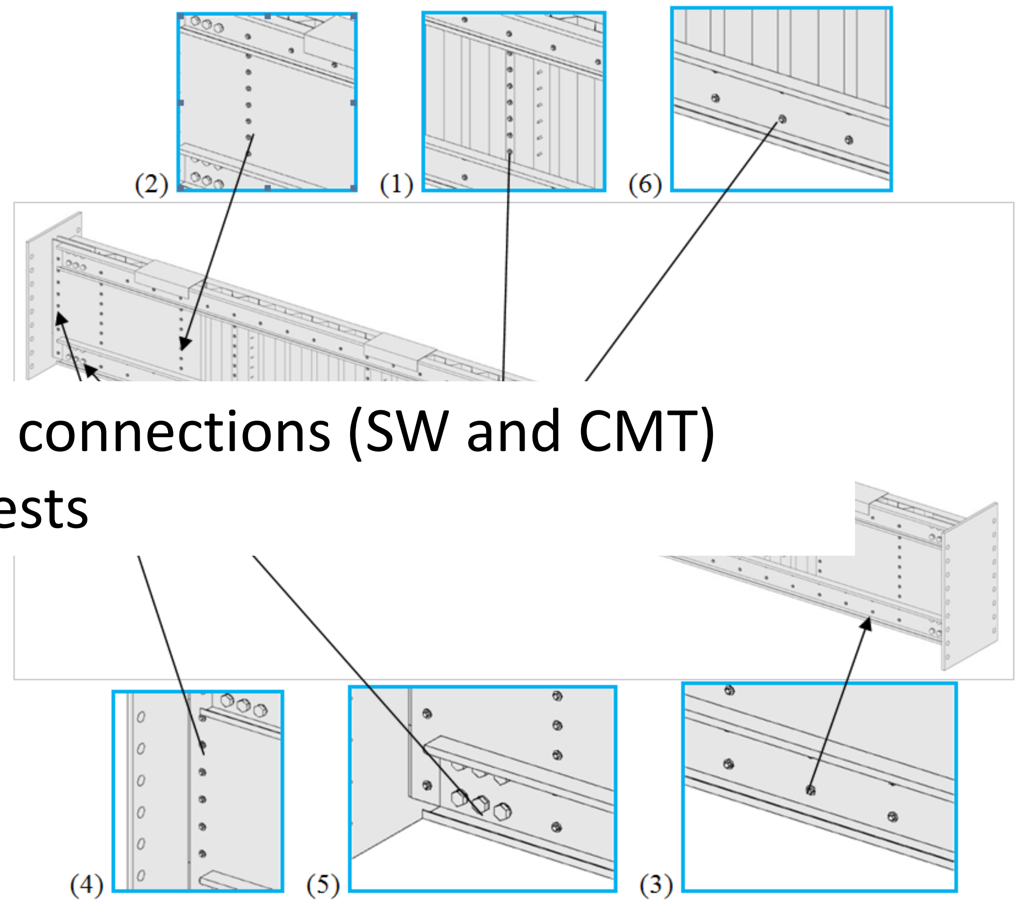
- to validate a new technological solution, CWB where the connections made of intermittent SW and MIG brazing;
- to validate it by a parametric study via numerical models using ABAQUS FEM tool;
- to adapt/extend the rules of the EN 1993-1-5, Annex D to this new type of beams;
- to develop a structural system able to satisfy easy prefabrication, automation and mass production.

WPs:

WP 1: Design of testing program
WP 2: Tests of welded connections and optimisation of fastening technology
WP 3: Tests on full scale CWB beams
WP 4: Numerical testing of beams and parametric investigations
WP 5: Exploitation and dissemination of results

WP 2: Tests of welded connections and optimisation of fastening technology

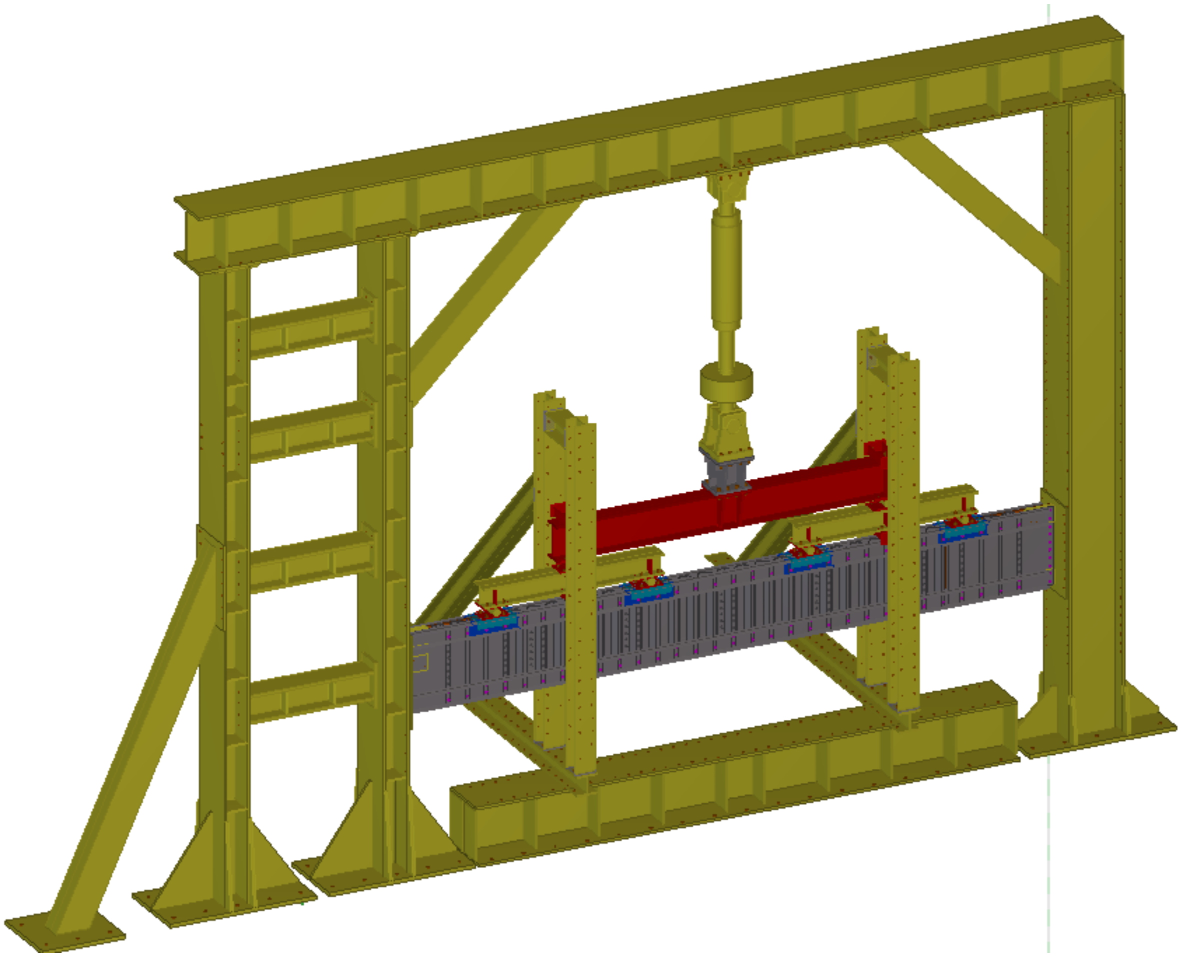




670 specimens for welded connections (SW and CMT)

95 specimens for tensile tests

WP 3: Tests on full scale CWB beams



5 full scale beam specimens

two using SW and three using MIG brazing

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WP 2
Tensile-shear tests on lap joint specimens

