COLUMN BEHAVIOUR OF AUSTENITIC STEEL HOLLOW SECTIONS

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Summary

Austenitic steels are the most common grade of stainless steels which supply structure with very good corrosion resistance. Despite the high initial material cost they are becoming widely used in conventional structures for their sustainability, various benefits and emergence of new design codes. The paper describes experimental investigation of residual stresses in hollow sections made from austenitic steel 1.4301. The residual stresses produced by forming and welding process were investigated by X-ray diffraction method for subsequent inclusion into numerical FEM model. Other important characteristics such as nonlinear stress-strain relationships and imperfections were also included. The model was verified on test results of a stub column. Subsequently experimental investigations of a set of stub columns were performed and the results are discussed. Finally results important for design are presented.

Keywords: Stainless steel, hollow sections, stub column test, residual stresses, imperfections, numerical modelling

1 Introduction

Carbon steel is recyclable traditional building material with high utility properties. Recently stainless steels are becoming used as load carrying construction material because of superior corrosion resistance and attractive surface finish together with excellent strength to weight ratio. These steels, despite a higher material cost, may lead to lower-cost constructions provided all life cycle of the structures is taken into account. Stainless steel structures in total have low energetic requirements, the basic assumption of sustainable development.

The most common stainless steel grade for structural applications is 1.4301 austenitic steel which is therefore used in this study as a material of cold-formed hollow sections with longitudinal weld, typical stainless steel structural elements. In last decades intensive research was performed describing significant behaviour differences and dissimilarities of stainless steels in comparison with common carbon ones, such as non-linear and asymmetric stress-strain diagram, anisotropy of stainless steels, increase of yield proof and collapse strengths due to cold-working process, influence of initial imperfections and residual stresses, etc. (see [1], [2]).

2 Residual stresses in RHS

Important part of this study covers experimental analysis of residual stresses in RHS 100×80×2 [mm] made of austenitic steel 1.4301. The X-ray diffraction method was used, based on measuring of change of distance of crystalline planes of the material and using Brag's law. In result the average elastic strain at specimen surface up to several μm depth was obtained. Combination of this method with electrolytic removing technique which didn't affect the residual stresses enabled through-thickness gradient measurement. Hence not only the surface flexural and membrane components of the stresses were measured, but complex through-thickness residual stress pattern was received.

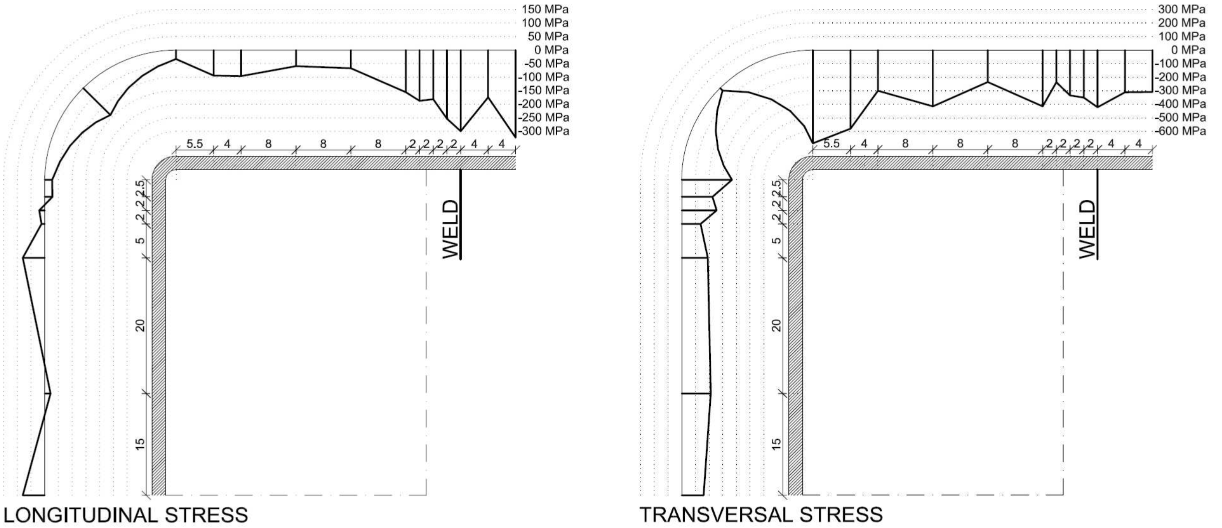

Fig. 1 Surface residual stresses in both directions for RHS 100×80×2 [mm]

