Simulation of the welding process of steel tube joints made of S355 and S690

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Auteur(e)s Janna Krummenacker

Encadrement Prof. A. Nussbaumer[1] / Prof. Dr.-Ing. T. Ummenhofer[2] / F. Zamiri Akhlaghi[1] / Willy Dufour[3]

[1] Laboratoire de la construction métallique (ICOM) / [2] KIT Steel and Lightweight Structures, Research Centre for Steel, Timbre and Masonry/ [3] Laboratory of mechanical Metallurgy (LMM)

Objective:

Welding is an important joining method for the work with metals. During the welding process, the material is heated and deforms plastically which leads to a change in microstructure in the heat affected zone, to complex residual stress distributions, and distortions. The residual stresses can have a major impact, among other phenomena, on the fatigue resistance of a welded structure. The aim of this work was to develop a model with the finite element software ABAQUS for the simulation of a welding process for butt welded tubes and the calculation of the resulting welding residual stress field.

Experimental study:

The tensile tests were conducted with two different steel grades (S355 and S690) at three different temperatures (20° C, 250° C and 800° C) in order to verify the temperature dependent reduction factors for the yield stress and the Young's modulus given in the Eurocode 3 (see Fig. 1). Different strain rates were used, because the deformational behavior of steel at elevated temperatures is dependent on the deformation rate (Fig. 2).

