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EXPERIMENTAL INVESTIGATIONS ON SPOT WELDED BUILT-UP COLD-FORMED STEEL BEAMS

BY

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Abstract. WELLFORMED research project proposes a new technological solution for built-up beams made of corrugated steel sheets for the web and thin-walled cold-formed steel profiles for the flanges, connected by spot welding. The research integrates an extensive experimental program on small specimens subjected to shear, consisting of two or three layers of steel sheet connected by spot welding and tests on full scale beams, followed by numerical simulations to characterize and optimize the connecting details. The paper presents the results of the first part of the experimental program, *i.e.* small specimens subjected to shear.

Keywords: built-up beams; cold-formed steel sections; corrugated web; spot welding; experimental tests.

1. Introduction

Built-up steel beams, with sinusoidal or trapezoidal corrugated webs, represent a relatively new structural system that has been developed in the last

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two decades. An increased interest for this solution was noticed for the mainframe of single storey buildings and steel bridges, respectively. The main advantage of this type of element is the effect of the corrugation in stability problems, leading to increased buckling resistance, with a more economical design. In the solutions developed so far, the flanges are made of flat sheets, welded to the sinusoidal sheet for the web, involving a specific welding technology. For these elements, the flanges provide the main bending resistance, with a small contribution of the sinusoidal corrugated web that offers shearing capacity. The design of corrugated web beams is included in Annex D of EN 1993-1-5 (CEN, 2006a) together with the specific aspects covered by EN 1993-1-1 (CEN, 2005) and EN 1993-1-3 (CEN, 2006b).

A new technological solution of such a built-up beam, consisting of trapezoidal corrugated web and parallel flanges made of thin-walled cold-formed steel lipped channel sections (CWB), was developed within the CEMSIG Research Center (http://www.ct.upt.ro/en/centre/cemsig) of the Politehnica University of Timisoara, in which the connections between the flanges and the web were done by self-drilling screws. It is important to emphasize that the new solution, as a whole, is composed of cold-formed steel elements only, avoiding the combination of two types of products, namely cold-formed elements for the web and hot-rolled for the flanges. A detailed presentation of this solution, the state-of-art related to this type of element, and the different connecting technologies, was presented by Dubina *et al.* (2013, 2015).

The CEMSIG Research Center is currently carrying out the WELLFORMED research project, funded by UEFISCDI, which proposes a new connecting solution to be used for the CWB presented above, i.e. spot welding. The research project involves a large experimental program on small spot-welded specimens subjected to shear, consisting of two or three layers of steel sheet, and tests on full scale beams, to demonstrate the feasibility of the proposed solution and to assess their performances, followed by numerical simulations to optimize the connecting technique and to extend the solution by parametric studies. It is expected from this solution to cover medium spans, up to 24 m length. Also, it can be a reliable alternative to purlins or secondary beams, where these have to cover large bays.

The paper presents the results of the experimental program done on the small specimens subjected to shear, consisting of two or three layers of steel sheets, connected by spot welding.

2. Technical Solution. Details and Technologies for Connections

The proposed new solution is based on an experimental program previously developed within the CEMSIG Research Center of the PU

Timişoara, in which five corrugated web beams with flanges of back-to-back cold-formed lipped channel steel profiles were tested, having a span of 5157 mm and a height of 600 mm, with different arrangements for the self-drilling screws position and for the additional shear panels (Dubina *et al*., 2013, 2015).

The components of the standard solution are shown in Fig. 1 and are detailed on the following: (1) 2×C120/2.0 back-to-back lipped channel sections for flanges - grade S350GD+Z; (2) A45/0.7 corrugated steel sheet with a nominal thickness of 0.7 mm – grade S320GD+Z; (3) additional flat plates (830×1 mm) at the beam ends, where the shear force is maximum - grade S320GD+Z; (4) reinforcing profiles U150/2.0 under load application points - grade S350GD+Z; (5) self-drilling screws for web-to-flange connection - STP-6.3×25; (6) self-drilling screws for connecting shear plates - STP-5.5×25; (7) self-drilling screws for overlapping the corrugated webs - STT-4.8×20; (9) bolts M12 gr. 8.8 for flange to endplate connection.

