Modelling of 3D-printed thin-walled titanium structures

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Introduction

- Titanium has desirable properties in terms of strength to weight ratio, corrosion resistance, and biocompatibility [1]. This makes it an ideal candidate for structural applications in aerospace and biomedical components.
- Lattice structures (made of small individual struts) and thin-walled structures are typically more compliant than predictions from finite element simulations based on elasto-plastic beam theory [2]. Beam theory does not capture the stress concentration at sharp edges, and therefore does not predict the evolution of plastic zones properly. This work focuses on a T-shaped thin-walled structure.

- **Goals:**
  1. Deriving strains and yield surfaces using both Euler-Bernoulli beam theory and Abaqus simulations and identifying differences.
  2. Computing a failure surface using Abaqus.
  3. Assessing the evolution of plasticity after the onset of yield and its effect on mechanical behavior using Abaqus.

Geometry and models

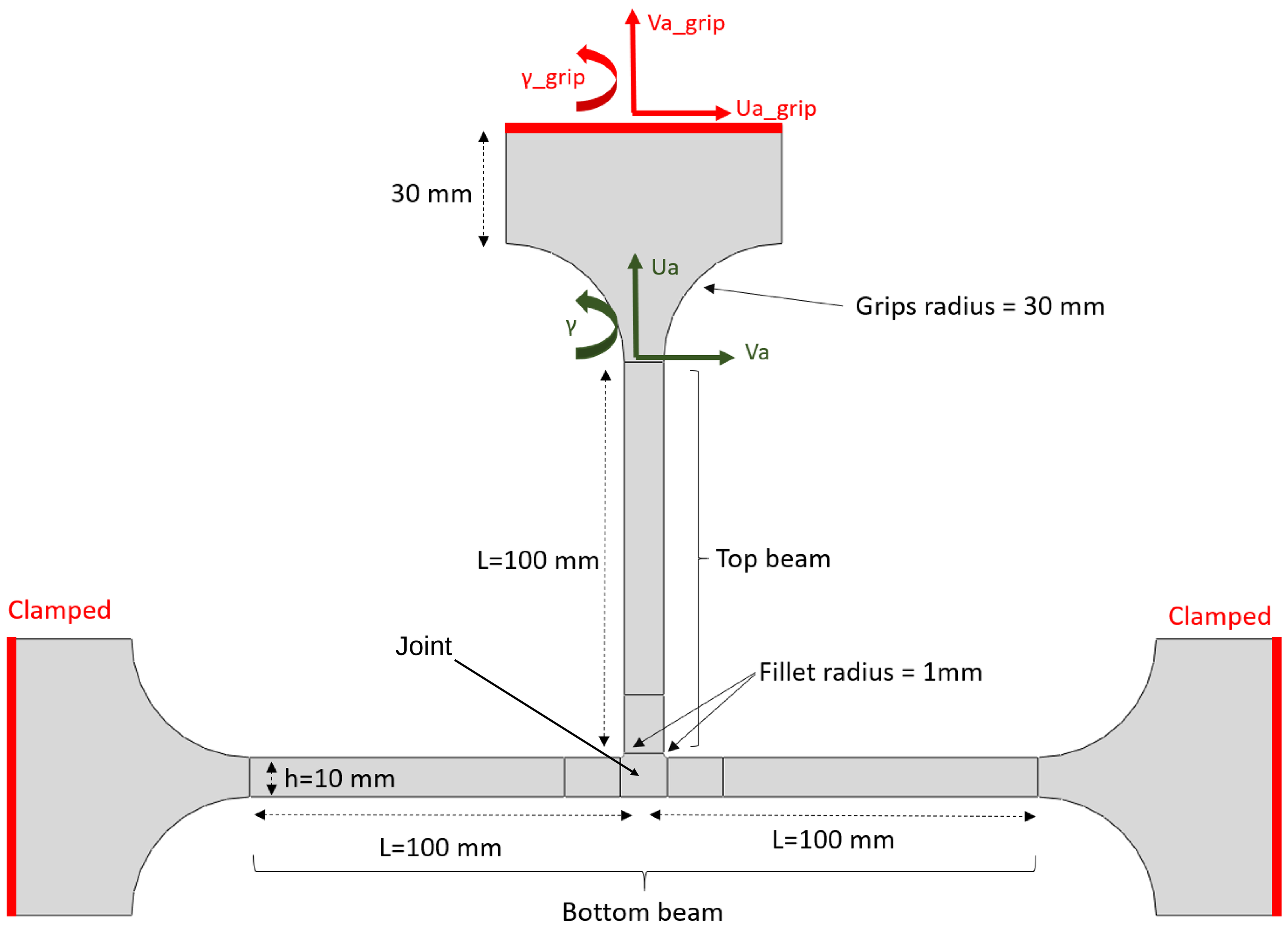

Fig.1: Abaqus 2D model with grips.

- Models are 2D, and infinite width (out of page) is simulated using plane strain elements.
- The loads and boundary conditions are shown in red. Displacements are applied at the top, and the bottom ends are clamped.
- Two models, with and without grips. The model with grips is shown.
- The model without grips only consists of the top and bottom beam.
- The onset of yield and failure are only considered near the joint (where both beams meet).

Elastic Strains

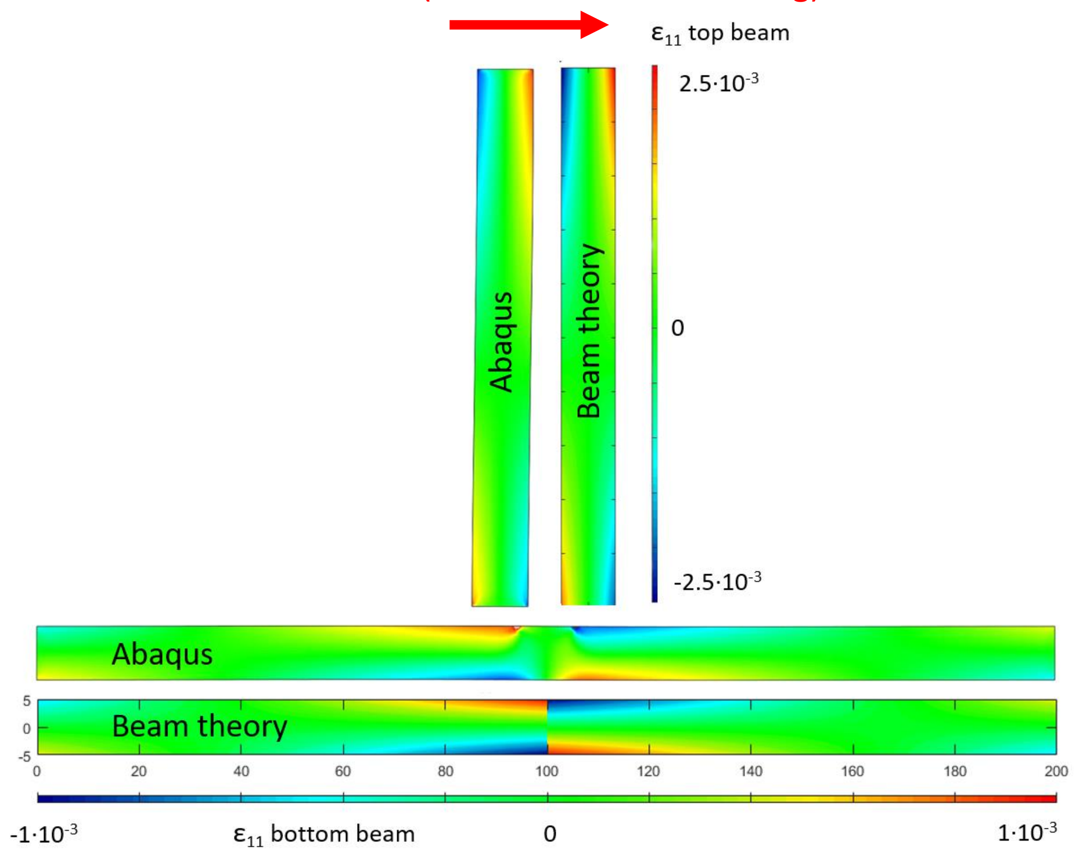

Fig. 2: Contour plot of the longitudinal strain (ε_{11}), for an applied horizontal displacement (Ua) of 1 mm. Comparison between elastic beam theory and Abaqus model without grips.