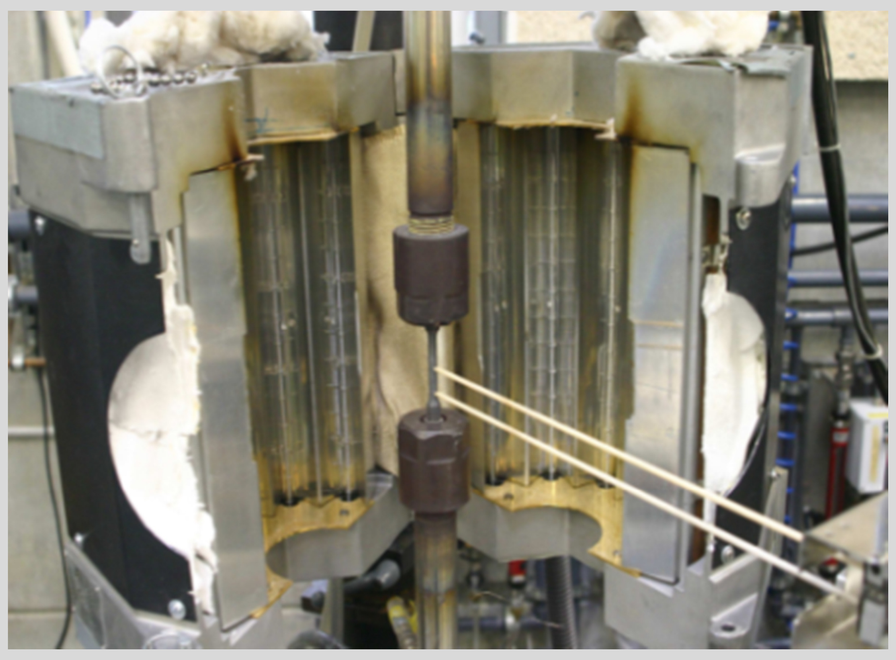

Fig. 1: Test set-up

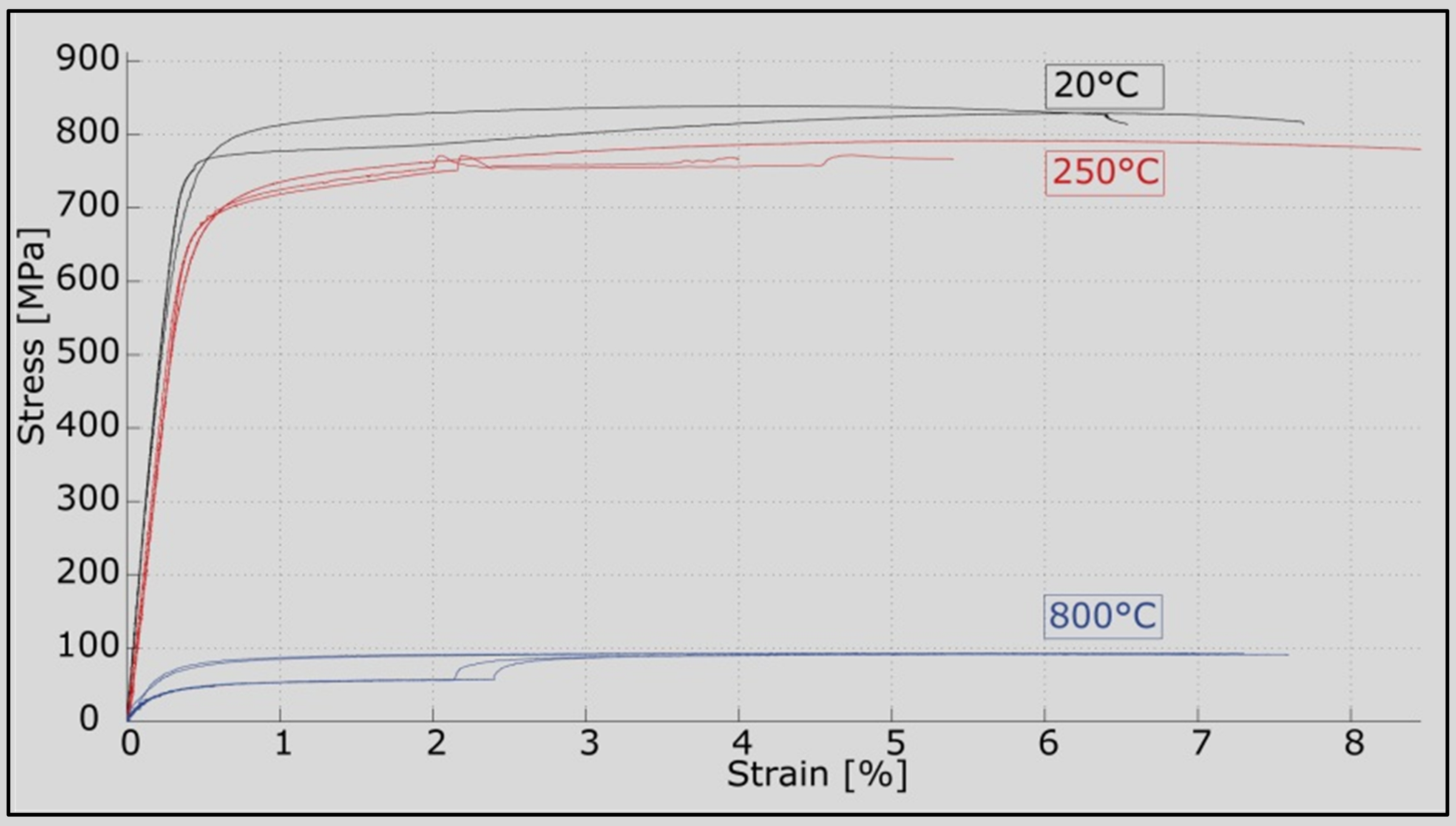

Fig. 2: Stress-strain curves of tests with S690

The values obtained in the tests were compared to the reduction factors given by the Eurocode 3 for fire design of steel structures as well as the values found in the theses by Wichers and Outinen. Fig. 2 shows this comparison exemplarily for the Young's modulus of the high strength steel type S690.

