Modelling of small-specimen tensile testing techniques for standardisation efforts

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Abstract

Conventionally, sub-size specimens, are used for tension testing of materials. The standards of the testing methods are well-established for loading in the uniaxial direction [1]. However, in certain operating conditions, the amount of material needed for sub-size testing may not be available. This necessitates the formulation of a robust methodology centered around miniature-sized specimen.
This study aims to showcase the initial efforts undertaken to explore small-specimen tensile testing techniques that can eventually be used towards standardisation of the selected methodology.

Introduction

Miniature-sized, or small-sized, specimens are usually specimens which have a physical gauge length of less than 6mm [2]. The foremost advantage of using a smaller specimen is realized in material consumption for testing. Small-specimen testing also provides other numerous advantages such as:

- Development of new alloys in extreme environments (such as in fusion reactors),
- Improved and effective use of irradiated material specimen,

The use of small-specimen testing techniques is beneficial to the nuclear industry in ageing nuclear power plants for life extension safety cases. For this reason, the material under consideration for the study is SS316H.
The miniaturized uniaxial tensile testing technique (MUxTT) has been performed previously by numerous authors [2]. This is essentially a scaled-down version of the sub-size testing. This method, however, is greatly affected by the manufacturing processes used. Kumar et al [4] use ingeniously designed specimen to develop SS304LN, but the lack of standardisation is problematic, especially since the shoulder of the specimen can introduce strain sensitivity.
There is potential to evaluate these properties using novel geometries as well. One such test technique proposed is the *Small Ring Test (SRTT)* [3]. The Small Ring Test was originally developed to identify secondary stage creep parameters. This technique involves stretching a ring with the help of supporting pins to evaluate the tensile test parameters. The study performed by Kazakeviciute et al [3] on aluminium alloys (7175-T7153) has shown promising results. This study has been used as a reference point to model SS316H.

Methodology

The study was performed in order shown below. The readings in the brackets denotes the mesh size used after performing a mesh sensitivity analysis:

1. Perform sub-size tensile test on SS316H (room temperature)
2. FE modelling of sub-size specimen (1.0 mm)
3. FE modelling of SS316H with MUxTT (0.1 mm)
4. FE modelling of SS316H with SRTT (0.15 mmm)

The sub-size tensile test was performed at different loading rates and no rate-dependent sensitivity was found for SS316H. Abaqus FEA package was used for modelling.
Geometric nonlinearity is turned on during the loading step of these explicit analyses. For the SRTT, a surface-to-surface contact was established between the specimen and the pin. All analyses used the element type C3D8R with enhanced hourglass control. Rate dependency was also not found for the SRTT. The point at the centre of the 1/8th symmetry of the axis, lying on the plane perpendicular to the axis of the motion, was chosen as the reference point.

Results

The dimensions of the ring are a maximum of 11 mm (outer diameter). The inner diameter is 9 mm and the ring thickness is 2 mm. The MUxTT specimen has a shoulder fillet of 0.15 mm radius and a gauge length of 4 mm and a thickness of 2mm. Based on the experimental evidence, as presented in [3], the displacement of the pin in the SRTT was limited to 4mm. The deformed ring is shown in fig. 1.