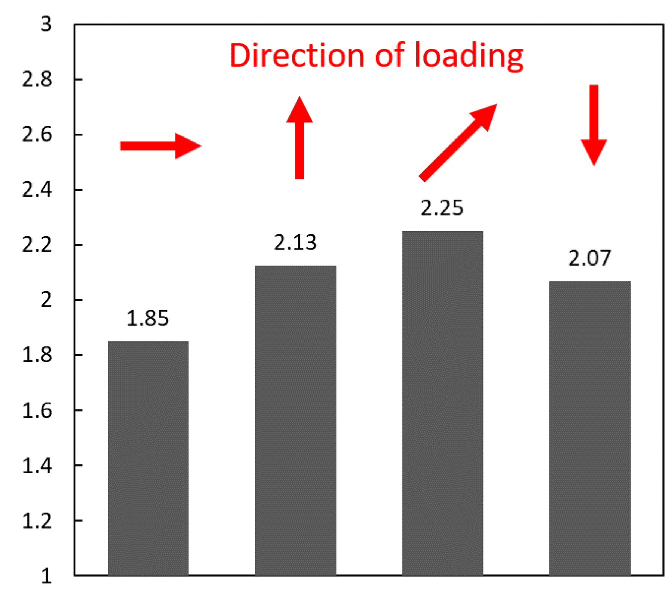

Fig 3: Strain concentration factor at the fillet (ratio of maximum strain between Abaqus and beam theory) as a function of loading angle.

- Beam theory captures the deflections (not pictured here) in both beams very accurately, with slight deviations when loading horizontally.
- Elastic beam theory accurately predicts the strains in the system, at the exception of the joint itself (where both beams meet).
- The maximum strains occur at the fillets because of strain concentration.
- The strain concentration factors are close to 2, and depend on the direction of loading.

