27/28th International Conference
**ENGINEERING MECHANICS 2022**
Milovy, Czech Republic, May 9 –12, 2022
Paper **#81**, pp. 97–100, doi: 10.21495/51-2-97

# LASER-WELDED I-SECTIONS STAINLESS STEEL BEAM-COLUMNS

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**Abstract:** *The use of stainless steel for structural purposes has recently generated great interest due to its excellent corrosion resistance, ease of maintenance and attractive surface finish. Therefore, as demand increases, the range of structural products is growing and new manufacturing processes and design procedures for this material are being developed. Currently, there is very little experimental data on laser-welded stainless steel members and their design is not included in current design standards. Therefore, the torsional behaviour and resistance of laser-welded I-section members loaded by combined compression and major-axis bending have been investigated in the present study through physical laboratory experiments and numerical modelling. The experimental programme adopted seven beam-columns specimens made of austenitic stainless steel grade EN 1.4301 (AISIS 403L) including initial geometric imperfection measurements and tensile material tests. The test results were subsequently used for validation of a finite element model, developed in ABAQUS software to replicate the beam-column behaviour. The accuracy of the models was evaluated by comparison with the test results.*

**Keywords: Laser-welding, Stainless steel, Numerical modelling, Beam-columns, I-sections.**

## 1. Introduction

Stainless steel is characterized by its good resistance to corrosion in combination with very favourable mechanical properties, such as high ductility and strain hardening. In addition, the use of stainless steel leads to a significant reduction in the cost of surface treatment of individual structural elements and maintenance of the entire structure during its lifetime. However, acquisition costs can be up to 3 times higher than for carbon steel structures. With the increasing demand for structural stainless steel, manufacturers have begun with developing new technologies to produce materials and profiles. In the last decade, stainless steel sections started using laser-welding in their production achieving a higher degree of automation, higher production speeds, quality, and precision. Laser-welding is a fabrication method that uses lasers to locally melt and fuse together metallic elements, i.e., welding without adding filler material. As a result of this welding, there is minimal heat input and therefore fewer residual stresses. Compared to traditional arc welding, laser-welding enables the heat input to be kept to a minimum and thus leads to lower thermal distortions and residual stresses (Bu and Gardner, 2019).

Due to the relative novelty of the use of laser-welded profiles for construction purposes, so far, few experimental and numerical studies have been carried out. Recently, in order to investigate the structural response of laser-welded stainless steel I-section members, experimental and numerical research has been performed, including stub-column and flexural buckling tests (Gardner et al., 2016), bending tests on laterally restrained beams (Bu and Gardner, 2018), laterally-restrained beam-columns (Bu and Gardner, 2019) and beam-columns susceptible to flexural-torsional buckling (Kucukler et al., 2020). Based on the obtained results, the design provisions of Eurocode (EN 1993-1-4, 2006) was found to be safely applicable to the design of laser-welded stainless steel cross-sections but it is overly conservative in the stocky range. Previous research on the behaviour of conventional welded austenitic stainless steel I-section beam-columns has been reported including physical experiment results, finite element (FE) modelling and material tests (Feber and Jandera, 2020). Despite the increasing interest in structural stainless steel, there is still a lack of experimental and numerical data. Thus, the objective of this paper is to study the behaviour of the laser-welded austenitic stainless steel beam-column loaded by compression and major axis bending.

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## 2. Experimental program

To investigate the behaviour of laser-welded stainless steel I-section beam-columns loaded by axial force and bending moment, exhibiting the major axis flexural buckling failure mode an experimental study was carried out. The testing programme comprised of testing beam-columns, measuring geometric properties and initial geometric (local and global) imperfections and material coupon tests. The tests were performed in the laboratory of the Czech Technical University in Prague using a 650 kN hydraulic jack. Two cross-section sizes I-96 × 100 × 5 × 8 and I-100 × 100 × 6 × 10 were considered (labelled here as CR01 and CR02 respectively and designated as follows: I- section height $h$ × section width $b_f$ × web thickness $t_w$ × flange thickness $t_f$) in grade 1.4301 austenitic stainless steel.

Tensile coupon tests were performed to determine the actual mechanical properties of the material from which the specimens were fabricated. Three tensile test specimens were fabricated and subsequently tested from the web and flanges of each cross-section. Two strain gauges and one mechanical extensometer were used to measure the relative strain. A summary of the key measured properties is given in Tab. 1, where $t$ is the nominal plate thickness, $E_0$ is the initial elastic modulus, $\sigma_{0.2}$ the yield stress at 0.2% plastic strain, $\sigma_{1.0}$ the stress at 1.0% plastic strain, and $\sigma_u$ the ultimate stress, $\varepsilon_u$ is the strain at ultimate stress, $n$ and $n_{0.2,1.0}$ are measures of the degree of nonlinearity of the material response.

