The Institution of Structural Engineers

Structural performance of aluminium members with optimised cross-sectional properties

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Introduction

The use of aluminium within the civil engineering industry has increased significantly due to industrial and technological developments and properties of the material itself such as its:

- Low density – which reduces foundation loads, allows for faster erection time and reduces costs associated with the transport of members to site.
- High recyclability – thus sustainable.

The extent of use of aluminium as a structural building material is limited due to its low elastic modulus which creates strength and stability issues.

These issues can be overcome through an appropriate design of the cross-sections (i.e. provide sections with an increased weight to stiffness ratio):

- Using structural topology optimisation techniques, sections with improved weight-to-stiffness ratios can be produced.
- With the power of 3D printing, any kind of optimised shape can be produced.

Aims and Objectives

This study investigates the performance of recently developed optimised aluminium beam and column members designed through an advanced structural topology optimisation technique to:

- Improve the manufacturability of the most optimum cross-section; and
- Investigate its compression behaviour while evaluating the applicability of Eurocode 9 (EC9) – the aluminium design codes – for the design of the newly developed optimised section.

Impacts of the project

- Encourage the use of novel design tools such as topology optimisation to develop non-standard but efficient members.
- This project provides one potential solution to the problem of more structurally efficient sections.
- Further develop work with the aim to make an impact on design guidelines and specifications.

Additive Manufacturing (3D Printing)

3D printing allows for the rapid and repeatable production of prototypes with complex geometries.

Other benefits are the:

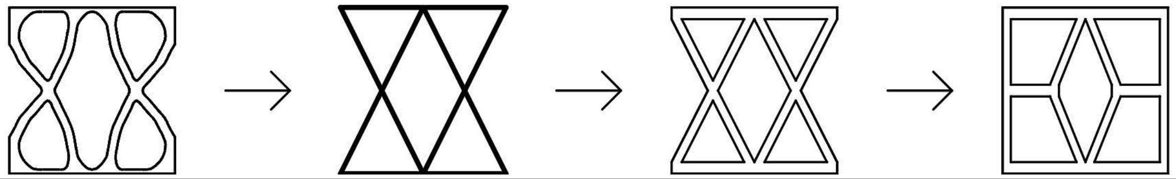
- Production of bespoke structural elements;
- Reduction of waste, time and increased material savings;
- Facilitation of easier integration of members into Building Information Modelling (BIM); and
- Easier integration of design changes.

Key References:

1. Grekavicius, L., Hughes, J.A., Tsavdaridis, K.D. and Efthymiou, E. 2016. Novel Morphologies of Aluminium Cross-Sections through Structural Topology Optimization Techniques. *Key Engineering Materials*. **710**, pp.321–326.
2. Tsavdaridis, K.D., Hughes, J.A., Grekavicius, L. and Efthymiou, E. 2017. Novel Optimised Structural Aluminium Cross-Sections Towards 3D Printing. *In: Meboldt M., Klahn C. (eds) Industrializing Additive Manufacturing - Proceedings of Additive Manufacturing in Products and Applications (AMPA 2017)*. AMPA 2017. Springer, Cham, pp.34-46

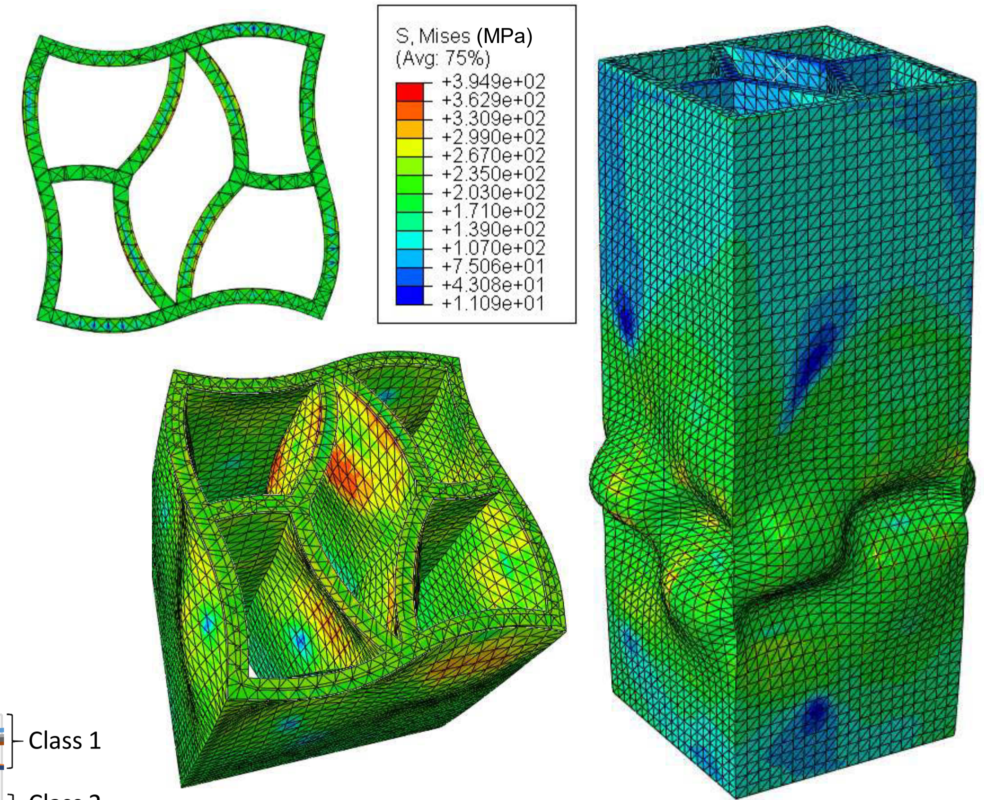
Morphogenesis Process

- A rather complex optimised shape was previously proposed by the same team at the University of Leeds [1,2], as an outcome of an intensive structural topology optimisation study. The aim herein is to simply the geometry of the previously proposed section – see below left, through an incremental morphogenesis process.
- A 5-15% increase in performance was obtained with the modified section when compared to the original optimised section under the criteria: second moment of area, radius of gyration and stub-column compressive capacity.
- A 5-7% increase in stub-column compressive capacity was obtained when comparing the newly modified section to standard sections with similar cross-sectional area.