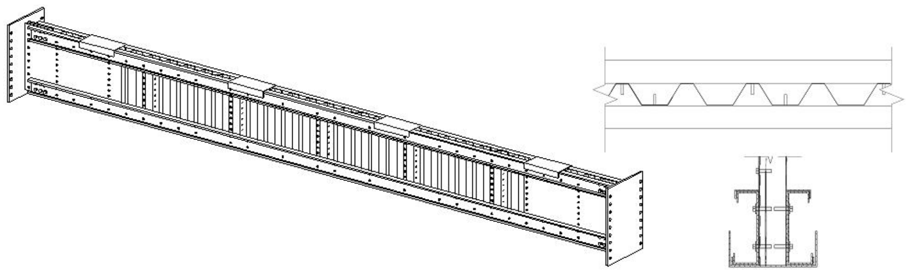


Fig. 1 − Standard solution of the CWB and specific web and flange details.

The experimental program was completed with tensile tests on specimens extracted from beam components (profiles and corrugated sheet) and tests on connections, for the different combinations of thicknesses.

Currently, within the WELLFORMED research project, the spot welding replaces self-drilling screws, reducing the workmanship and the cost of joining technology, increasing the degree of automation of fabrication of the proposed beam. Two beams with cold-formed steel profile for flanges and corrugated steel webs will be tested (see Fig. 2), having the same dimensions as those using self-drilling screws, considering different spot welding arrangements and different thicknesses for the web and for the shear panels.

In order to determine the behaviour of all types of joints used for the built-up beams, six different types of connections were investigated (see Fig. 3), *i.e.* (1) SW1 – seam fastening for the overlapping of corrugated steel sheets; (2) SW2 – seam fastening for the connection between the corrugated steel sheet and shear panels; (3) SW3 – connection between the shear panels and the flanges; (4) SW4 – connection between the shear plates and the end support; (5) SW5 – connection between the flanges and the end supports; (6) SW6 – connection between the flanges and the corrugated web. Different combinations of thicknesses (0.7 mm, 0.8 mm, 1.0 mm, 1.2 mm, 1.5 mm, 2.0 mm and 2.5 mm) have been used, resulting a total of 340 small specimens subjected to shear, consisting of two or three layers of steel sheets connected by spot welding.

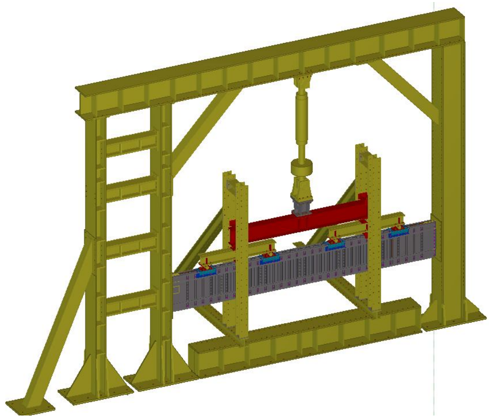


Fig. 2 − Spot-welded built-up corrugated web beam. Test setup.

Also, the mechanical properties of the CWB components have been investigated, by testing samples cut out from the same base material used to produce the components of the beam. A total number of 35 specimens have been tested according to CEN (CEN, 2009), 5 for each type of thickness.