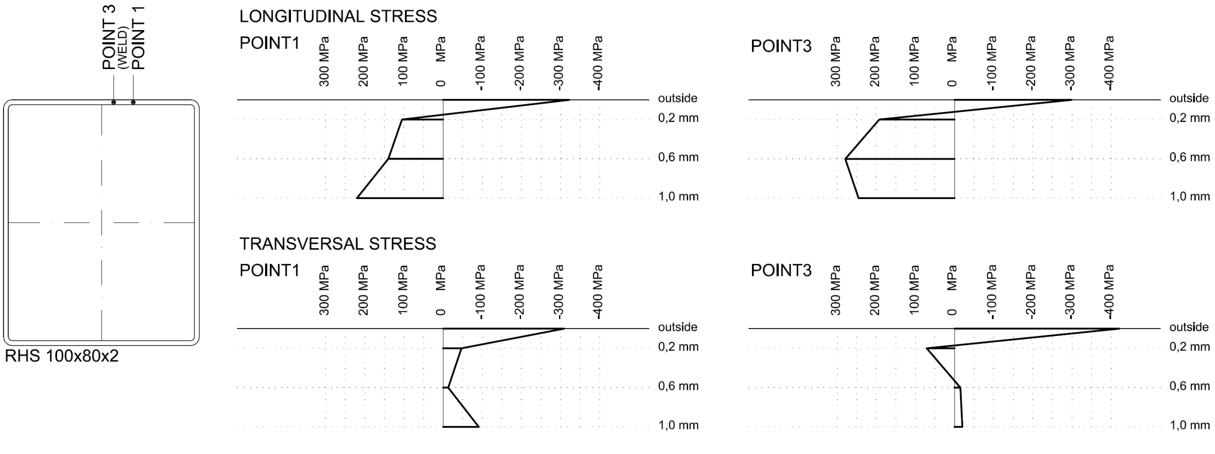

Fig. 2 Through thickness residual stress gradient in weld area

Results of the measurements in the outer surface layer of a quarter of specimen are presented on **Fig. 1**. Residual stresses in both longitudinal and transversal directions with respect to specimen axis were measured. The through-thickness gradients were measured in ten positions and within half of a web-thickness, but only two of them, in the weld area, gave successful results (**Fig. 2**). Other measurements didn't show a good diffraction pattern due to large grains of austenitic structure under the surface of material, even despite of 10 mm oscillation of irradiating X-ray beam. More information is given in [3].

The through thickness residual stress gradient in point 3 situated in the centre of the longitudinal weld showed average longitudinal tension stress within the half of web thickness of about 170 MPa. The point 1 located at distance of $4t_w$ from the centre of the weld showed average tension stress on the measured part of thickness of about 120 MPa. Therefore, tension area in vicinity of the weld is much larger than commonly regarded in mild carbon steel. Tension residual stresses inside the thickness of the web are partly compensated with surface compression stresses in both locations. Outside of the weld area the surface longitudinal residual stresses are moderate and in web without weld even change the sign.

In addition to X-ray diffraction method also destructive sectioning method for residual stress evaluation is under way. A width of each stripe in the sectioning method is 20 mm, which together with 10×5 mm measuring grid for strain-gauges placed on both sides of a stripe and slow and coiled cutting leads to reasonable accuracy of results excluding annealing effects. However, the strong gradient of stresses is not possible to measure. The results will be published later.