*Tab. 1: Measured tensile material properties.*

| Specimen | $t$ [mm] | $E_0$ [MPa] | $\sigma_{0.2}$ [MPa] | $\sigma_{1.0}$ [MPa] | $\sigma_u$ [MPa] | $\varepsilon_u$ [-] | $n$ [-] | $n'_{0.2;1.0}$ [-] |
|---|---|---|---|---|---|---|---|---|
| CR01-web | 5 | 163 743 | 321.67 | 399.40 | 696.51 | 0.72 | 5.5 | 2.9 |
| CR01-flange | 8 | 175 967 | 292.09 | 351.02 | 682.97 | 0.75 | 6.6 | 2.3 |
| CR02-web | 6 | 164 652 | 329.40 | 402.10 | 686.51 | 0.73 | 5.2 | 2.8 |
| CR02-flange | 10 | 172 218 | 296.29 | 353.83 | 688.70 | 0.74 | 7.2 | 2.3 |

All structural steel sections exhibit a number of initial imperfections resulting from the manufacturing process. Geometric imperfections could significantly affect the stability of beam-columns. As an effect of laser welding, lower temperatures are introduced into the material comparing to arc-welding, therefore the initial imperfections in laser welded profiles are usually smaller. The geometry imperfections of each specimen is determined using laser scanning. This method allows the actual shape of the sample surface to be scanned and then the deviations from the 'ideal' plane to be subtracted.

Before the beam-columns were tested, 15 mm thick end plates were welded to both ends of each specimen and then the geometry and imperfections of each specimen were carefully measured. The end plates were connected to the knife-edge supports, which allowed to achieve pinned end conditions about the major axis and fixed end conditions about the minor axis. By means of long oval holes in the supports, it was possible to adjust the test specimen position to achieve the required initial loading eccentricity and thus ensure the required bending moment. Lateral deflections were prevented using circular tubes spread between the columns of the test frame, which can be seen in Fig. 1. Plastic tubes were used between the specimen and the lateral supports to minimize friction and to allow free movement in the bending direction. During each experiment, the applied load, the deflection of the column in both directions and strains in the middle of the column and near the end plates were recorded. The failure modes observed in the specimens were overall flexural buckling in the major axis direction. This means that the lateral supports were effective.

## 3. Numerical modelling and validations

To complement the experimental study, numerical models were developed using the finite element software Abaqus (ABAQUS, 2014). The local and global imperfections were introduced through the corresponding eigenmodes from buckling analysis, and their amplitudes were introduced by the value measured on each specimen. In addition, residual stresses caused by the manufacturing process (welding) were also considered in the models following the procedure for laser-welded I-sections (Gardner et al., 2016). Validation of the numerical models was performed by comparing the applying force versus in-plane displacement at mid-height of physical laboratory tests with corresponding FE model data, as shown in Fig. 2.

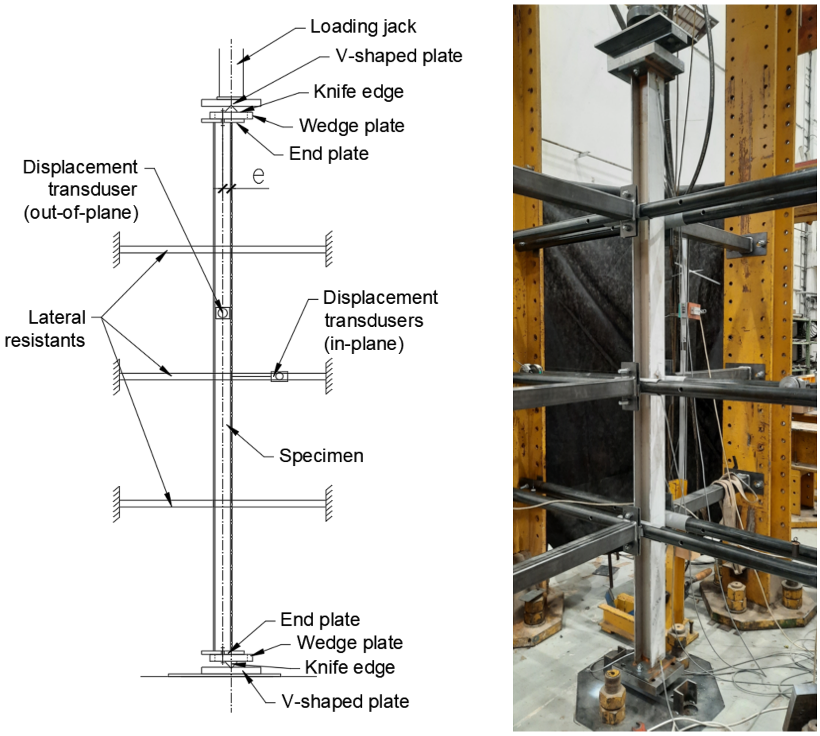


*Fig. 1: Test set-up.*

A complete list of the tested specimens is given in Tab. 2, including the specimen length ($L$), the eccentricity of the applied force ($e$), the measured global ($w_g$) and local ($w_l$) initial imperfections, the ultimate capacity from experiments ($F_{EXP}$) and from the numerical study ($F_{FEM}$). The accuracy of the beam-column FE models with nonlinear material properties and combinations of local and global imperfection was evaluated through the ratio of numerical to experimental ultimate loads ($F_{FEM}$/ $F_{EXP}$). The ratio of $F_{FEM}$/ $F_{EXP}$ less than 1 indicates the safe side of strength prediction. Overall, the results from the numerical study are in good agreement with the experimental results, proving that the developed FE model is capable of accurately estimating the ultimate load-carrying capacities of the stainless steel members.