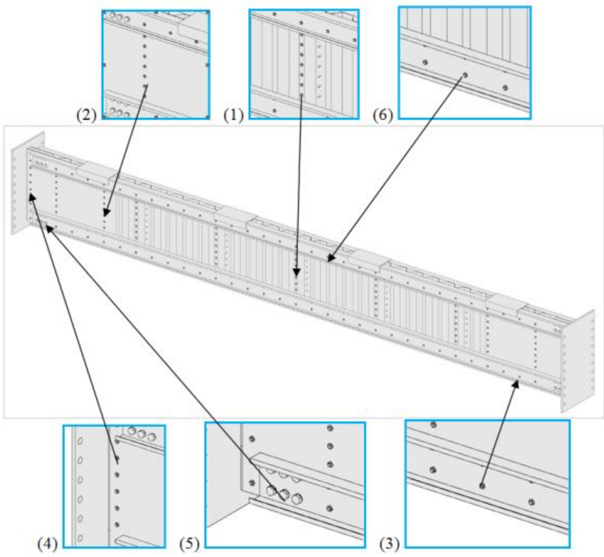


Fig. 3 − Position in the beam of welding connections.

3. Experimental Tests on Small Specimens Connected by Spot Welding

The spot welding combinations between different sheet thicknesses, experimentally tested, are shown in Table 1. The notations t_1 and t_2 represent the thicknesses of the steel sheets in the connection and d_s is the diameter of the spot-welding. As already mentioned, a total number of 340 specimens were tested. The dimensions of the specimens (see Fig. 4) were chosen in accordance with the specifications given in Chapter 8.4 of EN 1993-1-3 (CEN, 2006 b). According to Table 1 and EN 1993-1-1 (CEN, 2005), all types of connections have been tested using a single welding spot.

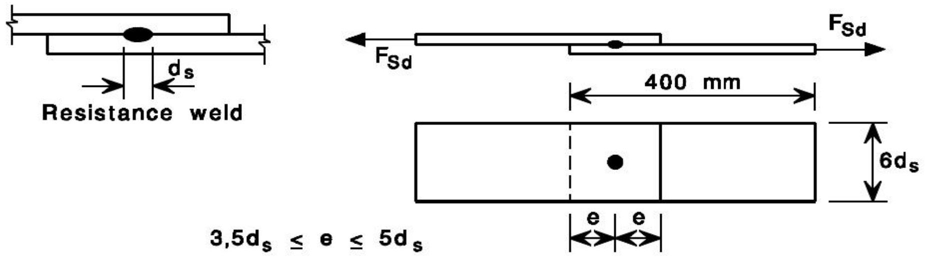


Fig. 4 − The dimensions of the specimens according to EN1993-1-3 (CEN, 2006b).

Table 1
Types of Spot Welding Connections (One Spot Welding Per Specimen)

Name	t_1 [mm]	t_2 [mm]	No of tests	d_s [mm]	Name	t_1 [mm]	t_2 [mm]	No of tests	d_s [mm]
SW-0.7-0.7	0.70	0.70	7	4.2	SW-1.0-1.0	1.00	1.00	7	5.0
SW-0.7-0.8	0.70	0.80	7	4.2	SW-1.0-1.2	1.00	1.20	7	5.0
SW-0.7-1.0	0.70	1.00	7	4.2	SW-1.0-1.5	1.00	1.50	7	5.0
SW-0.7-1.2	0.70	1.20	7	4.2	SW-1.0-2.0	1.00	2.00	7	5.0
SW-0.7-1.5	0.70	1.50	7	4.2	SW-1.0-2.0	1.00	2.50	7	5.0
SW-0.7-2.0	0.70	2.00	7	4.2	SW-1.2-1.2	1.20	1.20	7	5.5
SW-0.7-2.5	0.70	2.50	7	4.2	SW-1.2-1.5	1.20	1.50	7	5.5
SW-0.8-0.8	0.80	0.80	7	4.5	SW-1.2-2.0	1.20	2.00	7	5.5
SW-0.8-1.0	0.80	1.00	7	4.5	SW-1.2-2.5	1.20	2.50	7	5.5
SW-0.8-1.2	0.80	1.20	7	4.5	SW-1.5-1.5	1.50	1.50	7	6.1
SW-0.8-1.5	0.80	1.50	7	4.5	SW-1.5-2.0	1.50	2.00	7	6.1
SW-0.8-2.0	0.80	2.00	7	4.5	SW-1.5-2.5	1.50	2.50	7	6.1
SW-0.8-2.5	0.80	2.50	7	4.5	SW-2.0-2.0	2.00	2.00	7	7.1
					SW-2.0-2.5	2.00	2.50	7	7.1