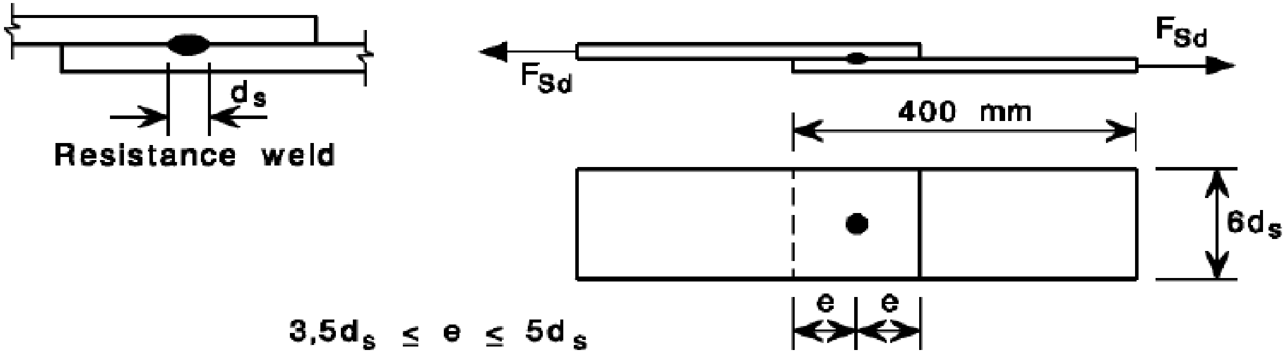
Spot welding

Telwin Inverspotter 14000 Smart Aqua equipment

TELWIN

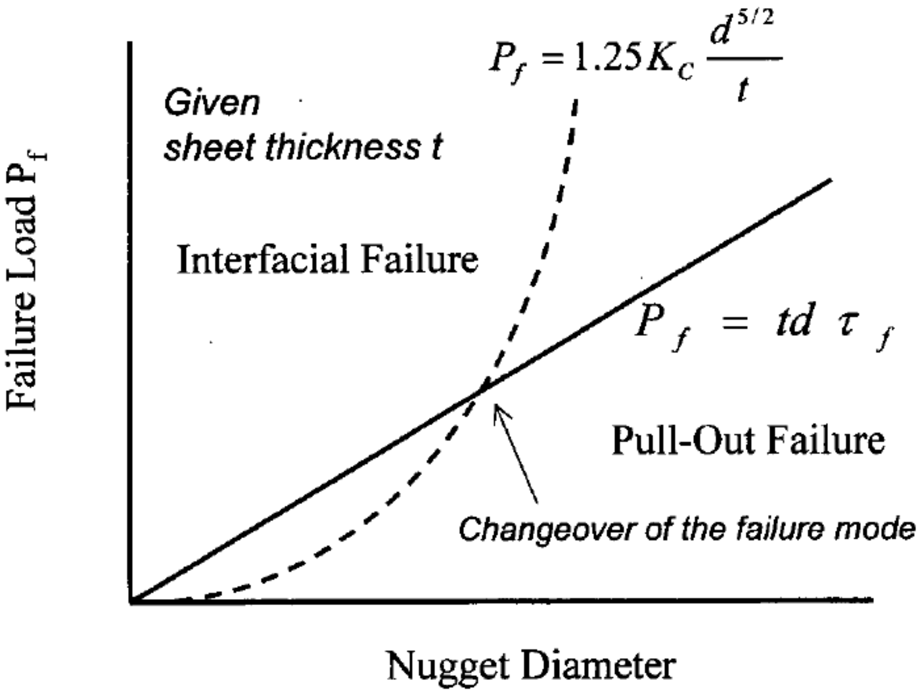
UPT Universitatea Politehnica Timişoara

SPOT WELDING



EN 1993-1-3

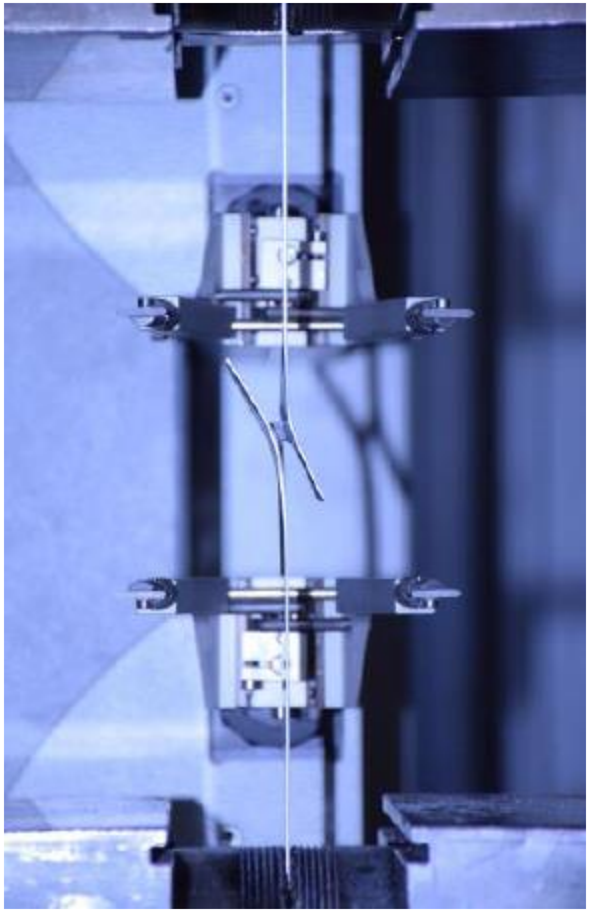
$$d_s = 5\sqrt{t}$$

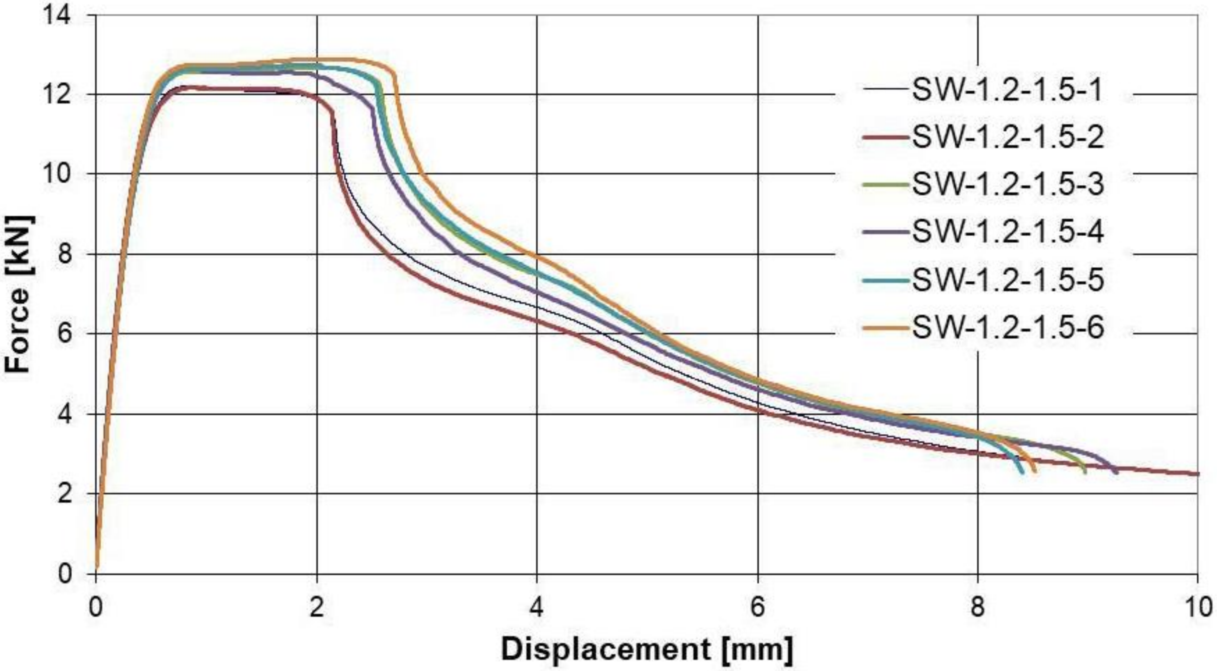


SPOT WELDING – preliminary investigations

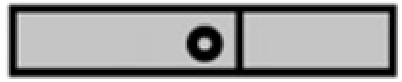
	Name	I_s [A]	Power [%]	F [daN]	pressure [bar]	t_s [ms]
REG 1	SW-1.2-1.5-1	10366	70	365	6	380
REG 2	SW-1.2-1.5-2	10336	70	365	-	380
REG 3	SW-1.2-1.5-3	11088	75	483	6.8	600
REG 4	SW-1.2-1.5-4	11088	75	472	6.6	600
REG 5	SW-1.2-1.5-5	11055	-	457	6.4	600
REG 6	SW-1.2-1.5-6	11775	80	449	6.2	600

SPOT WELDING – preliminary investigations



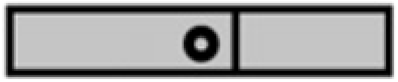


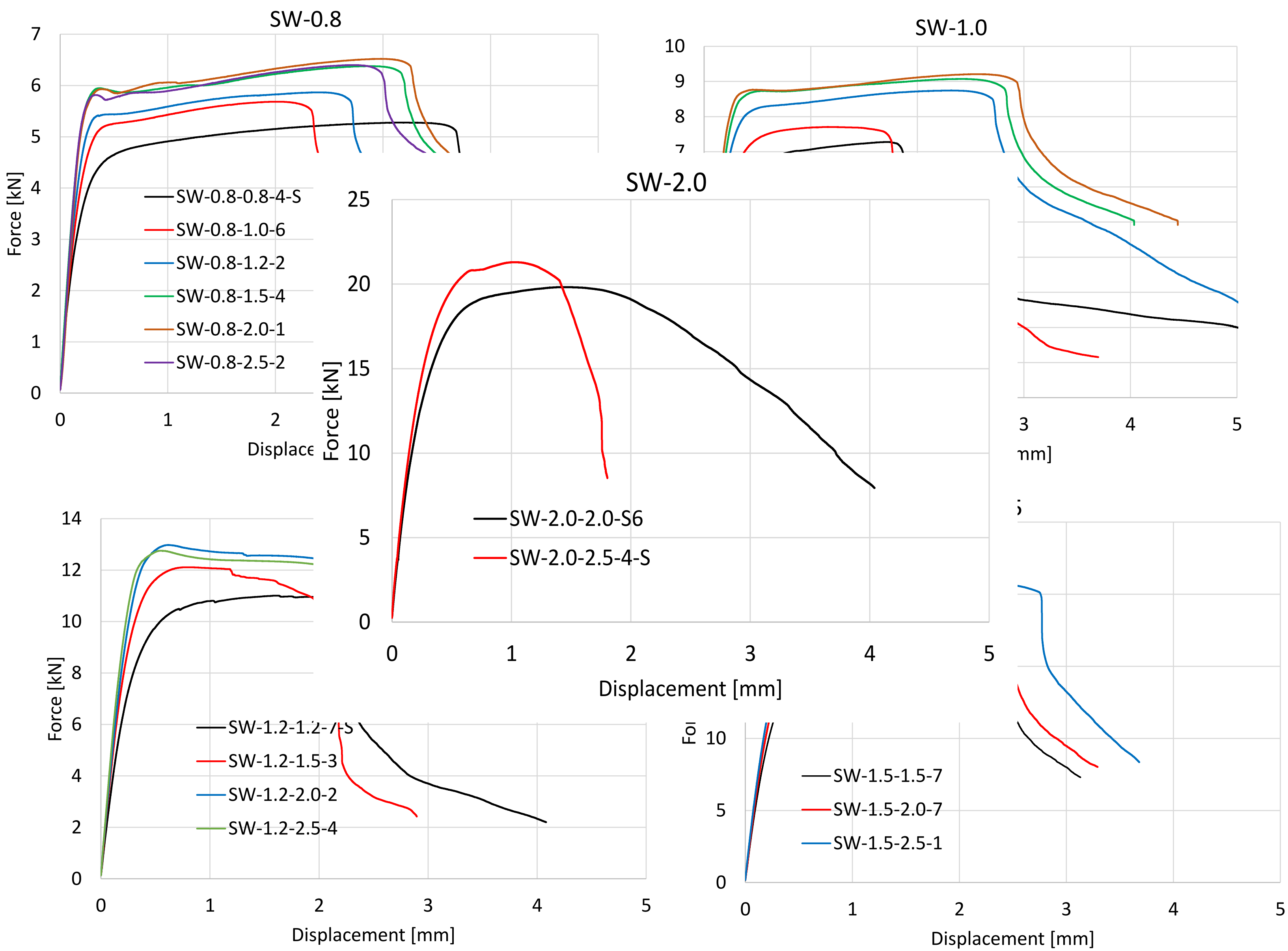
⇒ Smart Auto Mode



Name	No. of tests	Nominal dimensions			Measured dimensions				Failure mode
		t_1 [mm]	t_2 [mm]	d_s [mm]	min(t) [mm]	$d_{s.measured}$ [mm]	$b = 6 d_s$ [mm]	e [mm]	
SW-0.8-0.8	7	0.80	0.80	4.5	0.80	5.10	27.02	19.92	Nugget pull-out
SW-0.8-1.0	7	0.80	1.00	4.5	0.81	5.10	27.30	20.60	Nugget pull-out
SW-0.8-1.2	7	0.80	1.20	4.5	0.80	5.30	27.76	20.64	Nugget pull-out
SW-0.8-1.5	7	0.80	1.50	4.5	0.80	5.50	27.47	20.45	Nugget pull-out
SW-0.8-2.0	7	0.80	2.00	4.5	0.80	5.50	27.74	21.41	Nugget pull-out
SW-0.8-2.5	7	0.80	2.50	4.5	0.79	6.00	27.57	21.38	Nugget pull-out
SW-1.0-1.0	7	1.00	1.00	5.0	0.99	5.40	30.48	25.15	Nugget pull-out
SW-1.0-1.2	7	1.00	1.20	5.0	1.00	5.40	30.48	27.54	Nugget pull-out
SW-1.0-1.5	7	1.00	1.50	5.0	1.01	5.50	30.69	25.42	Nugget pull-out
SW-1.0-2.0	7	1.00	2.00	5.0	1.01	6.00	30.85	26.31	Nugget pull-out
SW-1.0-2.0	7	1.00	2.50	5.0	1.01	6.20	30.60	27.73	Nugget pull-out
SW-1.2-1.2	7	1.20	1.20	5.5	1.19	5.60	33.13	24.70	Nugget pull-out
SW-1.2-1.5	7	1.20	1.50	5.5	1.21	5.80	33.07	26.00	Nugget pull-out
SW-1.2-2.0	7	1.20	2.00	5.5	1.21	6.00	33.46	27.55	Nugget pull-out
SW-1.2-2.5	7	1.20	2.50	5.5	1.20	6.40	33.33	27.23	Nugget pull-out
SW-1.5-1.5	7	1.50	1.50	6.1	1.53	6.50	37.24	29.75	**Interfacial fracture**
SW-1.5-2.0	7	1.50	2.00	6.1	1.54	7.00	37.32	31.00	Nugget pull-out
SW-1.5-2.5	7	1.50	2.50	6.1	1.52	7.50	37.48	31.57	Nugget pull-out
SW-2.0-2.0	7	2.00	2.00	7.1	1.99	7.50	42.15	36.28	**Interfacial fracture**
SW-2.0-2.5	7	2.00	2.50	7.1	1.97	7.80	42.61	35.99	**Interfacial fracture**

