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Experimental and Numerical Determination of Strength of Portable Firefighter Ladder

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Abstract. Portable fire and rescue service ladder are widely used during fire and rescue works. Ladders are mostly made of aluminium alloy at present and this material changes its mechanical properties upon thermal exposure. Determination of the load capacity of ladders using experimental and numerical simulation is described in this paper.

Introduction

Portable ladders are universally used equipment of fire brigade units, where they belong to the equipment of most fire engines. Fire Rescue Service of the Czech Republic uses portable four-piece aluminium ladders from different manufacturers. Ladders are complexly loaded both mechanically and thermally. At present, the ladder's operational suitability is verified according to the standard [1]. The ladder is loaded with a three-point bend, see Fig 1 and any residual deflection determines the further usability.

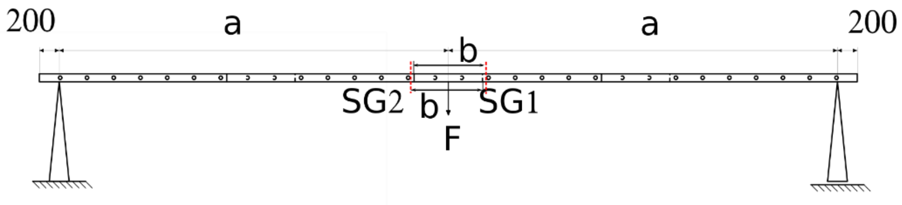

Fig. 1: Scheme of the test portable ladder

The vast majority of ladders used are from only two manufacturers and therefore only these two types were examined in the following. Numerical models for both types were created and verified experimentally.

Experiments

Experimental verification of ladder strength was based on the loading setup according to the mentioned standard [1]. With regard to the available resources, the water tank was chosen to load the ladder, see Fig. 2. The load was monitored using a load cell and a potentiometric displacement sensor was used for deflection measuring of assembled ladder. Strains around the connection ladder detail were monitored using resistance strain gauges. Material properties of the aluminium alloy used were determined by tensile testing, when the tests were carried out at normal temperature at elevated temperatures and on material exposed to different temperature levels.

Fig. 2: Portable ladder test

The tests were performed on temperature-unaffected ladders, where three specimens from both main manufacturers were tested. The ladder assemblies were loaded to total destruction, failure of one specimen can be seen in Fig. 3. Results of all destructive bending tests can be seen in Fig. 4.