The diameters of the welding points, d_s, was determined according to EN 1993-1-3 (CEN, 2006 b) for the case of resistance welding, *i.e.* $d_s = 5\sqrt{t}$, where t is the smallest thickness of the connected steel sheets. The possible failure modes are the full button pull-out and the interfacial fracture of the spot welding.

Experimental tests were conducted using the UTS universal testing machine. The distance between the extensometer's sensors was 80 mm. Fig. 5 shows a tested specimen with one spot welding of the SW-1.2-1.5 set, developing the full button pull-out failure.

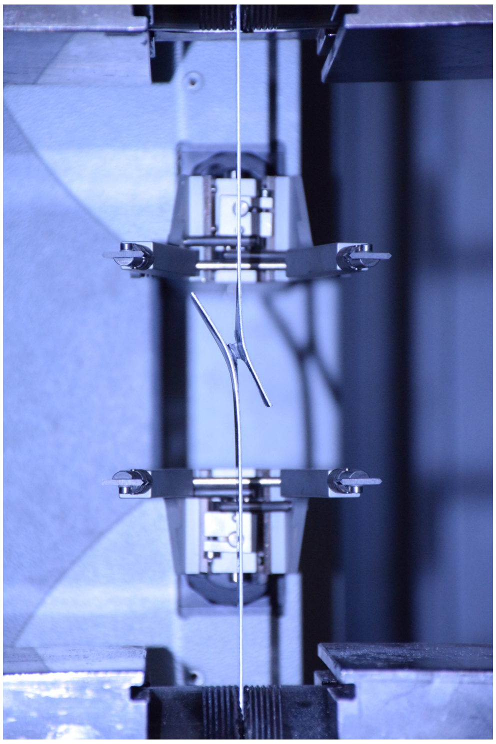


Fig. 5 – Full button pull-out failure mode.

Another important aspect of the investigation was the welding regime. The welding equipment has default factory settings counting for different thickness combinations, the so-called "SMART" setting, but also allows the possibility to use user-defined programs. Table 2 shows, as an exemplification, the parameters analysed for the set of SW-1.2-1.5 specimen. The following parameters were considered: welding current I_s (A), force between the electrodes F (daN), pressure (bar) and welding time, t_s (ms), for electrodes of 13 mm diameter and 32 mm radius of the tip.

Table 2
Welding Regimes for the Set SW-1.2-1.5

	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

Fig. 6 shows the set of six SW-1.2-1.5 specimens with the parameters shown in Table 2, before and after testing. It can be noticed that in all cases the failure mode was the full button pull-out. Fig. 7 depicts the comparison of the force-displacement curves for the specimen set above. It can be seen that the specimens have very good capacity and ductility, the maximum recorded force exceeding 12 kN.

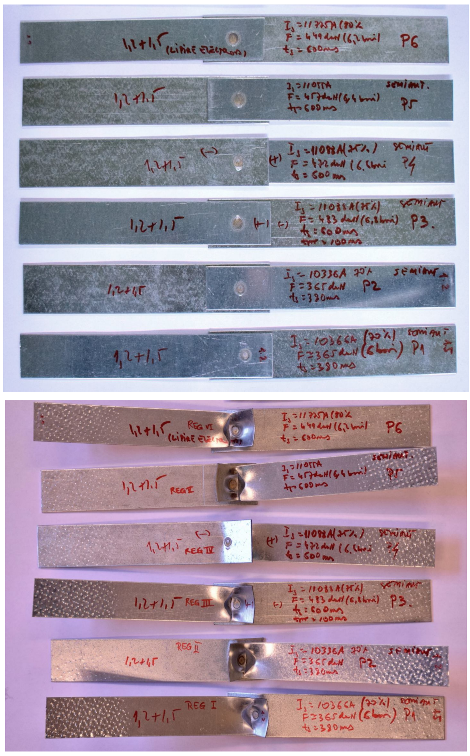


Fig. 6 − Specimens SW-1.2-1.5 before and after testing, using different welding regimes.