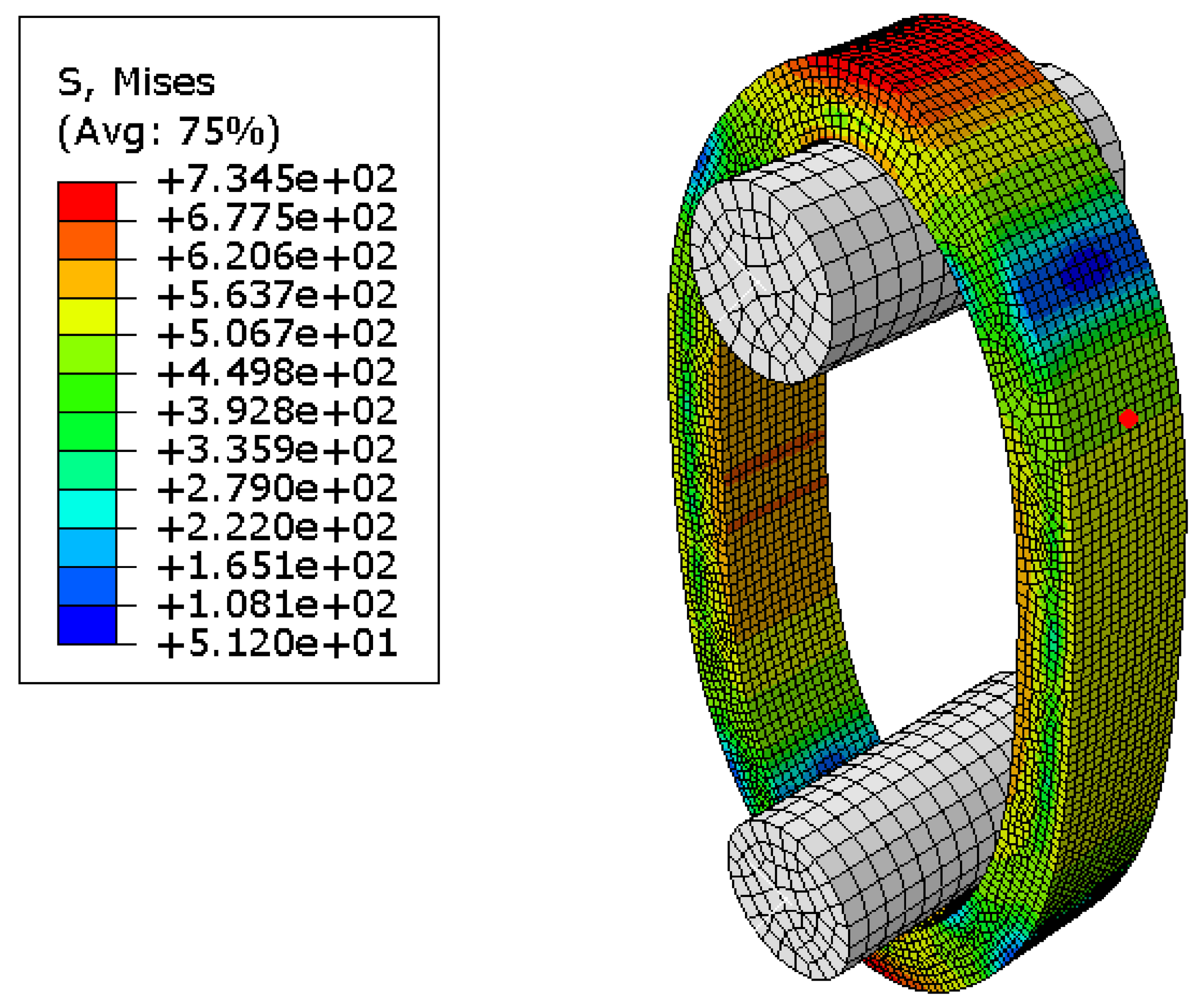

Fig. 1: Deformed SRTT specimen

As evident in fig. 1, the ring undergoes a complex state of stress, as compared to the relatively simple stress state undergone by the MUxTT/sub-size specimen. The rate of loading used in all analyses was 0.1 mm/min.