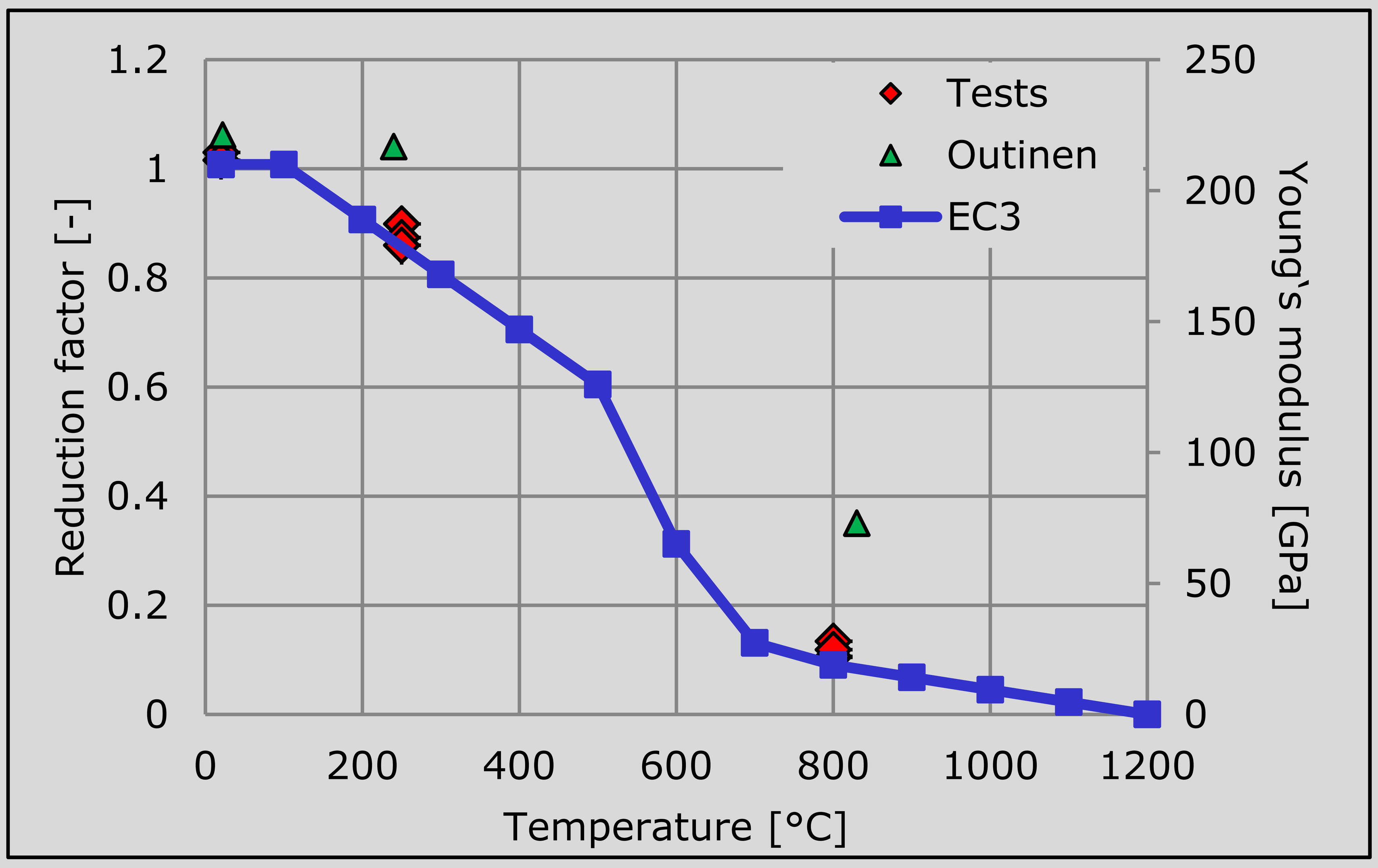

Fig. 3: Young's modulus for S690 given by the EC 3, the test results and by Outinen

Numerical simulation:

A finite-element-simulation of the welding process is an acknowledged method to predict the syllable welding residual stress distribution. In order to reduce the complexity of the models and to save computation time many simplifications have to be made.