Based on the tests performed on all the specimens presented in Table 1, the following general conclusion can be drawn, i.e. both the capacity and the ductility obtained for the tested specimens are very good. Moreover, compared to the same specimens tested using self-drilling screws, the capacity of the tested specimens is double but the ductility is decreased.

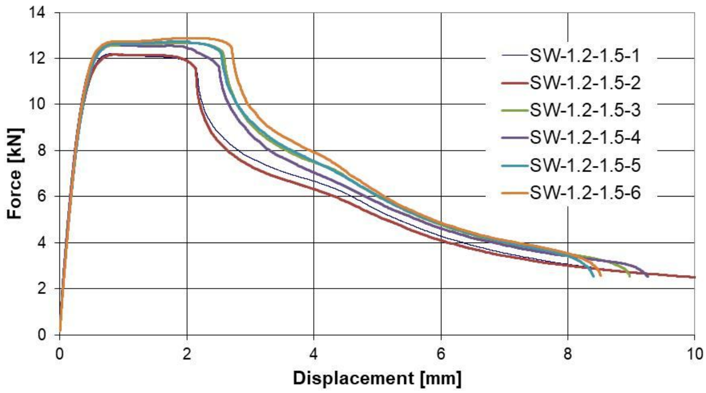


Fig. 7 – Force-displacement curves for SW-1.2-1.5 specimens (one spot weld).

4. Numerical Simulations

The numerical model applied to simulate the behaviour of the corrugated web beams, that will be tested experimentally, have been created using the commercial FE program ABAQUS/CAE v. 6.14.

Rectangular 4-noded shell elements with reduced integration (S4R) were used to model the thin-walled components. CONN3D2 element types, with 2 nodes and 6 DOF per node, have been used to model the self-drilling screws and bolts. RB3D2 elements were used as rigid body for load transfer and multi-point constrain beam (MPC-Beam) for DOF coupling between groups of specified nodes.

The material behaviour used for numerical modelling was in accordance with the recorded curves from tensile tests taken from the same base material used to produce the components of the beam. The spot welding and the bolts were introduced using CONN3D2 element type according to the mean values recorded from tests of each type of connection. General contact with the following parameters have been used, *i.e.* (1) normal direction – hard contact; (2) transversal direction – a friction coefficient of $\mu = 0.1$.

Finally, initial imperfections according to first 3 eigen modes from a linear bucking analysis have been used.

Fig. 8 presents the FEM load-displacement curves for the beam CWB having the following components: (1) 2×C120/2.0 back-to-back lipped channel sections for flanges - grade S350GD+Z; (2) CW60 corrugated steel sheet with the height of the corrugation of 60 mm and nominal thickness of 1.2 mm for the first and last panel of the web and 0.8 mm for the rest of the panels- grade S320GD+Z; (3) additional flat plates (600 × 1 mm) at the beam ends, where the shear force is maximum - grade S320GD+Z; (4) reinforcing profiles U150/2.0 under load application points -grade S350GD+Z; (5) spot welding for the web-to-flange connection, shear plates and for overlapping the corrugated webs; (6) bolts M12 gr. 8.8 for flange to endplate connection.