3 Stub column tests

A large testing programme of 11 SHS stub columns was carried out (one of them annealed). Web of the specimens ranged from 60 to 100 mm with thickness 2, 3 and 4 mm. The length of each column was equal to three-times the web width to exclude global buckling.

Tab. 1 Stub column tests

Specimen	Length [mm]	Depth [mm]	Breath [mm]	Thickness [mm]	Outer corner radius [mm]	Area [mm^2]	Ultimate load F_u [kN]	End shortening at F_u [mm]
SHS 60×60×2A	180	60.06	60.14	2.22	2.21	528	274	2.32
SHS 60×60×2B	180	60.07	60.10	2.11	2.25	506	260	1.60
SHS 80×80×2A	240	79.86	79.92	1.86	2.55	598	222	0.90
SHS 80×80×2B	240	79.76	80.04	1.82	2.40	585	202	1.01
SHS 80×80×4A	240	80.28	80.41	3.88	6.03	1285	750	5.18
SHS 80×80×4B	240	80.17	80.42	3.80	5.98	1260	725	3.47
SHS 100×100×3A	300	99.91	100.00	2.71	4.44	1105	576	1.89
SHS 100×100×3B	300	99.91	100.10	3.00	4.47	1219	550	1.64
SHS 100×100×3C*	300	99.98	100.11	3.08	4.30	1249	548	-
SHS 100×100×4A	300	99.86	99.92	3.69	5.20	1498	801	2.99
SHS 100×100×4B	300	99.86	99.92	3.69	5.20	1498	798	3.14

* Annealing process could cause decrease of yield and proof strength of cold-worked material

The tests were governed by force-control hydraulic jack with strain stabilisation for several load levels to get dynamic free response results. The values received from the testing are presented in **Tab. 1** and **Fig. 3** (see also **Fig. 5**). The dashed parts of diagrams show the non-stabilised, rather inaccurate parts of the relationships. The end shortenings of tested specimens were recorded by three inductive gauges and the strain in corners by strain-gauges glued in each corner of relevant section.