SW results

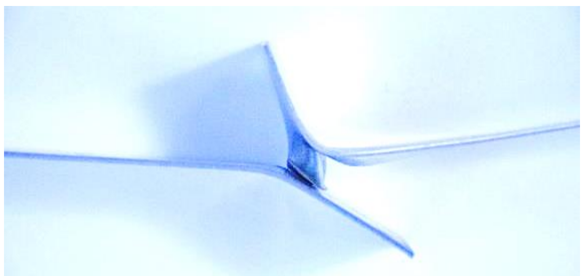


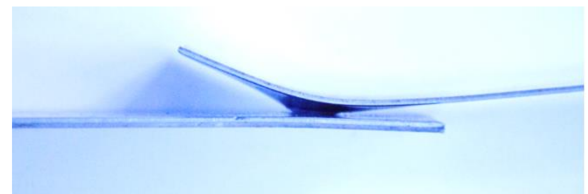

SW-0.8
Force [kN]
Displace
SW-0.8-0.8-4-S
SW-0.8-1.0-6
SW-0.8-1.2-2
SW-0.8-1.5-4
SW-0.8-2.0-1
SW-0.8-2.5-2
SW-1.0
SW-2.0
Force [kN]
Displacement [mm]
SW-2.0-2.0-S6
SW-2.0-2.5-4-S
Force [kN]
Displacement [mm]
SW-1.2-1.2-7-S
SW-1.2-1.5-3
SW-1.2-2.0-2
SW-1.2-2.5-4
Displacement [mm]
SW-1.5-1.5-7
SW-1.5-2.0-7
SW-1.5-2.5-1

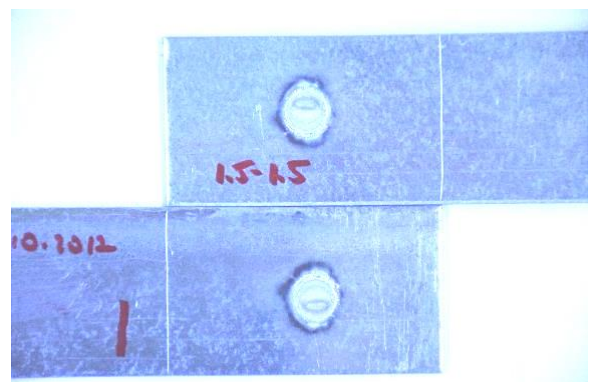
FAILURE MODES

Nugget pull-out
thin sheets

Interfacial failure
thick sheets







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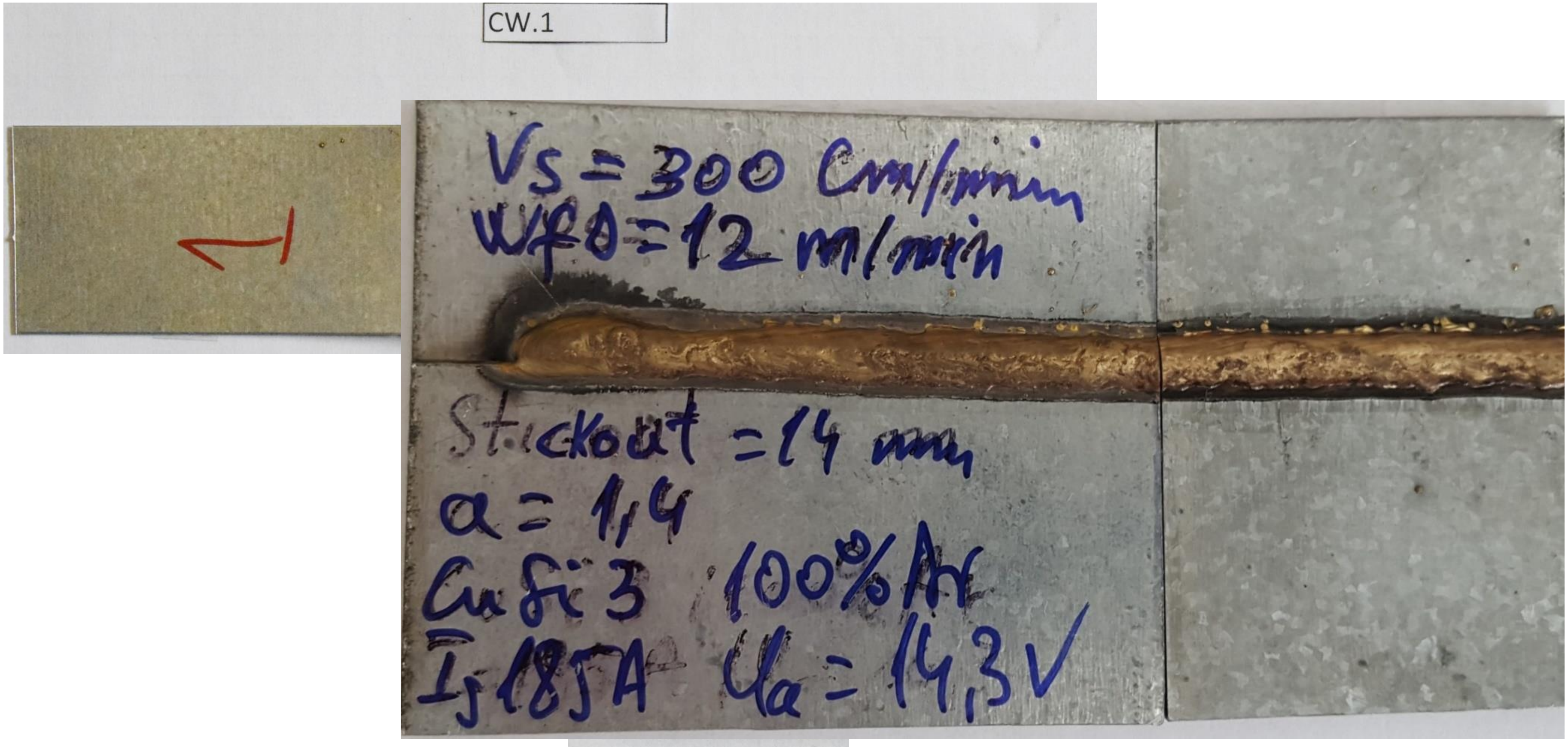
MIG/MAG welding equipment impulse welding

REHM GmbH, MEGAPULS.FOCUS 330

REHM®
Welding Technology

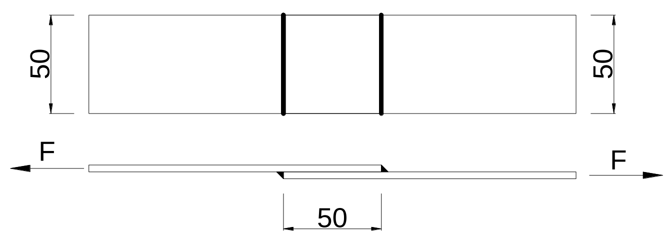
MIG/MAG welding equipment impulse welding - preliminary investigations



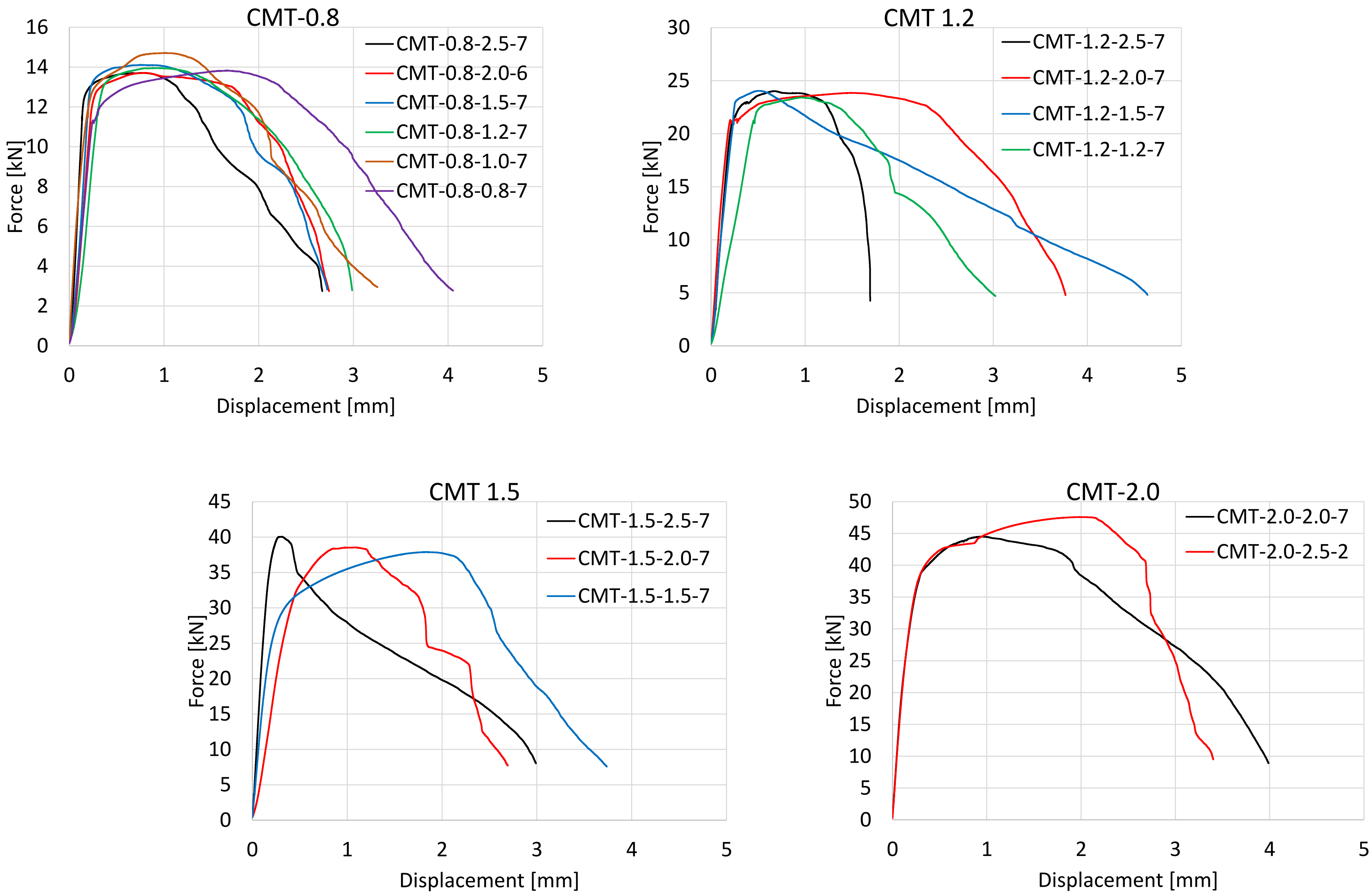
Semi-automatic control

filler material: CuSi 3 (EN 14640)
wire with 1 mm diameter

Name	No. of tests	Nominal dimensions			Measured dimensions		Failure mode
		t_1 [mm]	t_2 [mm]	b_{nom} [mm]	min(t) [mm]	$b_{measured}$ [mm]	
CMT-0.8-0.8	7	0.80	0.80	50	0.79	49.76	Heat affected zone
CMT-0.8-1.0	7	0.80	1.00	50	0.79	49.76	Heat affected zone
CMT-0.8-1.2	7	0.80	1.20	50	0.80	49.78	Heat affected zone
CMT-0.8-1.5	7	0.80	1.50	50	0.81	49.77	Heat affected zone
CMT-0.8-2.0	7	0.80	2.00	50	0.81	49.67	Heat affected zone
CMT-0.8-2.5	7	0.80	2.50	50	0.82	49.82	Heat affected zone
CMT-1.0-1.0	7	1.00	1.00	50	1.02	49.16	Heat affected zone
CMT-1.0-1.2	7	1.00	1.20	50	1.00	49.84	Heat affected zone
CMT-1.0-1.5	7	1.00	1.50	50	0.99	49.94	Heat affected zone
CMT-1.0-2.0	7	1.00	2.00	50	1.00	49.64	Heat affected zone
CMT-1.0-2.0	7	1.00	2.50	50	1.00	50.06	Heat affected zone
CMT-1.2-1.2	7	1.20	1.20	50	1.19	49.56	Heat affected zone
CMT-1.2-1.5	7	1.20	1.50	50	1.20	49.59	Heat affected zone
CMT-1.2-2.0	7	1.20	2.00	50	1.20	49.84	Heat affected zone
CMT-1.2-2.5	7	1.20	2.50	50	1.21	49.82	Heat affected zone
CMT-1.5-1.5	7	1.50	1.50	50	1.50	49.77	Heat affected zone
CMT-1.5-2.0	7	1.50	2.00	50	1.49	49.76	Heat affected zone
CMT-1.5-2.5	7	1.50	2.50	50	1.50	49.72	Heat affected zone
CMT-2.0-2.0	7	2.00	2.00	50	2.00	49.99	Heat affected zone
CMT-2.0-2.5	7	2.00	2.50	50	1.93	50.02	Heat affected zone