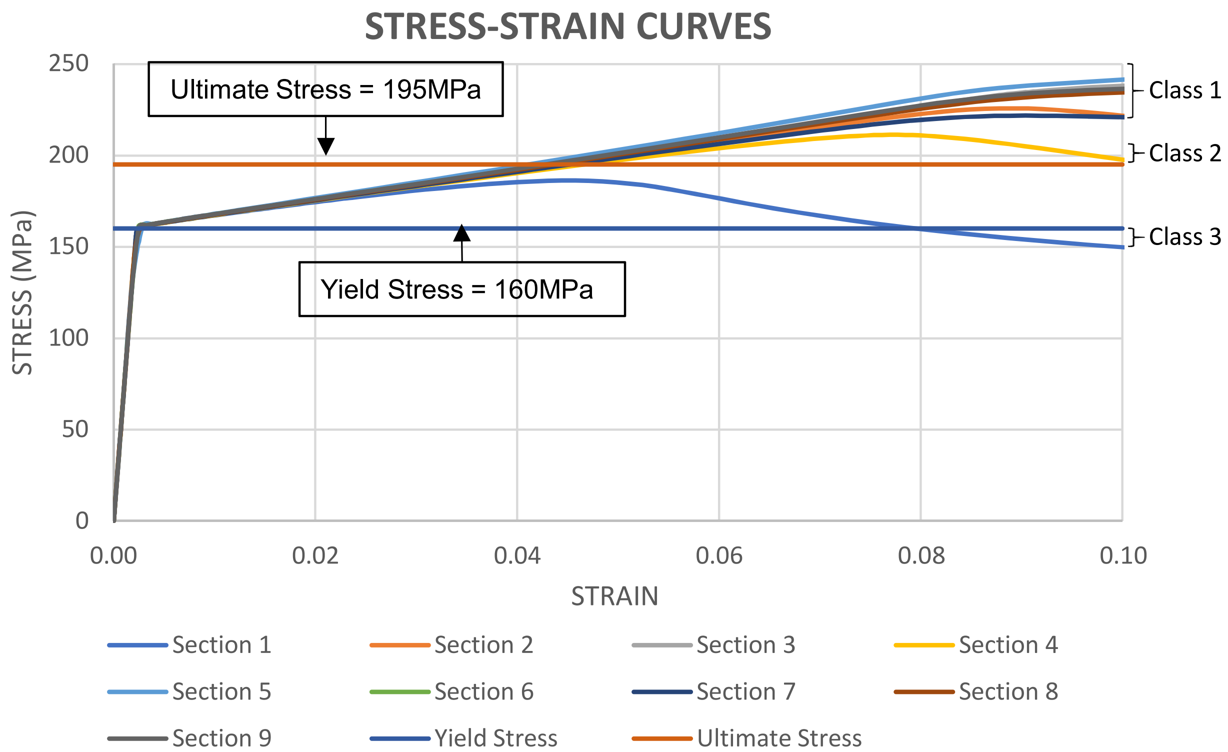
Parametric Finite Element Modelling (FEM)

- The aluminium alloy 6063-T6 was used due to its widespread use in structural engineering.
- A fixed-end stub column test setup was used to ensure uniform compression.
- Nine (9No.) models were tested with a 5mm to 10mm range of thicknesses.
- The thicknesses were chosen to provide a range of section classes under EC9 definition of section classification (see 'EC9 class' in bottom right table).
- Non-linearity, i.e. material and geometric imperfections were also included.
- The FE model was validated using results from the literature.



Results

- The failure mode of most of the sections tested was local buckling of the form seen in the FEM images on the right.
- EC9 is conservative when predicting the behaviour of the optimised sections under compression. This was due to the conservative outstand element class limits.
- The EC9 outstand element class limit was doubled for the Class 1 limit and increased by 44% and 15% for the Class 2 and 3 limits respectively.
- This provided section behaviour classes similar to that found in the FEM results (see 'Modified EC9 Class' in bottom right table).



Section No.	Initial EC9 Class	Modified EC9 Class	FEM Class
1	Class 4	Class 3	Class 3
2	Class 3	Class 1	Class 1
3	Class 3	Class 1	Class 1
4	Class 4	Class 2	Class 2
5	Class 2	Class 1	Class 1
6	Class 2	Class 1	Class 1
7	Class 4	Class 1	Class 1
8	Class 2	Class 1	Class 1
9	Class 1	Class 1	Class 1

Conclusions

- Existing EC9 classification limits are conservative when predicting the compression behaviour of the proposed optimised section.
- Modification of the outstand element slenderness limit provides a more accurate compression behaviour prediction.

Future work

- To consider the applicability of existing design guidance for sections under flexure, shear, torsion and a combination of the design cases.
- To undertake pin ended compression tests to understand effect of a compressive stress gradients
- To undertake physical testing of 3D printed sections to allow for more accurate analysis of section behaviour.