Yield and failure surfaces

Yield criterion beam theory: $\varepsilon_{11} > \varepsilon_{yield}$

Yield criterion Abaqus: Equivalent plastic strain (PEEQ) > 0

Failure criterion Abaqus: PEEQ > 0.2

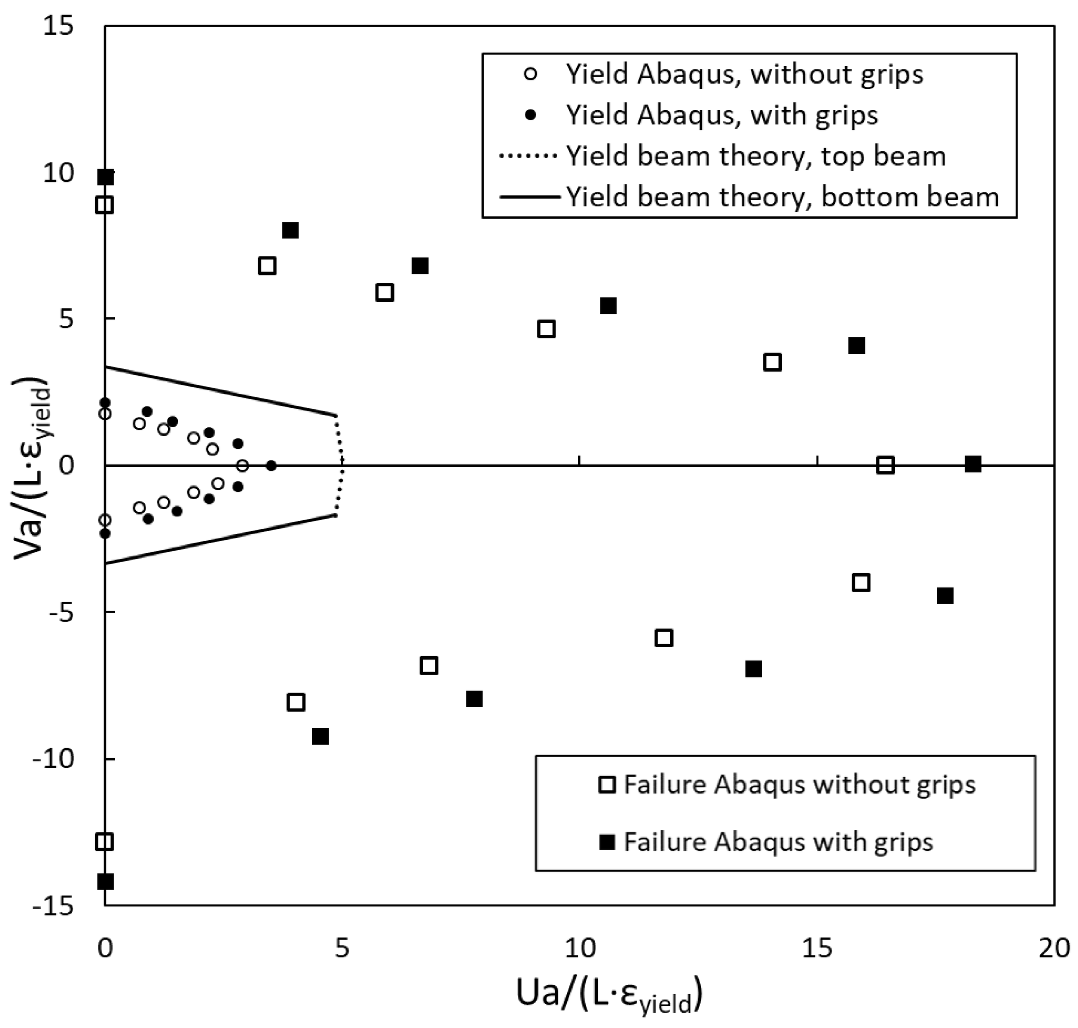

Fig. 4: Yield and failure surfaces for both Abaqus models, and yield surface from beam theory. Ua is the horizontal displacement and Va is the vertical displacement.

- Beam theory overstimates the loads that the system can withstand before yield, by a factor of about 2. This factor is close to the strain concentration factor. Beam theory predicts the onset of yield either in the top or bottom beam with a sharp transition, but in reality yield always happens at the fillet.
- The model with grips is more compliant, since the grips constrain the plates less.
- The structure is more resistant to horizontal loads than to vertical loads.
- The structure is more resistant to downwards loads than to upwards loads.