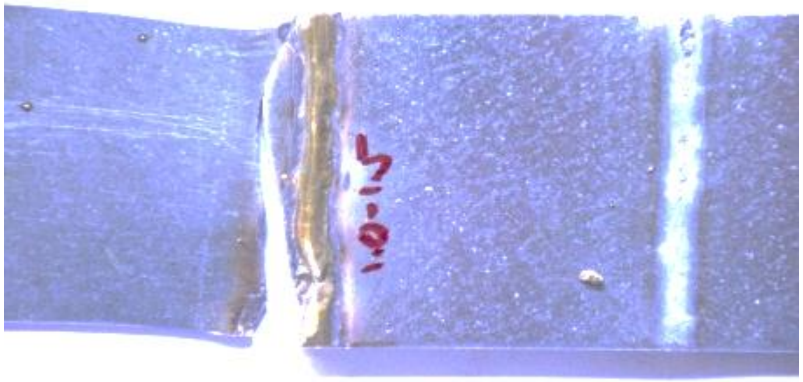


MIG brazing results



FAILURE MODES

fracture in the heat affected zone



base material fracture

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Tensile tests

t (mm)	$R_{p0.2}$ (MPa)	R_{eH} (MPa)	R_m (MPa)	A_g %	A_{gt} %	A_t %
0.8	S280GD+Z					
1.0						
1.2	S350GD+Z					
1.5						
2.0						
2.5						

where:

$R_{p0.2}$ - stress at 0.2% strain

R_{eH} - maximum value of stress prior to the first decrease in force

R_m - stress corresponding to the maximum force

A_g - plastic extension at maximum force

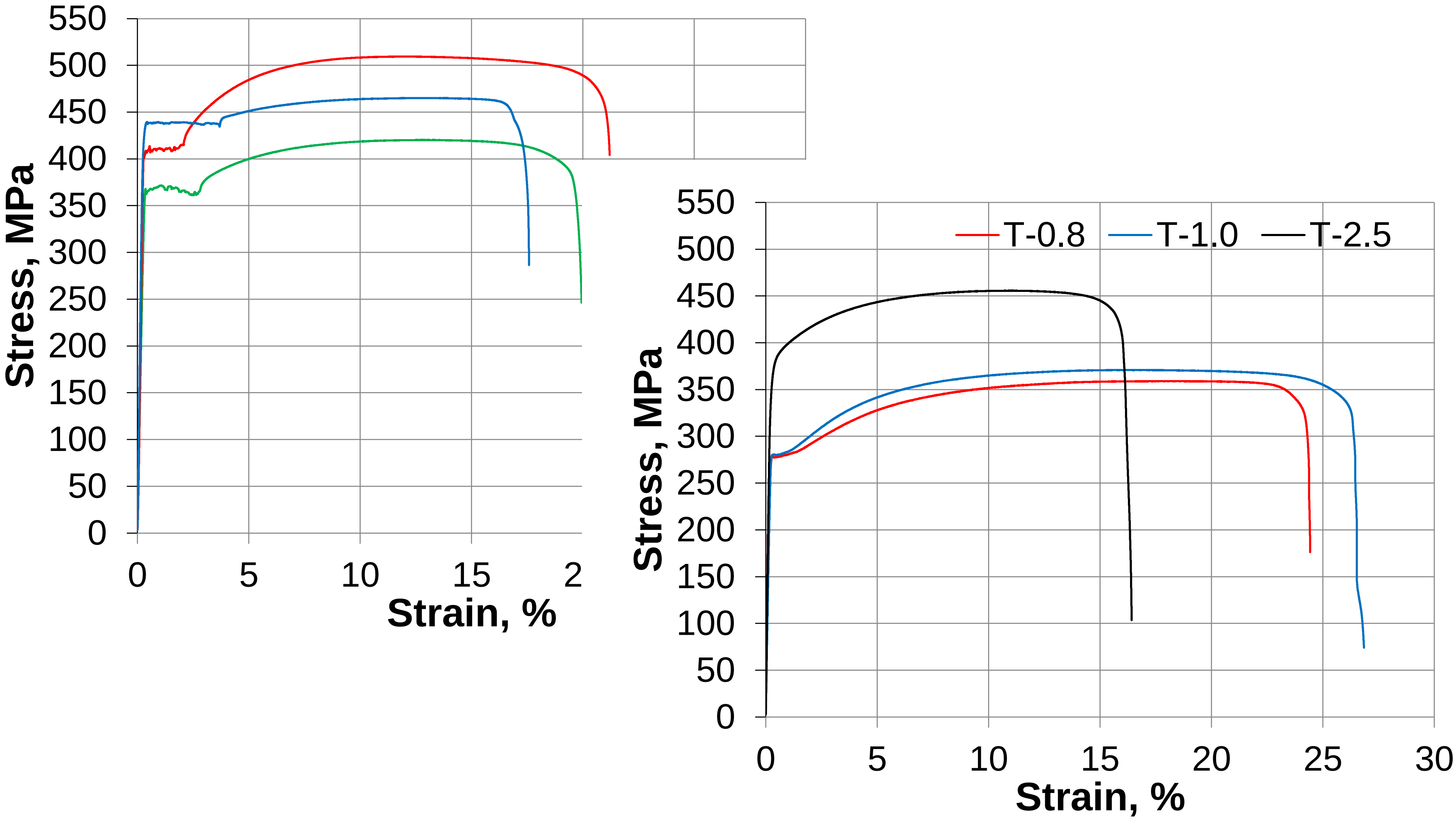
A_{gt} - total extension at maximum force

A_t - total extension at the moment of fracture

5 specimens for each thickness

ISO 6892-1, Metallic materials - Tensile testing - Part 1: Method of test at room temperature

Tensile tests

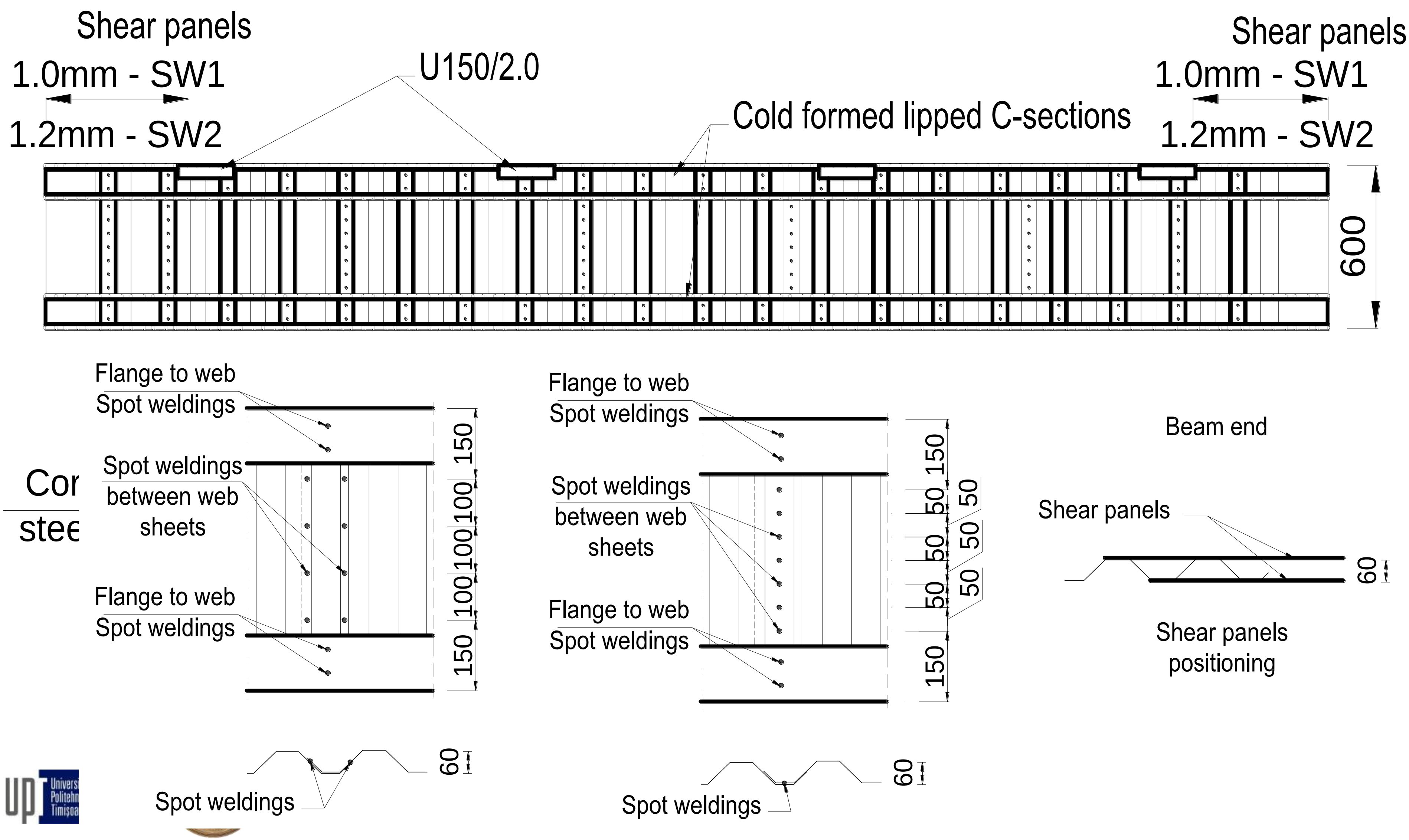


ISO 6892-1, Metallic materials - Tensile testing
- Part 1: Method of test at room temperature

