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Fire ladder test simulation

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1. Introduction

The fire ladders could be exposed to high temperatures during their service. The exposure leads to mechanical properties degradation and a ladder could become unsafe for further use. According to regulations the fire ladders must be continuously tested to prove their capability. The test is based on ladder bending. Assembled ladder is supported on the ends and loaded in the middle by defined weight. The capability is assessed on the base of deflections under load and residual deflections. The regulation does not include the basis for assessment (material properties and ladder design) so it is probably arise from experience. Thus there is need to get better insight to ladder stress during service, relation between this stress and described test results according to material failure and the influence of mechanical properties degradation on limit loading.

2. Material data calibration

There were performed material tests on specimens cut out of ladder. There was tested the base material and material exposed to defined temperatures and defined periods of time as is shown in Table 1.

Table 1. Temperatures and exposure times of specimens and calibrated material parameters

temperature [°C]	time [min]	A [MPa]	B [MPa]	n [-]
20	-	200	153	0.3
200	120	190	147	0.28
200	240	185	150	0.28
200	480	180	162	0.33
300	5	120	232	0.48
300	30	80	328	0.57
300	120	77	267	0.55
400	5	120	232	0.48
400	30	30	200	0.41

The Johnson – Cook plasticity model [1] was considered, thus actual yield stress can be expressed as

$$\sigma_y = A + B\left(\varepsilon_{pl}\right)^n .$$

The experimental data were used for material parameters *A*, *B* and *n* calibration employing Levenberg-Marquardt nonlinear least square algorithm. The calibrated values can be seen in Table 1. The material model also includes a ductile damage cummulation [1] in the form

$$\varepsilon^f = d_1 + d_2 e^{(-d_3\eta)},$$

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 = 0.089 and d_3 = 2.44 were adopted from [2].

3. Ladder testing

Three assembled ladders were tested in total. The supports were placed 200 mm from the ladder ends thus their distance was 3815 mm. One support was fixed and the second was movable in horizontal direction. In the middle was installed weight carrier connected with IBC container which was gradually filled by water during the test. Force gauge HBM S9M with 10 kN range connected to container was used for applied load monitoring. The deflection was monitored by potentiometric gauge with range 900 mm. Also strain gauges were installed in one case. All gauges where connected to universal measuring amplifier module HBM Quantum 840 which was connected with PC. For data recording with sampling frequency 10 Hz was used software HBM Catman Easy. The results are shown in Fig. 1. On the base of the measurements was estimated limit load as Flim = 3482 N.

4. Numerical simulation

The FE model of ladder was created. It consists of four instances (ladder segments) coupled by tie constrain. All parts of ladder are modeled 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. For simulations was used commercial software Abaqus.

5. Results

In Fig. 1. are shown computed and measured dependencies of load on deflection. The magnitude of ductile damage parameter for load corresponding to measured limit load was obtained. On the base of this value were estimated limit loads and limit deflections for cases of ladders with degraded mechanical properties. Quite interesting are results of partially degraded ladders. It demonstrates high sensitivity on the ladder assemblage. The case with degraded material of the end of the ladder shows relatively high limit force as well as high deflections in comparison of the case with degraded middle.

6. Conclusions

The material parameters of Johnson – Cook plasticity model were calibrated. The limit load was experimentally measured and was used for limit loads of degraded ladder estimation employing numerical simulations considering ductile damage cummulation. There was shown significant dependency between limit loads and deflections on the ladder assemblage. This aspect in not included in current regulations.

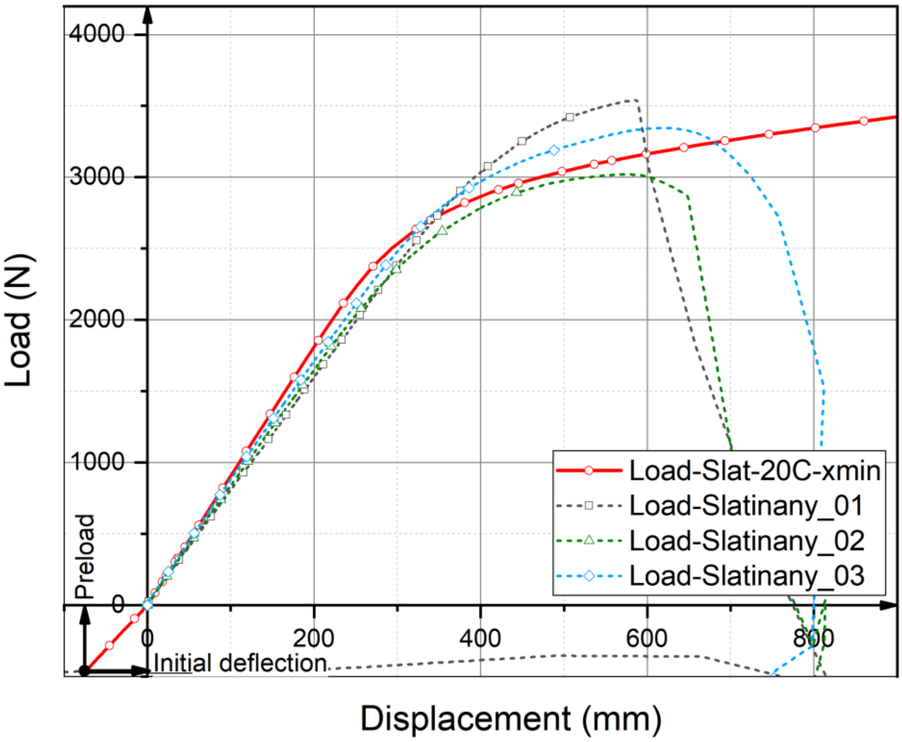

Fig. 1. Load vs. displacement. Dotted lines are experimental results. Full line is computed response for unexposed basic material

Acknowledgements

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