*Tab. 2: Comparisons of ultimate load obtained from experiments and FE simulations.*

| **ID** | **Cross-section** **I-$h \times b_f \times t_w \times t_f$** | **$L$ [mm]** | **$e$ [mm]** | **$w_g$ [mm]** | **$w_l$ [mm]** | **$F_{EXP}$ [kN]** | **$F_{FEM}$ [kN]** | **$F_{FEM}/F_{EXP}$ [-]** |
|---|---|---|---|---|---|---|---|---|
| CR01-a | I-96 × 100 × 5 × 8 | 3529 | 10 | 0.55 | 0.07 | 272.62 | 249.16 | 0.914 |
| CR01-b | I-96 × 100 × 5 × 8 | 3492 | 50 | 0.86 | 0.14 | 168.19 | 157.72 | 0.938 |
| CR01-c | I-96 × 100 × 5 × 8 | 2688 | 10 | 0.88 | 0.11 | 350.45 | 312.37 | 0.891 |
| CR01-d | I-96 × 100 × 5 × 8 | 2689 | 50 | 0.59 | 0.13 | 201.54 | 191.60 | 0.951 |
| CR02-b | I-100 × 100 × 6 × 10 | 3528 | 50 | 1.06 | 0.06 | 209.57 | 199.62 | 0.953 |
| CR02-c | I-100 × 100 × 6 × 10 | 2690 | 10 | 0.77 | 0.09 | 405.71 | 403.22 | 0.994 |
| CR02-d | I-100 × 100 × 6 × 10 | 2689 | 50 | 0.52 | 0.09 | 249.42 | 246.86 | 0.990 |
| Mean | | | | | | | | 0.947 |
| COV | | | | | | | | 0.036 |

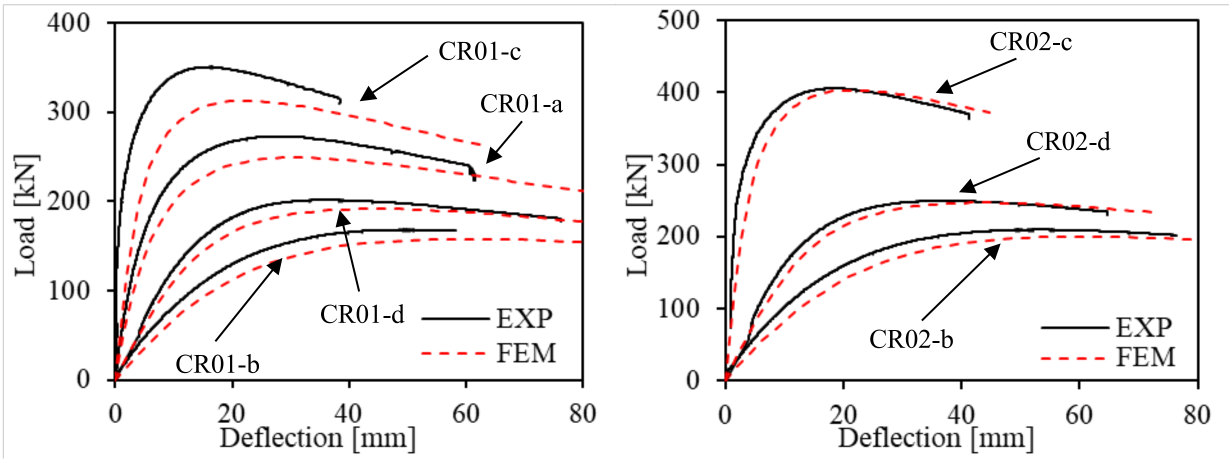


*Fig. 2: Comparison of FE model and test: load versus mid-height displacement.*

## 4. Conclusions

The experimental and numerical modelling programmes have been performed to investigate the structural performance of austenitic stainless steel I-section beam-columns. Initially, seven laboratory tests were carried out on laser-welded beam-columns subjected to combined compression and major-axis bending. A detailed description of the test setup, experimental procedure and test results including tensile coupon tests has been presented herein. Finite element model of austenitic stainless steel I-section beam-columns with nonlinear material properties and combinations of initial geometric imperfections was created and validated against the obtained experimental results. The observed failure modes from the experiments corresponded with the ones predicted by the numerical models. The models showed a very good agreement when compared to the experiment results with the mean ratio $F_{FEM}/ F_{EXP}$ 0.947 and coefficient of variation (COV) 0.036. This comparison showed that the developed numerical model represents the behaviour of the column accurately enough and therefore it can be used for the following parametric study.

## Acknowledgement

This study is supported by the Czech Science Foundation project: Global analysis methods for slender structures of stainless steels and other steels with nonlinear stress-strain diagram (GACR 20-24563S). The financial support is gratefully acknowledged.

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