WP 3: Tests on full scale CWB beams

SPOT WELDING

2 full scale beam specimens / span: 5157 mm and height: 600 mm



SPOT WELDING

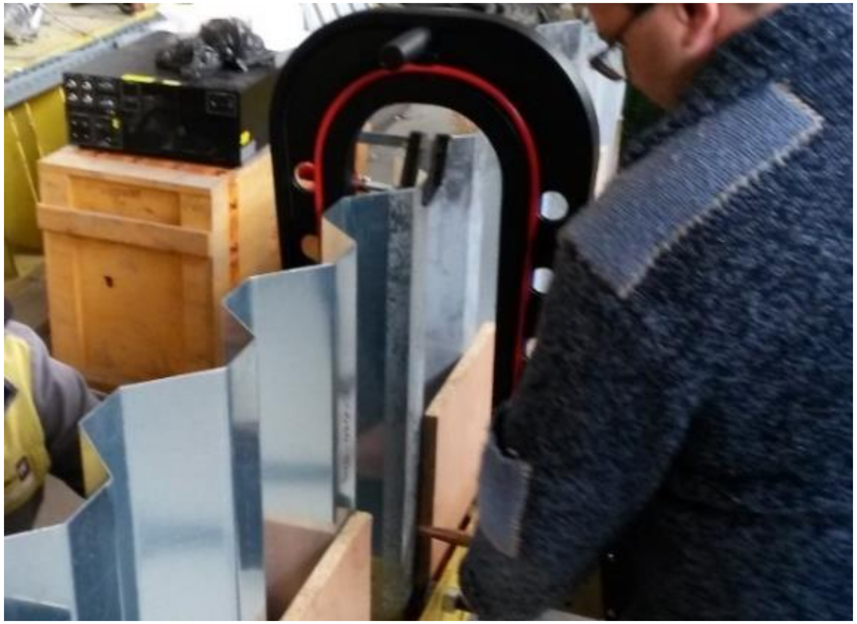
2 full scale beam specimens

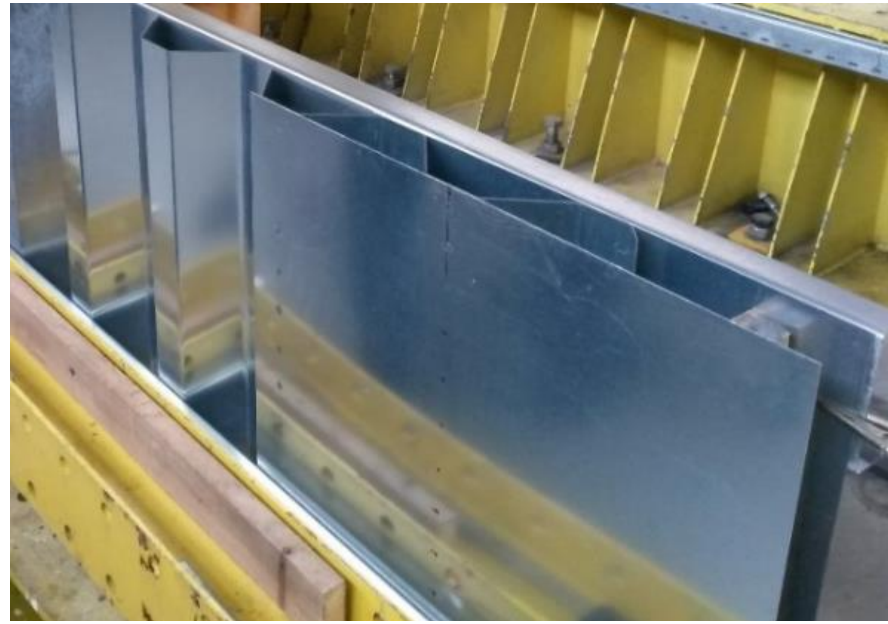
The components of the built-up beams:

- two back-to-back lipped channel sections for flanges - 2 × C120/2.0;
- corrugated steel sheets (panels of 1.05 m length with 60 mm height of the corrugation);
- additional shear panels - flat plates of 1.0 or 1.2 mm;
- reinforcing profiles U150/2.0 under the load application points;
- bolts M12 grade 8.8 for endplate connection.

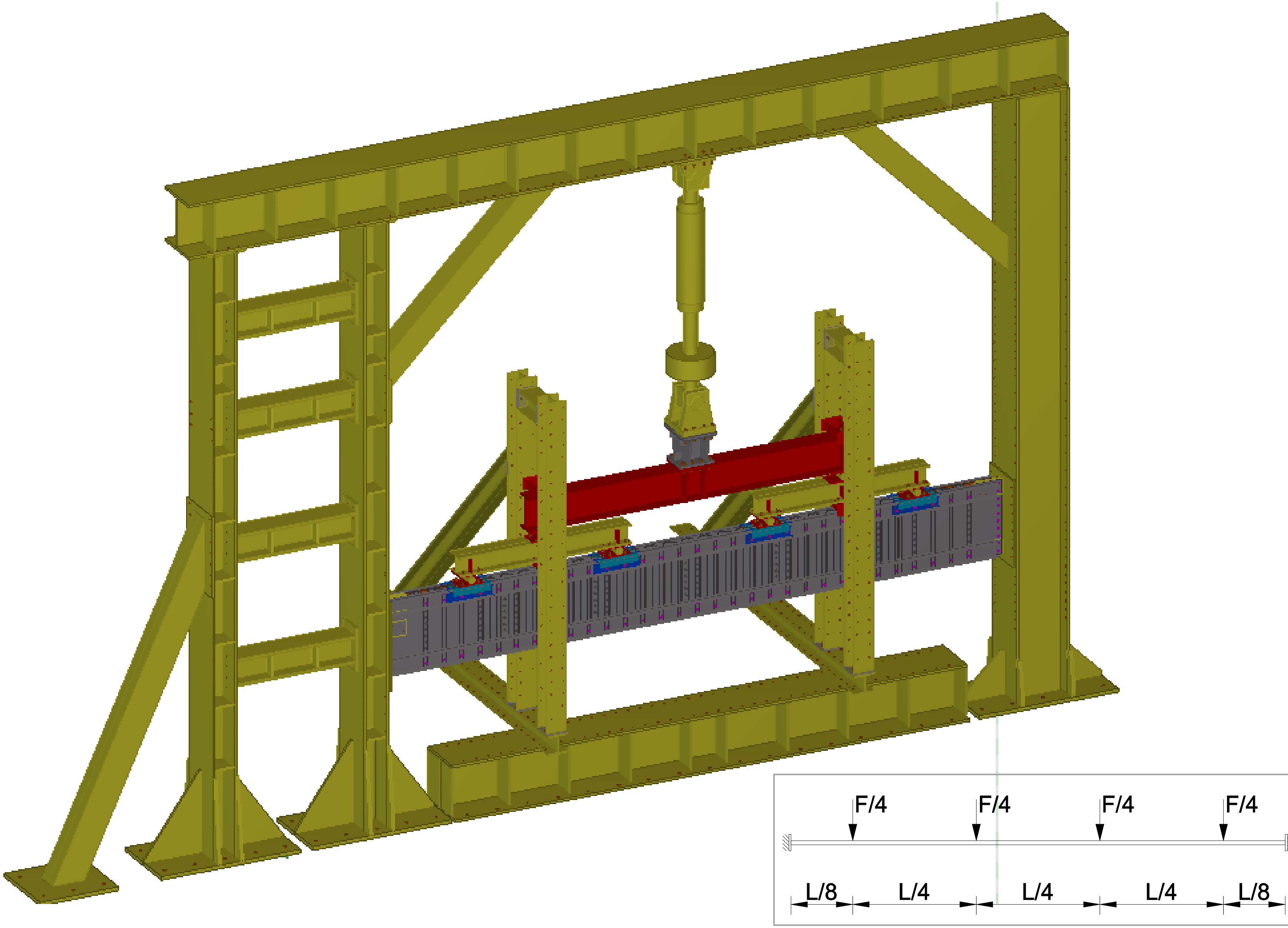
Name	Thickness			Length of shear panels*
	Outer corrugated sheets	Inner corrugated sheets	Shear panels	
CWB SW-1	1.2 mm	0.8 mm	1.0 mm	470 mm; 570 mm
CWB SW-2	1.2 mm	0.8 mm	1.2 mm	510 mm; 630 mm

* the length of the shear panels is different due to variable position of the web corrugation