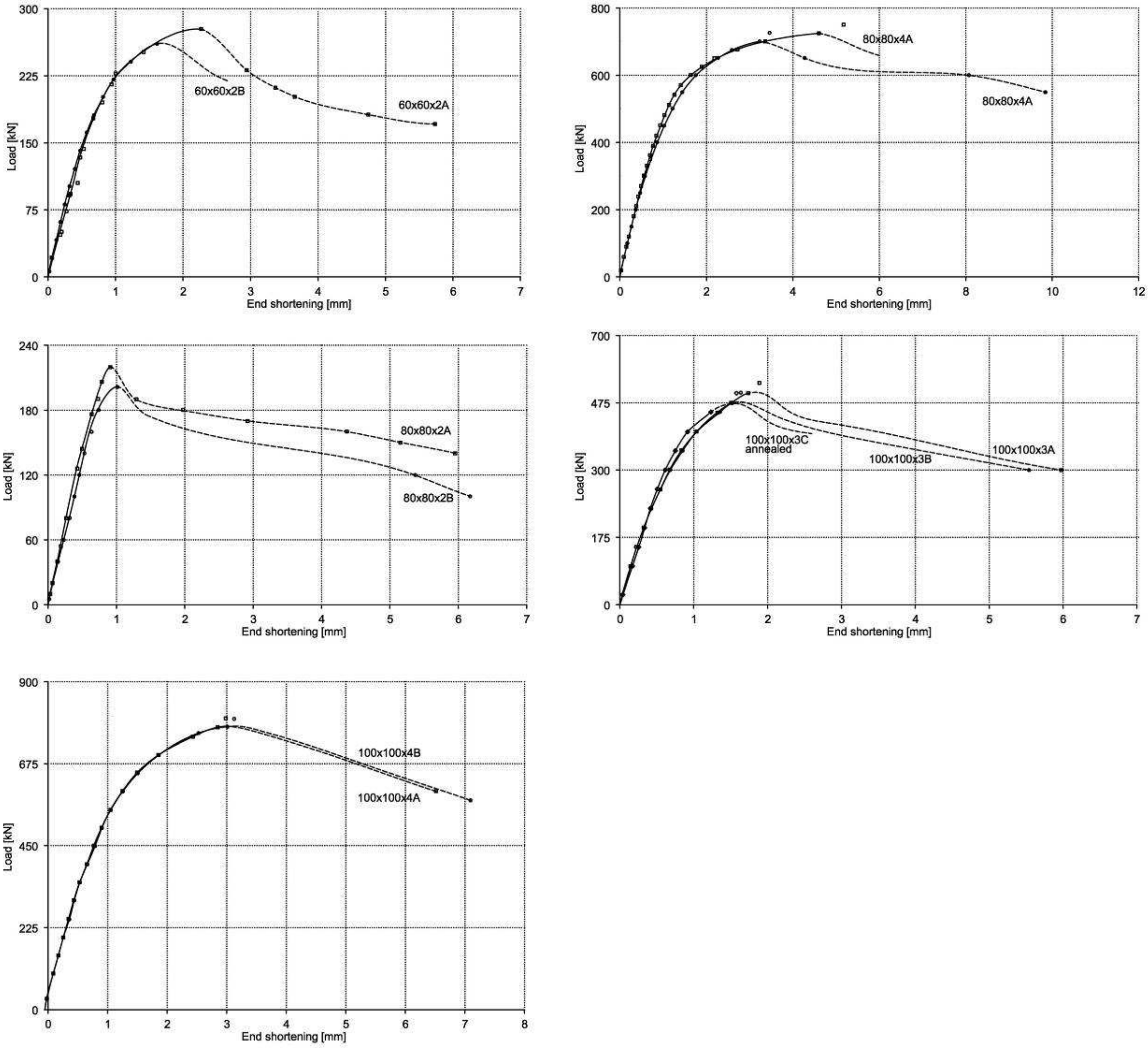

Fig. 3 Load-shortening stub column relationships

4 Initial deflections

Initial deflections are the most important imperfections and were measured for all tested specimens in all webs. Typical shape of the initial deflections is shown in **Fig. 4**, being similar for all section faces. The highest value is usually near the ends of a specimen and on the face with the longitudinal welding. This fact is probably caused by relaxed bending part of residual stresses.

In numerical studies the use of measured (true) initial deflections is rare. Usually the analytic linear elastic eigenmodes are used instead. Based on intensive numerical study the most suitable approach proved to be the shape of the first eigenmode with amplitudes taken as the maximum deviation from the line connecting two points of measured imperfections in a distance equal to web width excluding the parts near the column supports. The approach using maximum measured amplitude showed to be as too conservative [4].

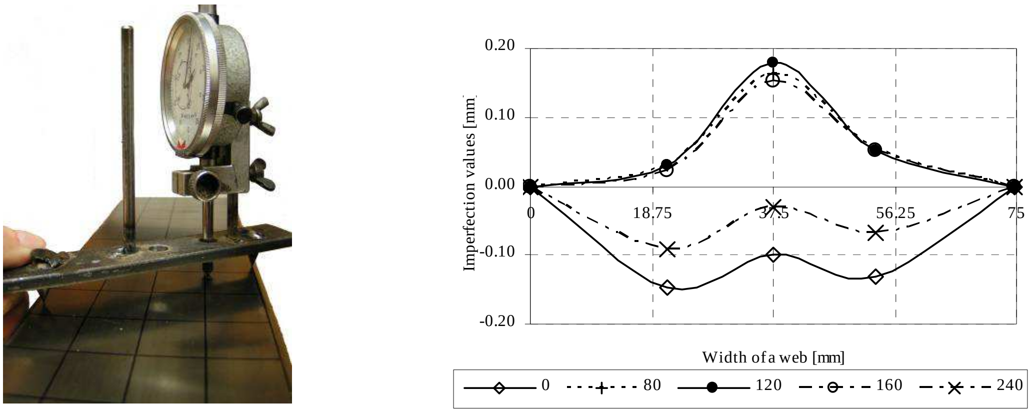

Fig. 4 Measuring of imperfections (left) and initial deflection along width of SHS 80x80x2A, face perpendicular to the one with welding (right)