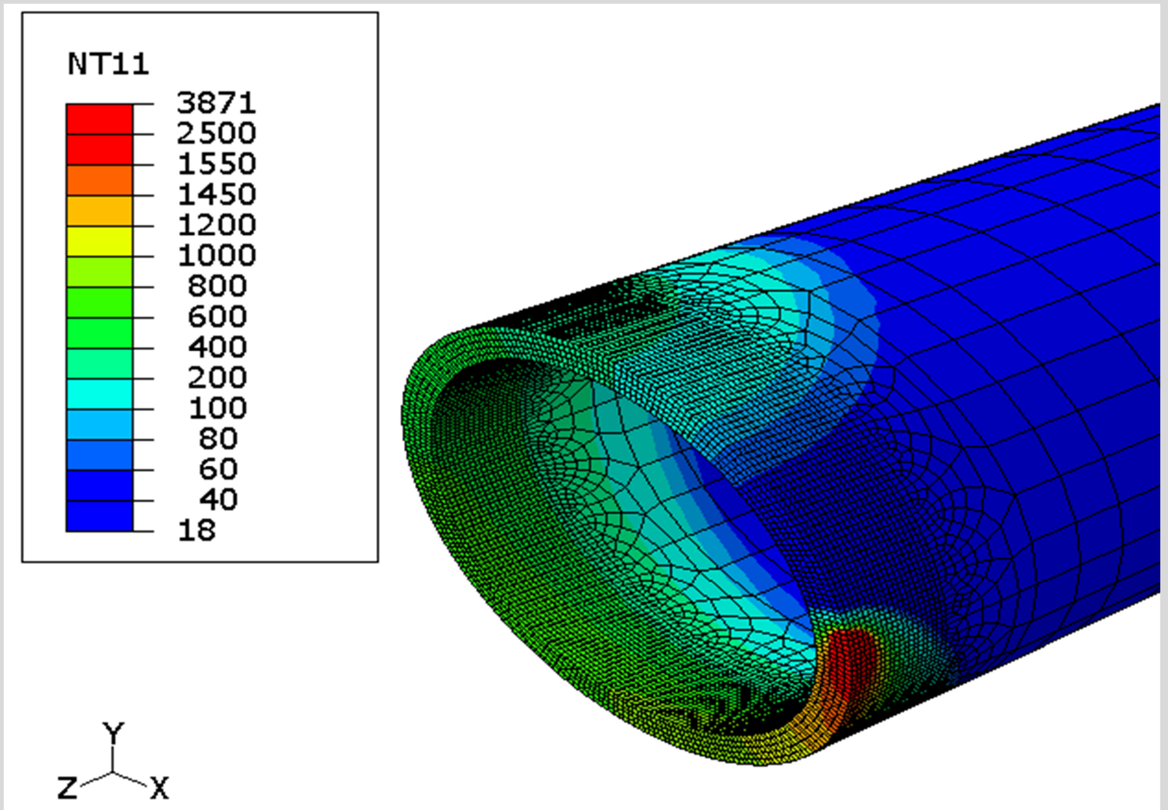

Fig. 4: Temperature distribution during the welding process

In this work, the numerical simulation was realized by decoupling the welding process into a thermal and a subsequent mechanical analysis. Fig. 4 shows the temperature distribution during the thermal analysis on one half of the tube in the simulation software ABAQUS.

In the parametric study in this work, a main focus was placed on the influence of the mechanical material behavior and the number of weld passes on the residual stress field.