process for the manufacturing

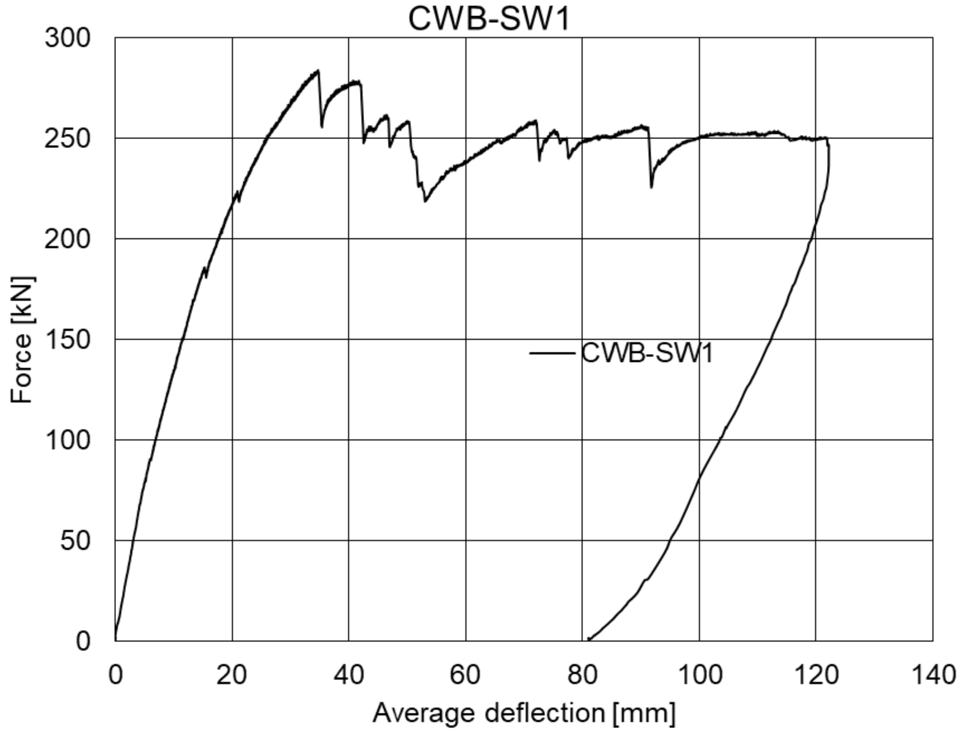


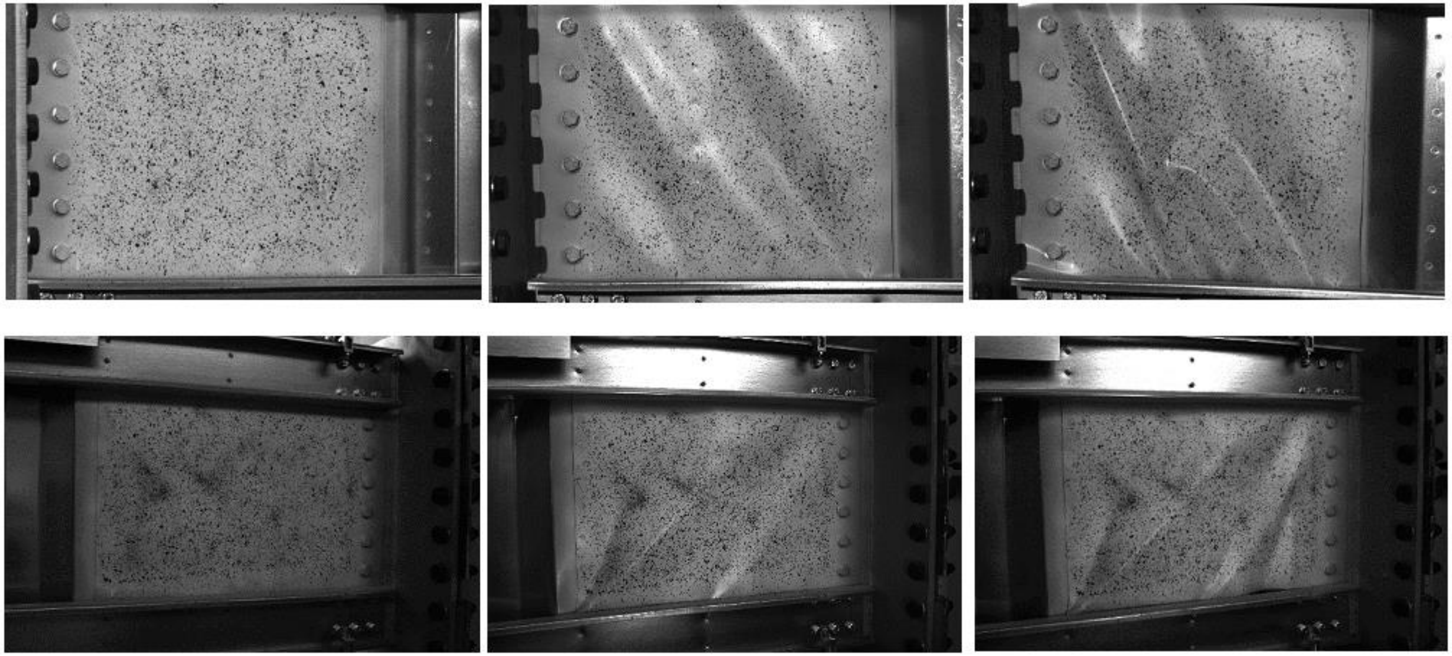
Monotonic load - v_{test}=2mm/min

6 points bending test

CWB SW-1

- First deformation – buckling of the shear panels , followed by distortion of corrugated web
- $K_{0\text{-}Exp}$ =11352.6 N/mm
- F_{max}= 283.8 kN
- Collapse at 123 mm





Development of the buckling of the end shear panels

Distortion of the web corrugation

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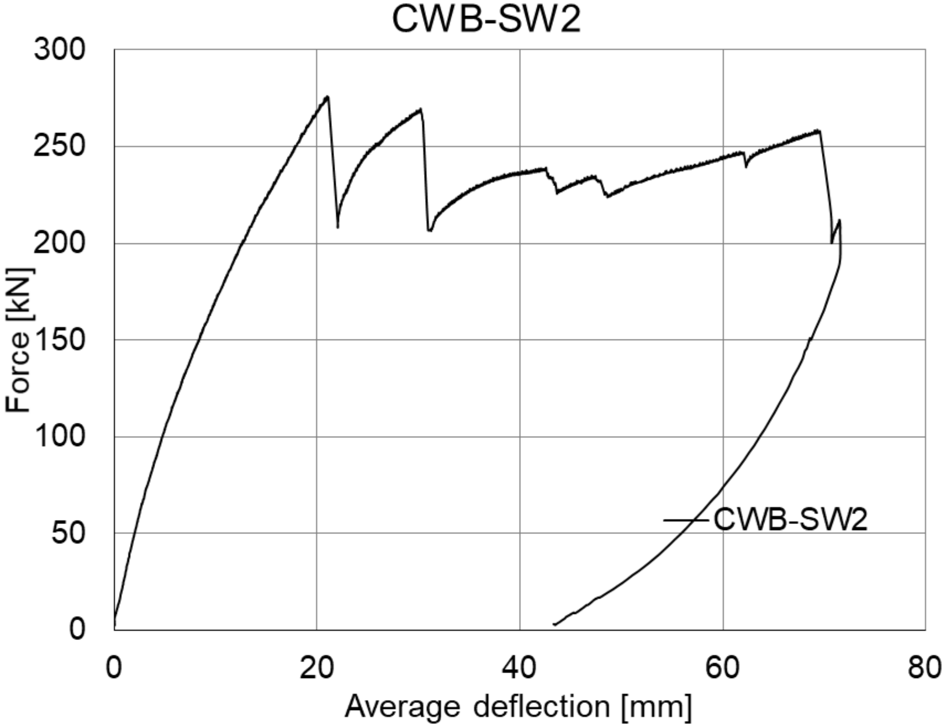
CWB SW-1

CWB SW-1

Spot welding failure between the web and the flange

CWB SW-2

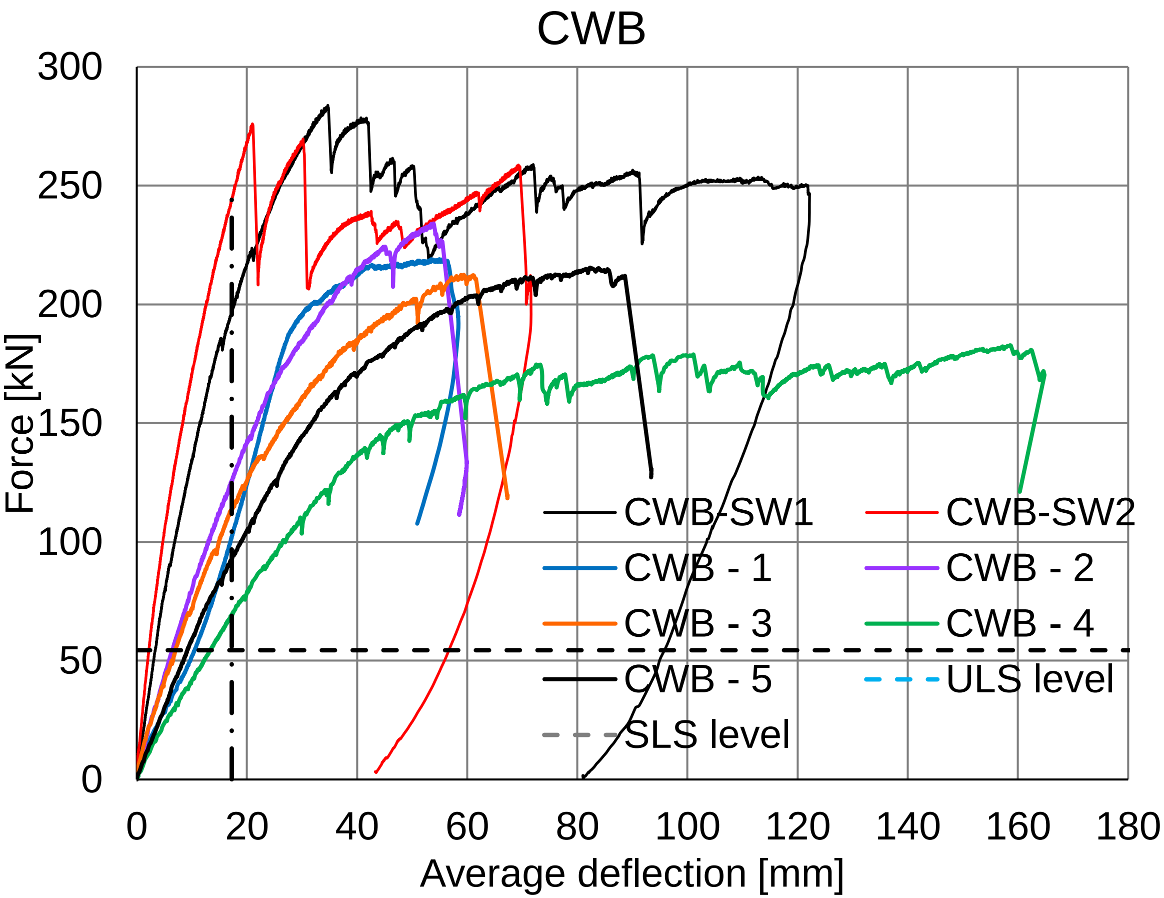


- First deformation – buckling of the shear panels , followed by distortion of corrugated web
- $K_{0\text{-}Exp}$ =15846.5 N/mm
- F_{max}= 276.0 kN
- Collapse at 69.5 mm

Development of the buckling of the end shear panels

Distortion of the web corrugation

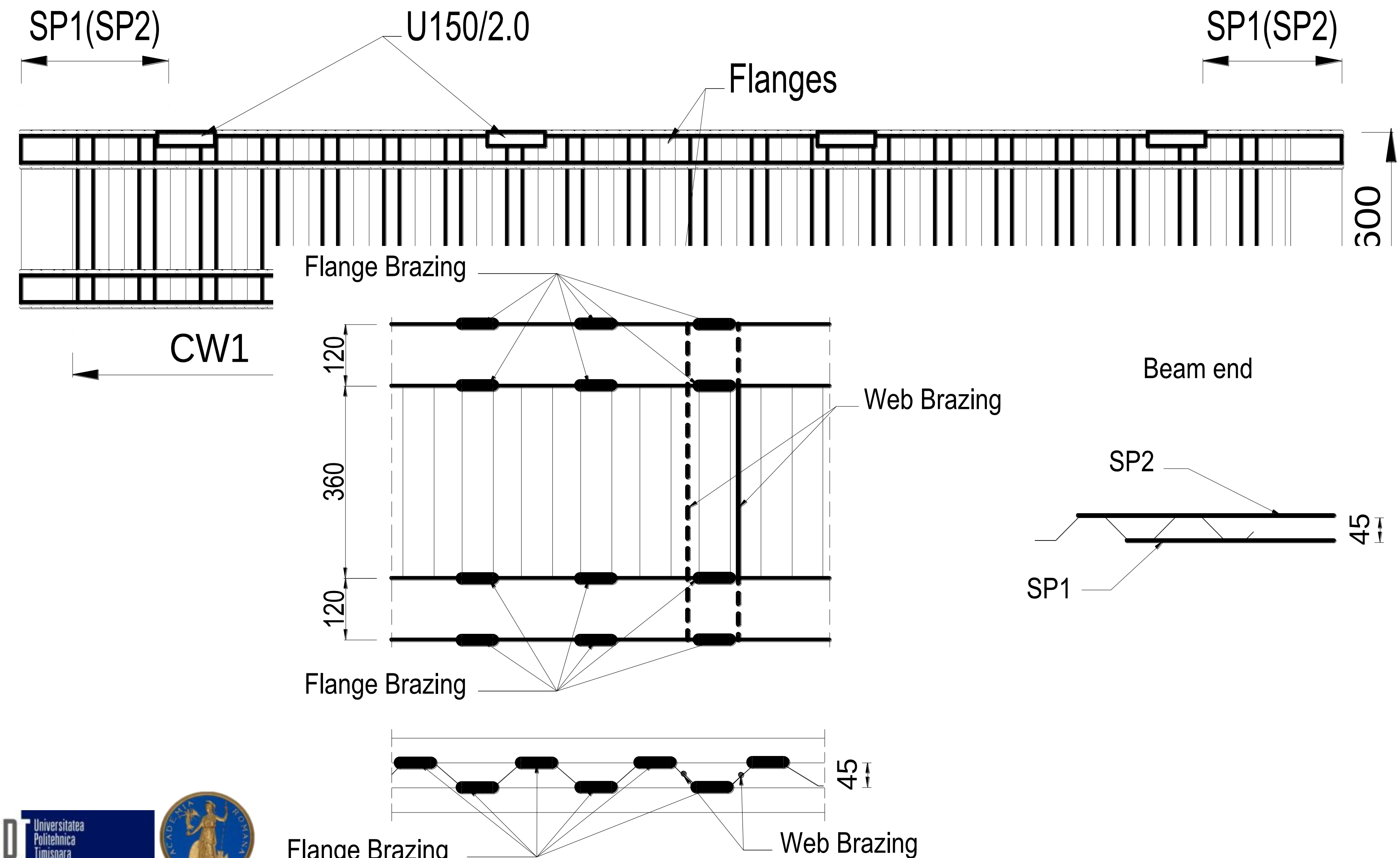
Spot welding failure between the web and the flange