5 Numerical analysis

The numerical geometrically and materially non-linear model including imperfections (GMNIA) using ABAQUS software package was prepared and verified on other tests, see Fig. 5. The presented GMNIA cover results considering residual free specimen, flexural only and flexural and membrane residual patterns due to [1]. Analysis of above tests is in progress and results will be presented at the conference.

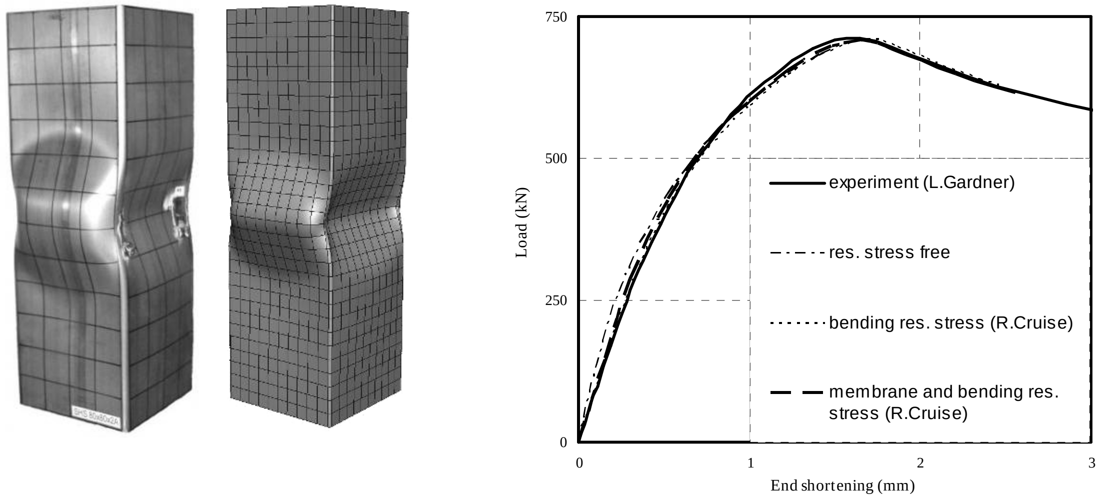

Fig. 5 Experimental (left) and numerical (right) shapes of deflections. Comparison of GMNIA with test by Gardner [5] using residual stress measured by Cruise [1]

For modelling of thin-walled cross sections the second order thin-shell element S9R4 with reduced integration and five degrees of freedom for each node was used. These elements are suitable for modelling of very thin plates with thickness-to-span ratio lower than 1/15, where the transverse shear strains are assumed to vanish [5]. This is fulfilled for all the tested specimens and was also numerically verified. Because of the second order character of the element, S9R5 don't lead to hourglassing which may occur to reduced integration elements and is in general computational-timesaving. It was chosen after testing several shell elements and mesh-sensitivity analysis.

6 Conclusion

Investigation of hollow structural elements made of austenitic steels which are becoming common in building industry due to high sustainable development potential was described. Initial imperfections important for design of such elements in compression were examined. X-ray diffraction method was used for detection of residual stresses due to cold forming and welding of the SHS/RHS elements. Results show pattern and magnitude of membrane and flexural residual strains, which proved to give large tension area in weld vicinity and with average magnitude of membrane residual stress much beyond 0.2 % proof stress. Residual stresses at thin layer of outer surface of the specimen are in compression.

Results of experimental investigation of stub columns from stainless steel SHS, their initial deflections and full load-shortening relationships are presented. Finally modelling and GMNIA of the columns is described. The preliminary results show insignificant influence of residual stresses in the tested specimens.

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