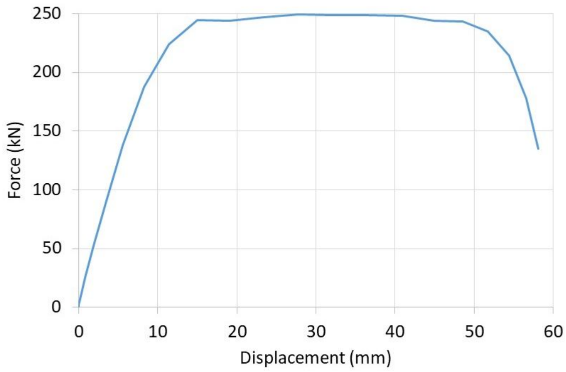
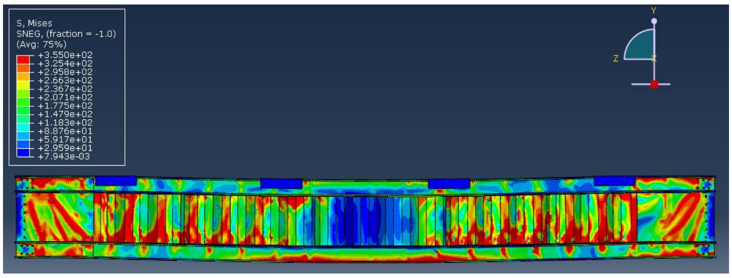
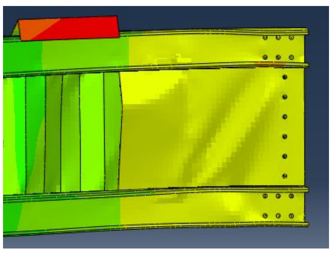


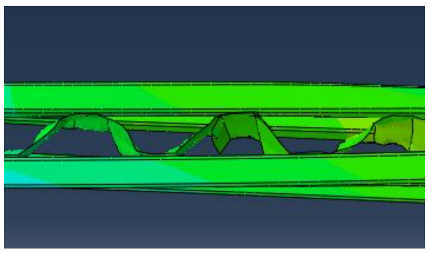
Fig. 8 − Force-displacement curves for the CWB specimens.



a



b



c

Fig. 9 – Stress distribution and deformation for the CWB: *a* – general view; *b* – buckling of the shear panel; *c* – distortion of corrugations.

5. Conclusions

Within the WELLFORMED research project, carried out at the CEMSIG Research Center of the Politehnica University of Timisoara, a new experimental program was started on built-up cold-formed steel beams, made of corrugated webs and back-to-back lipped channel profiles for flanges, connected by spot welding.

The paper presents the experimental results on small specimens subjected to shear, consisting of two or three layers of steel sheets, connected by spot welding, in order to characterize the behaviour of these joints.

The experiments 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;

all tested specimens developed full button pull-out failure.

Ongoing activities are carried out for two full-scale beam specimens to be tested in order to demonstrate the feasibility of the proposed solution and to evaluate their performance. The experimental research will be followed by numerical simulations to optimize the distribution/arrangement of the connections and parametric studies to see the limits of the system.

The results are encouraging and demonstrate the potential of this solution for standardization and industrial manufacturing.

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INVESTIGAȚII EXPERIMENTALE PE GRINZI METALICE COMPUSE DIN PROFILE FORMATE LA RECE ÎMBINATE PRIN SUDURĂ ÎN PUNCTE REALIZATE

(Rezumat)

În cadrul proiectului de cercetare WELLFORMED, derulat prin Centrul de Excelență CEMSIG al Universității Politehnica Timişoara, s-a propus o nouă soluție tehnologică pentru grinzi de oțel formate la rece cu secțiune compusă realizate cu inimă din tablă cutată şi tălpi din profile cu pereți subțiri formate la rece, îmbinate prin sudură în puncte. Proiectul de cercetare integrează un amplu program experimental pe astfel de grinzi la scară reală, pentru a demonstra fezabilitatea soluțiilor propuse şi evaluarea performanțelor acestora, urmat de simulări numerice în scopul caracterizării şi optimizării detaliilor de îmbinare. Lucrarea de față prezintă rezultatele unui amplu program experimental, pe specimene mici, supuse la forfecare, formate din două sau trei straturi de tablă din oțel şi îmbinate prin sudură în puncte.