Beam type	$K_{0\text{-}Exp}$ (N/mm)	F_{max} (kN)
CWB SW-1	11352.6	283.8
CWB SW-2	15846.5	276.0
CWB-1	6862.2	219.0
CWB-2	7831.5	230.6
CWB-3	7184.9	211.9
CWB-4	3985.0	161.8
CWB-5	5516.2	215.5

MIG brazing

3 full scale beam specimens / span: 5157 mm and height: 600 mm



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MIG brazing

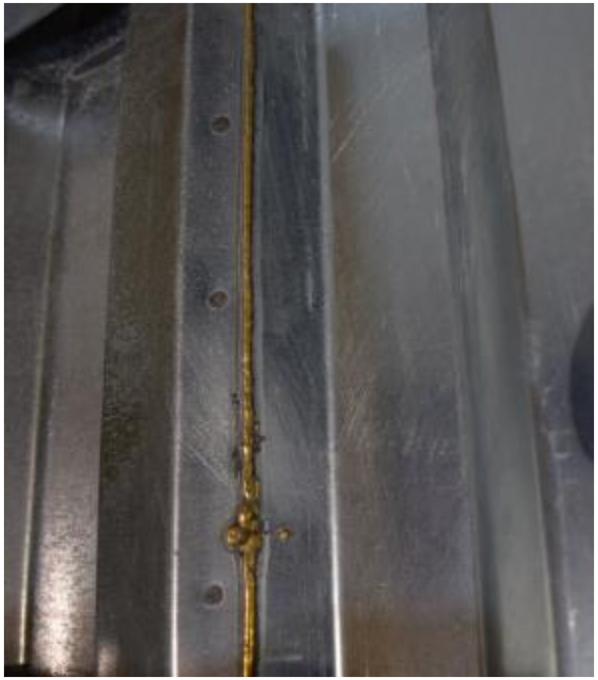
3 full scale beam specimens

The components of the built-up beams:

- two back-to-back lipped channel sections for flanges - 2 × C120/2.0;
- corrugated steel sheets (panels of 1.05 m length with 45 mm height of the corrugation);
- additional shear panels - flat plates of 1.0 or 1.2 mm;
- reinforcing profiles U150/2.0 under the load application points;
- bolts M12 grade 8.8 for endplate connection.

Name	Thickness				Length of shear panels*
	CW1	CW2	CW3	SP1(SP2)	
CWB CMT-1	1.2 mm	0.8 mm	0.8 mm	1.2 mm	470 mm; 570 mm
CWB CMT-2	0.8 mm	0.8 mm	0.8 mm	1.0 mm	470 mm; 570 mm
CWB CMT-3	1.0 mm	0.8 mm	0.8 mm	1.0 mm	470 mm; 570 mm

* the length of the shear panels is different due to variable position of the web corrugation



process for the manufacturing

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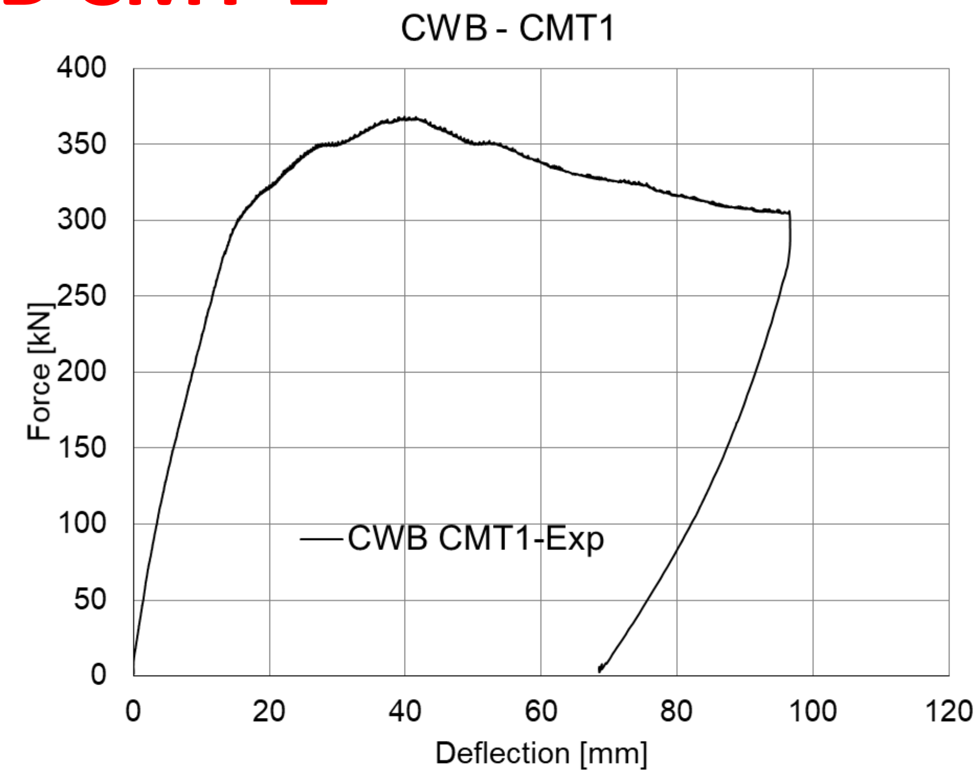
CWB CMT-1

- First deformation – buckling of the shear panels , followed by shear buckling of web corrugation
- $K_{0\text{-}Exp}$ =25787 N/mm
- F_{max}= 368.28 kN
- Collapse at 96.6 mm



Development of the buckling of the end shear panels

Shear buckling of the web corrugation

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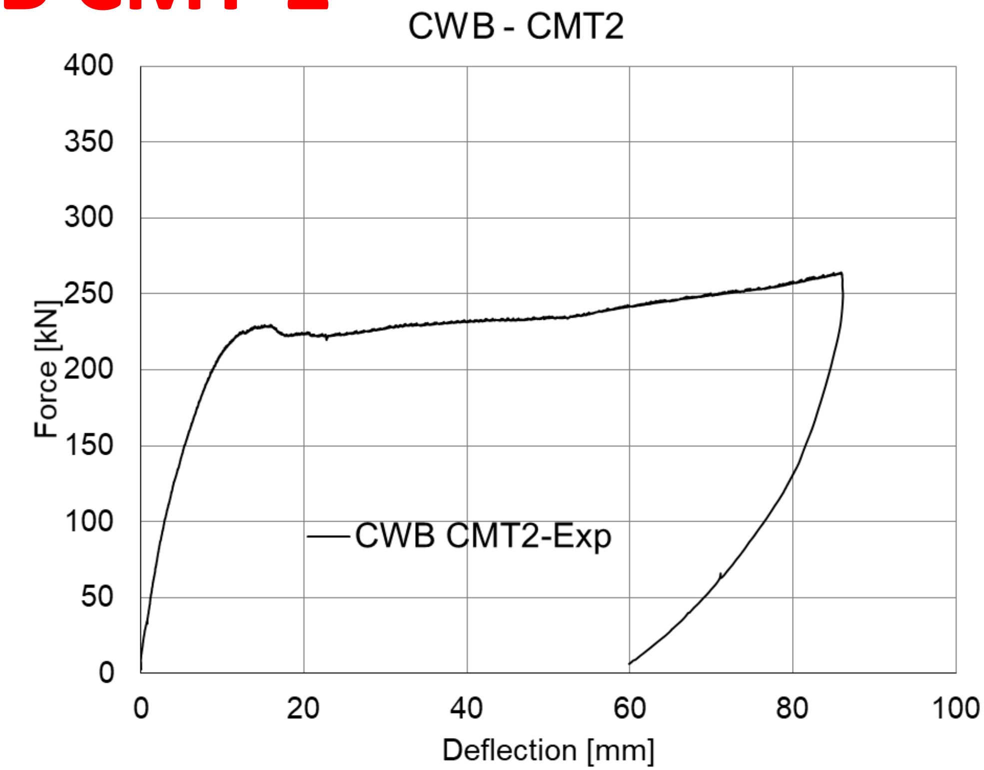
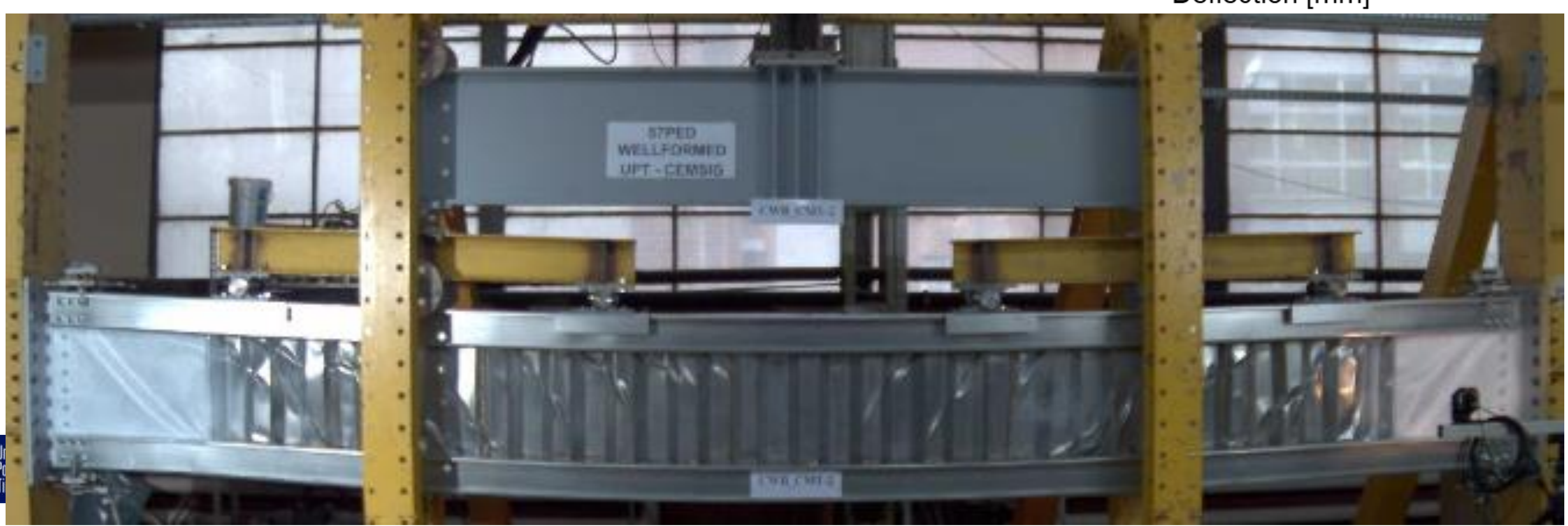
CWB CMT-2

- First deformation – buckling of the shear panels , followed by shear buckling of web corrugation
- $K_{0\text{-}Exp}$ =22559 N/mm
- F_{max}= 227.9 kN