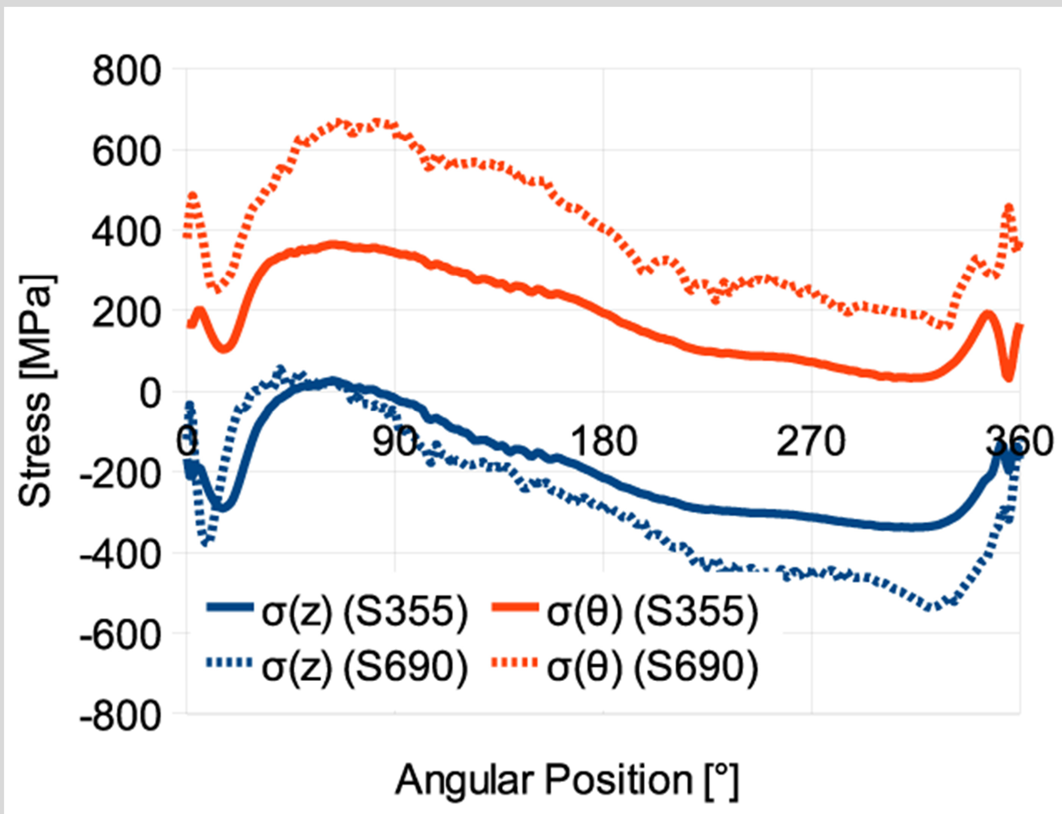

Fig. 5: Residual stresses in circumferential direction at the weld toe

Fig. 5 shows the influence of the steel type on the circumferential residual stresses. The tendency of the stress distributions is the same, but the magnitude and sign differ. The calculation of the stresses with one steel type therefore does not allow conclusions on the stress distribution for models with a different yield strength. Fig. 6 illustrates the influence of the weld pass number and therefore shows exemplarily the axial stress in circumferential direction at the weld toe of the models with steel type S355. The stress distribution of the single-pass model differs considerably from the one of the multi-pass model. Except at the start/end position no parallels can be found.

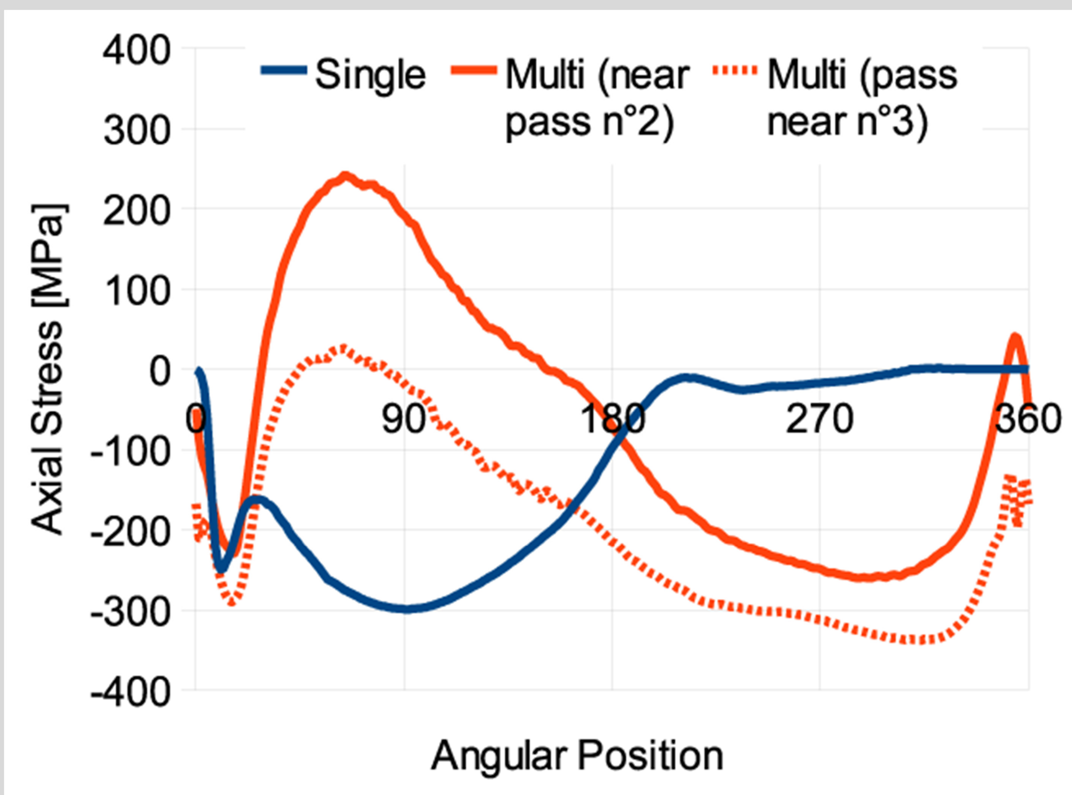

Fig. 6: Axial stress in circumferential direction at the weld toe (S355)

Conclusion:

The residual stress distributions show that it is essential to use a realistic material model with accurate data at high temperatures for an adequate welding simulation. For further research it is therefore recommended to study the influence of a more realistic material model and to include phase transformation effects especially for high strength steel. The analysis regarding the quality of an approximation of a multi-pass weld by a single-pass weld reveals the important influence of the weld pass numbers on the residual stress field. It can be concluded that this is an oversimplification and leads to non-realistic results.