Evolution of plastic zone

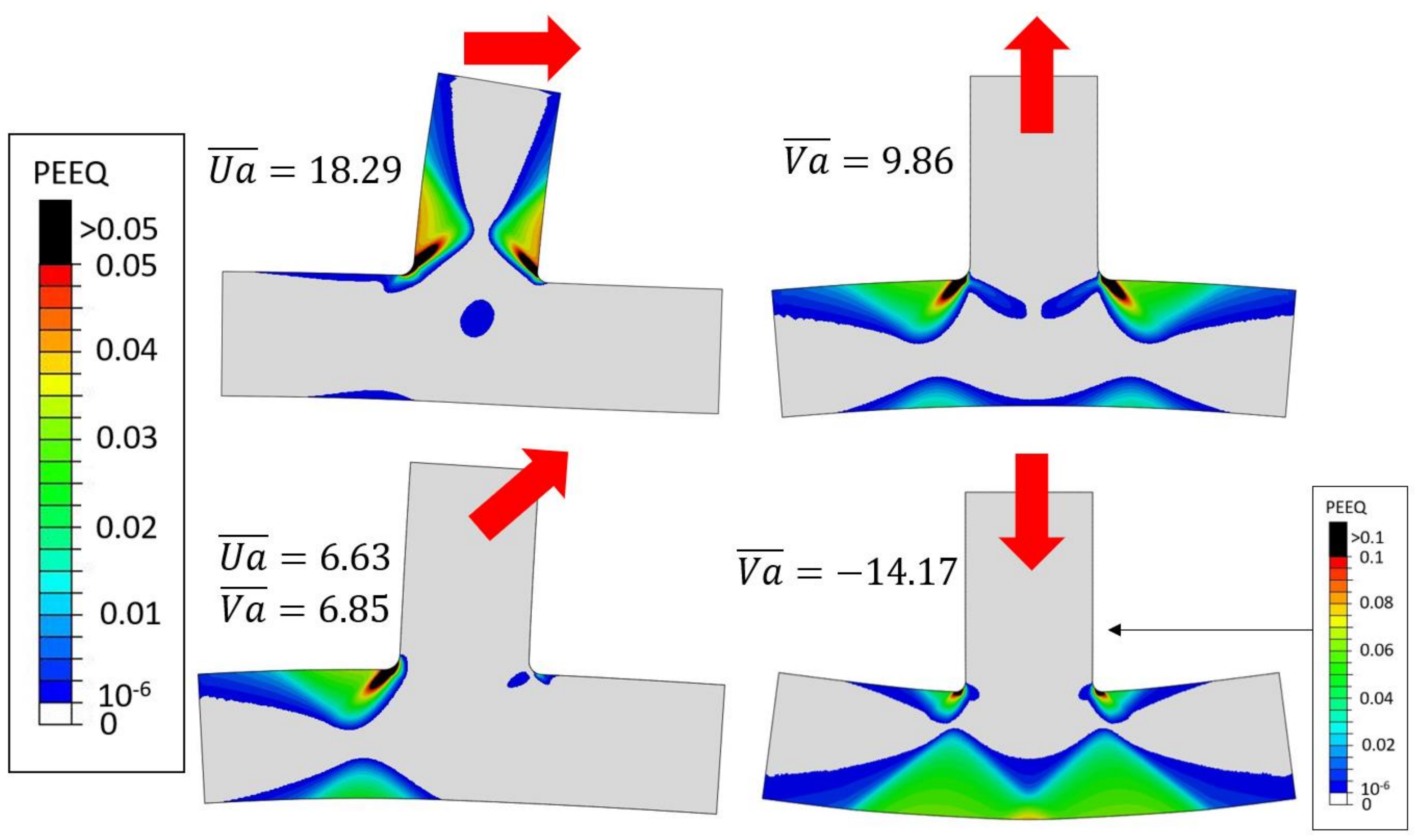

Fig. 5: Contour plot of the equivalent plastic strain near the joint at failure for 4 different loading angles (red arrows) , for the model with grips. The bar over the displacement indicated that it is normalized by ($L \cdot \varepsilon_{yield}$).

- Both the onset of yield and failure happen at the fillets.
- For most load cases, the plastic zone grows inside the bottom beam.
- This plastic zone can create a plastic hinge, therefore making the structure more compliant in some cases.
- The evolution of reaction forces and localization of the plastic zones can be used to create simplified models based on beam elements to capture the nonlinear behavior of the joint without running the complete 2D finite element simulation.

Conclusions

- Strain concentration of a factor of around two at the fillet is the most important aspect for the onset of yield, and it not captured by beam theory. One could scale the results from beam theory by this factor to obtain satisfactory results.
- The structure is more resistant to horizontal loads than to vertical loads, and there is asymetry with respect to vertical loads.
- At failure, a significant portion of the zone near the joint has undergone plastic deformation, therefore forming plastic hinges.
- The evolution of the plastic zones can be used as insights to create simplified models using beam elements that replace the joint with nonlinear springs, without the use of computationally expensive 2D finite element analysis.

References

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