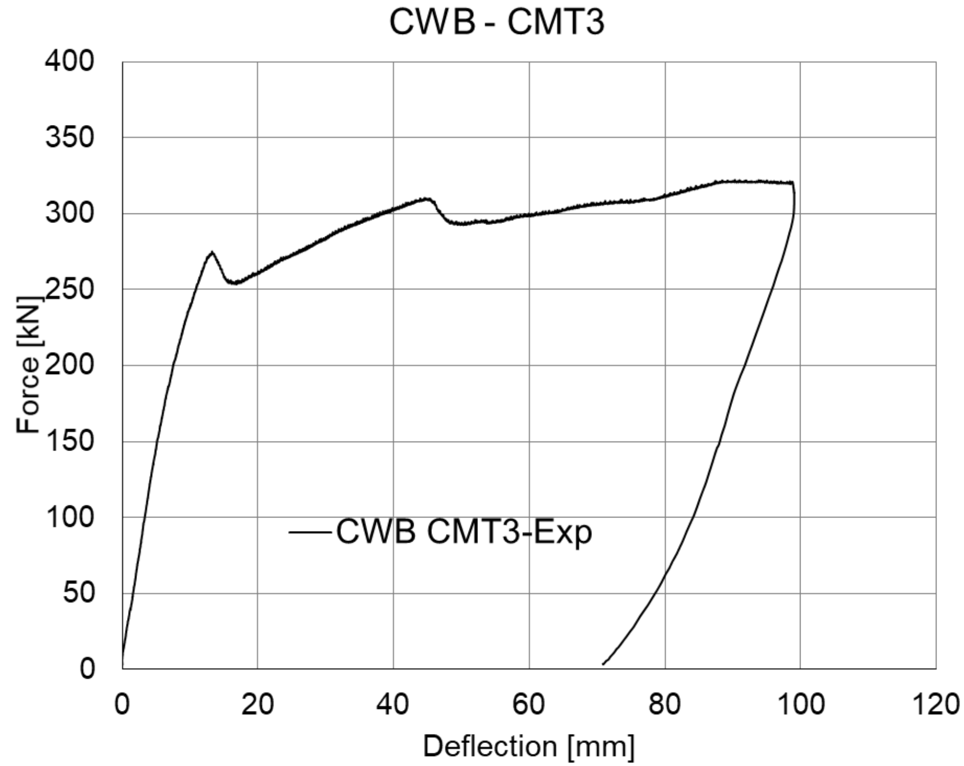


Development of the buckling of the end shear panels

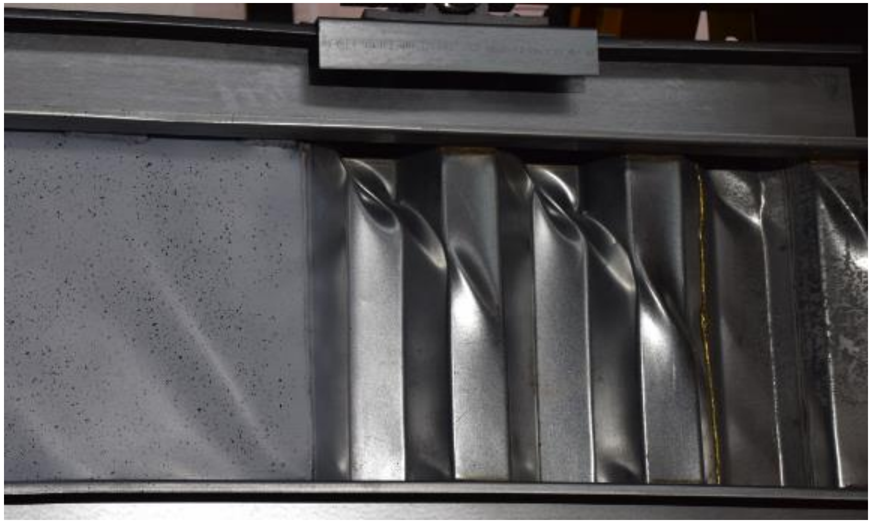
Shear buckling of the web corrugation

CWB CMT-3

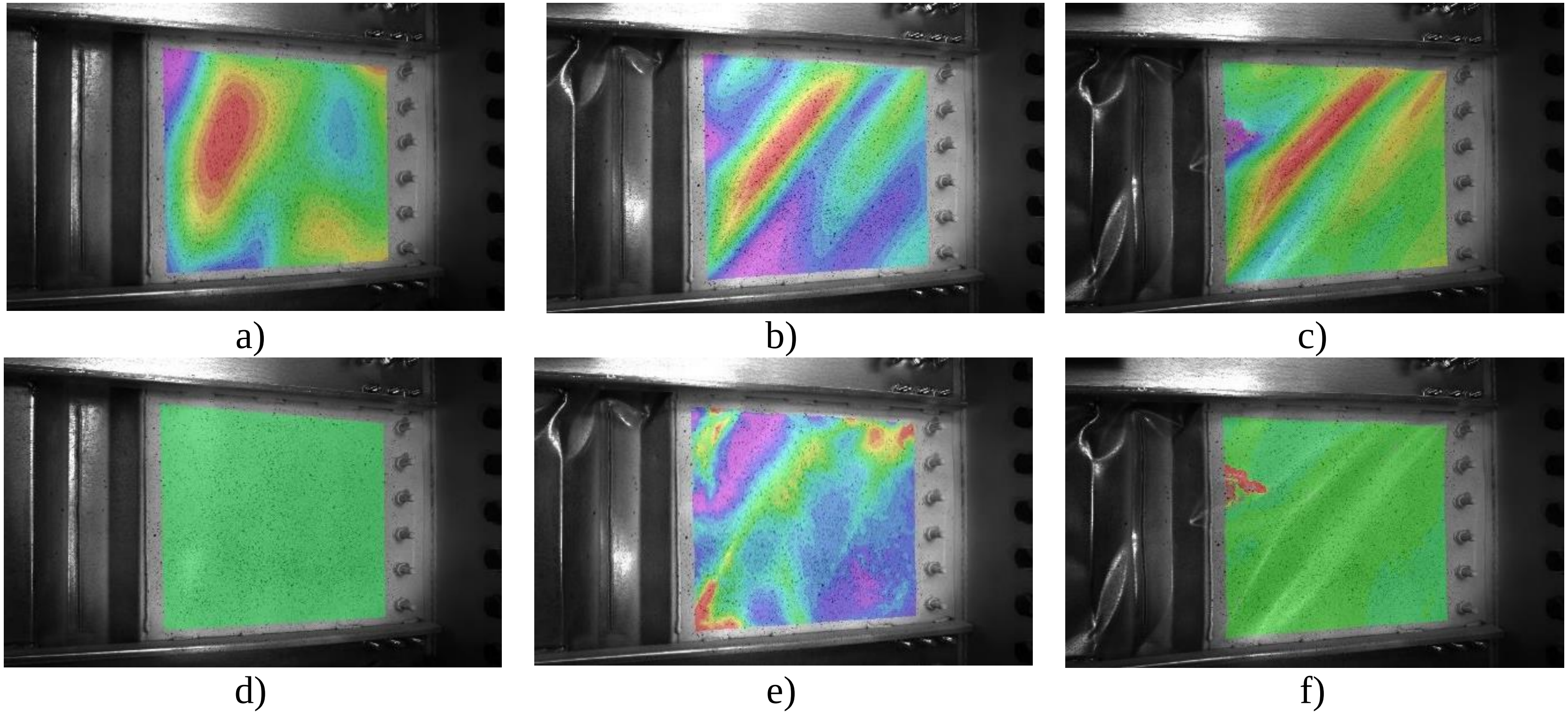
- First deformation – buckling of the shear panels , followed by shear buckling of web corrugation
- $K_{0\text{-}Exp}$ =24792 N/mm
- F_{max}= 273.5 kN



Development of the buckling of the end shear panels



Shear buckling of the web corrugation



Evolution of the out of plane deformations (a, b, c) and the corresponding principal strains (d, e, f) of a given shear panel

digital image correlation system (DIC)

isi-sys GmbH. Two GT6600 Prosilica series

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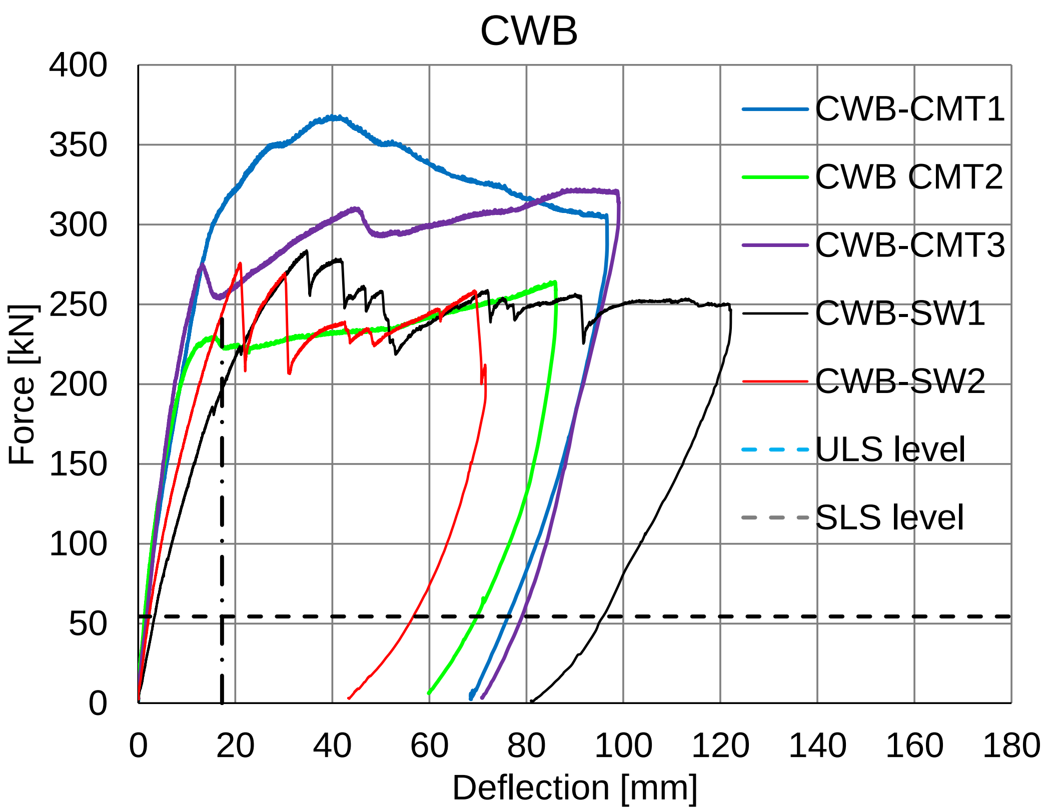

Beam type	$K_{0\text{-}Exp}$ (N/mm)	$F_{max\text{-}Exp}$ (kN)
CWB-CMT1	25787	368.2
CWB-CMT2	22559	227.9
CWB-CMT3	24792	273.5
CWB-SW1	11353	283.8
CWB-SW2	15847	276.0

CONCLUSIONS

An extensive experimental program was performed at the PU Timisoara on the purpose to demonstrate and evaluate the performances of proposed solutions:

- tensile-shear tests on lap joint specimens (**670 specs.** SW+CMT);
- tensile tests (**95 specs.)**;
- **5 full-scale beams** (2 SW + 3 CMT).

The experiments on tensile-shear tests on lap joint specimens shown:

- both the capacity and the ductility obtained for the tested specimens are very good;
- compare to similar specimens tested using self-drilling screws, the capacity of the tested specimens is double but the ductility is decreased.

CONCLUSIONS

SW: relevant tested specimens developed full button pull-out failure;
CMT: fracture in the heat affected zone.

Related to full-scale beams:

CMT

- the capacities obtained from the tested specimens are very good;
- compared to the SW solution, the results show an increased rigidity due to the stabilizing effect of the continuous welding (no distortion of the corrugation);
- Advantage: higher capacity / Disadvantage: increased time for manufacturing.

CONCLUSIONS

The results are encouraging and prove the potential of this solution to standardized beams and industrialized fabrication.

The experimental research is followed by numerical simulations (in progress), to optimize the distribution/arrangement of the spot welding connections, and by parametric studies to see the suitability of such beams to larger spans and the limits of the system.

Thank you for your attention!

ACKNOWLEDGEMENT

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