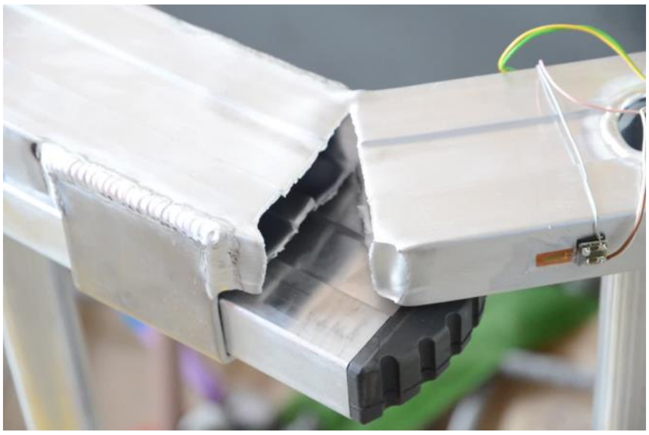

Fig. 3: Detail of ladder brake

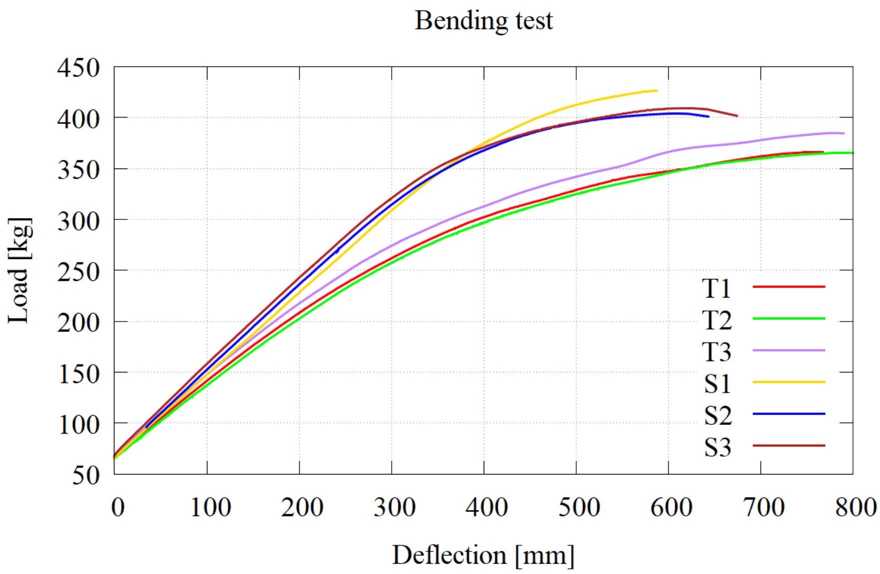

Fig. 4: Experiment results

Numerical simulation

Within numerical solutions, material model parameters were identified for unexposed and exposed state. The FE ladder model was created on the basis of geometry measured on real pieces. A numerical simulation of experiments on an unexposed ladder was performed and the results of the calculations were compared with the measured values, see Fig. 5.

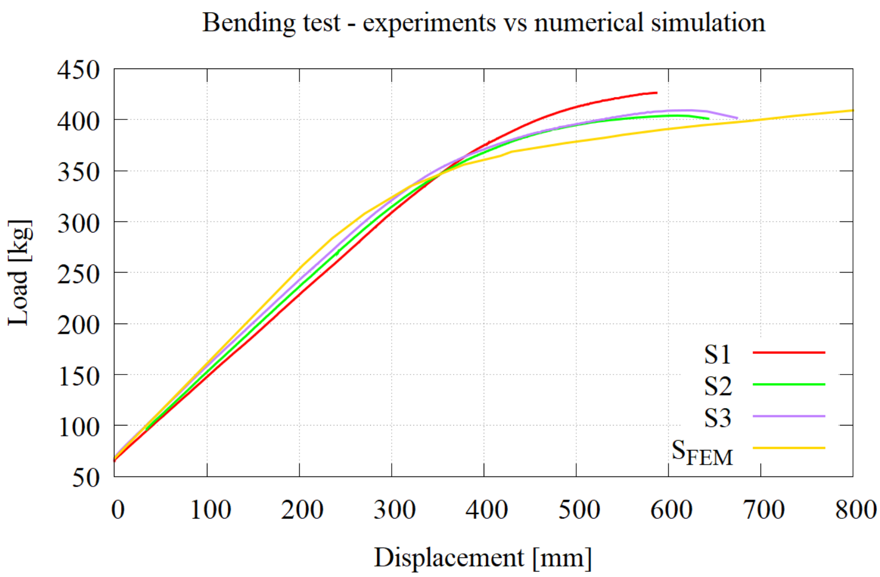

Fig. 5: Comparison of experimental results and numerical simulation

Furthermore, numerical simulations of hypothetical cases of ladders subjected as a whole to the same temperature exposures as samples for material tests were performed. Finally, the case of partially temperature-affected ladder was solved. A simple model of plasticity and ductile failure according to Johnson – Cook [2] was chosen for phenomenological description of mechanical properties of ladder material, when yield stress can be expressed as

$$\sigma_y = A + B(\varepsilon_{pl})^n \tag{1}$$

Material parameters *A*, *B* and *n* were calibrated using the Levenberg-Marquardt nonlinear least square algorithm. The material model also includes a ductile damage cumulation [1] in the form:

$$\varepsilon^f = d_1 + d_2 e^{-d_3 \eta} \tag{2}$$

where ε^f is fracture locus, η is stress triaxiality and $d_{1\text{-}3}$ are material parameters. Due to lack of experimental data only parameter d_1 was calibrated considering tensile tests and d_2 and d_3 were adopted from [3].

All parts of ladder are modelled as continuum solids. FE model contains about 230 000 linear elements with full integration. In the first step, the ladder is loaded by own weight and by weight of empty container. In the second step, only weight of container increases. The simulations were done for all cases when whole ladder had degraded mechanical properties. Since whole ladder is not exposed to higher temperatures in reality the simulation of this case was made. There was focus on two cases. In the first the exposed part is on the end of ladder and in second the exposed part is in the middle.

Conclusions

Strength tests were carried out on portable ladders that are most commonly used. Numerical models were created on the basis of material and structural tests. Numerical simulations of partially exposed temperature ladders show the limits of existing standards. Tests of thermally loaded ladders are being prepared to confirm obtained numerical results.

Acknowledgments

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