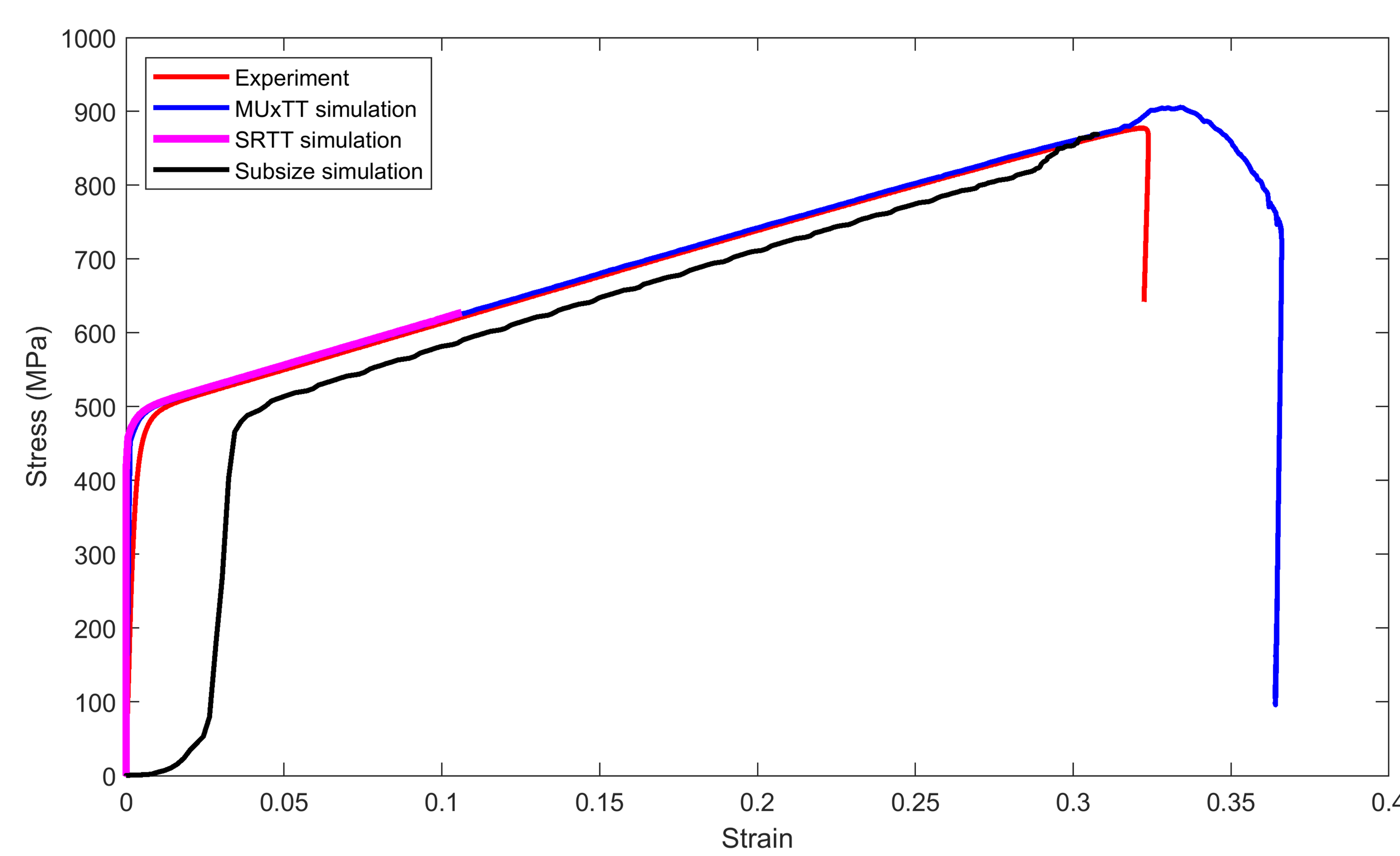

Fig. 2: Deformed sub-size specimen

While the results are discussed in detail in the next section, it was worth noting that there is an extremely good agreement between the experimental data and the data obtained from SRTT and MUxTT. The data from the SRTT, however, seems to be limited with respect to MUxTT. The coefficient of friction between the pin and the ring also did not have any significant impacts and was hence set as 0.2.

Discussion

All three forms of FE models are capable of providing an estimate of the yield point. The ultimate tensile strength is a parameter that cannot be obtained with the SRTT. As noted in [3], further deformation of the ring lends itself to an even more complex stress state and extracting information proves to be difficult.

However, it is also worth noting that the point of interest in such tests is the yield point and not the ultimate tensile strength point. Both the MUxTT and SRTT can provide that but the MUxTT needs further study for the strain sensitivity induced by the shoulder fillet. This sensitivity may be a reason why the MUxTT specimen has a longer necking regime.

The benefit of using the SRTT is its minimalist loading condition. The MUxTT needs to be clamped or a dedicated fixture must be designed to house the specimen during testing. It was also observed that the coefficient of friction has minimal effect on the loading of the SRTT since the coefficient of friction was varied from 0.1 to 0.4. Lastly, while the difference is minute, the SRTT is slightly better at predicting the yield point as compared to the MUxTT.

Conclusions

From this preliminary study, the following conclusions can be drawn:

1. SRTT serves as a viable technique for measuring small-specimen tensile testing
2. Coefficient of friction has minimal effect on FE model of SRTT
3. SRTT is marginally better at yield point prediction, as compared to MUxTT.

Future Work

There remains a lot of impetus to further this research due to its potential. Some of the planned and recommended future work is listed below.

1. Test more materials experimentally with SRTT and MUxTT (such as SS316 and P91).
2. Examine rate-dependency of small-sized specimen test techniques at power plant operating temperatures with the help of experiments and simulations.
3. Strain sensitivity in the shoulder fillet of MUxTT should be examined to further standardise this form of testing.

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