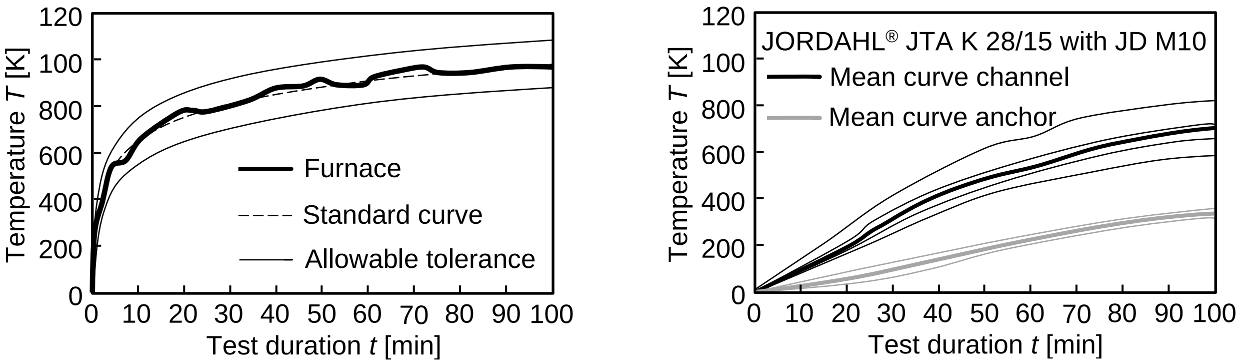
bolts were loaded by hanging loading weights or hydraulic actuators outside and a fireproof mechanism inside of the furnace. Three different load levels each were applied to the bolts which were installed either at the anchor or between the anchors.



a) b)

Fig. 5 a) Example temperature curves (Nause 1996): a) measured in fire chamber, b) measured at anchor (with 2 thermocouples) and channel (with 4 thermocouples)

If failure occurred at lower temperatures, deformation of bolt head and channels lip, at higher temp shear-off of the thread was observed. The measured temperature curves (Fig. 5b) allowed the observation that the anchors are protected by the engulfing concrete, thus experience much lower temperatures than the channels. However, the anchor channels introduce heat into the reinforcement. Therefore, a minimum spacing between the anchor channels must be kept to limit the damaging heat input.

2.4 Qualification and design of anchor channels for fire

In 2004, the evaluation of concrete fasteners concerning the resistance to fire was harmonized on the basis of the Technical Report TR 020 published by European Organisation for Technical Assessment (EOTA) (EOTA TR 020 2004) which is referenced in the European assessment documents for concrete anchors, e.g. in the above mentioned EAD 330008-XX-0601 for anchor channels with channel bolts. TR 020 provides two concepts:

- The simplified yet conservative approach using equations *to calculate the resistance to fire*: Depending on the aspired resistance class R30 to R120, reduced strengths are provided to calculate tension and shear load capacities corresponding to steel-related failure modes. Tension and shear load capacities corresponding to concrete-related failure modes are calculated for R90 and R120 using reductions factors.
- *To test the resistance to fire* employing experiments according to EN 1363-1: Pull-out and steel failure in tension and shear is tested in series with at least 5 tests of which 4 tests must sustain longer than 60 min. The test results are used for a regression analysis to determine values for R30 to R120. Currently, however, no test is defined to determine load capacities for concrete cone and splitting failure in tension as well as concrete pry-out and edge failure in shear.

A combination of both concepts is possible. Both concepts cover concrete fasteners with a fire attack from one side only. If the fire attack is from more than one side, the edge distance of the concrete fasteners must be larger than 300 mm and two times the embedment depth h_{ef}.

It is noteworthy that the European assessment document for anchor channels with channel bolts EAD 330008-XX-0601 stipulates the concept of experimental determination. Because tension capacities are smaller than shear capacities for steel failure modes of anchor channels, moreover, it is required to test the tension capacity under fire only and to equalize the shear capacity under fire ($V_{Rk,s,fi} = N_{Rk,s,fi}$) which is conservative. No other fire tests are required because currently, TR 020 specifies no tests for concrete failure modes. An example test series is presented in the following.

3. TESTS

3.1 Test specimen and setup

The presented fire tests on JORDAHL® anchor channels JTA W 50/30 were carried out and analyzed recently at the iBMB (MPA) of the TU Braunschweig (Blume 2018). The channels were furnished with forged anchors at the maximum intermediate spacing s_{max} of 250 mm and a minimum end spacing x_{min} of 25 mm. The anchor channels with an embedment depth of $h_{ef} = 94$ mm were cast into concrete members (C20/25: $f_{ck} \approx f'_c = 20$ MPa). After curing, the concrete members were used as the top slab of a furnace (internal footprint times height: 1000 mm × 1500 mm × 1500 mm). Matching JORDAHL® T-bolts JB M16 with a stressed area of 157 mm^2 were installed together with fixtures to load the channel bolts axially. The loaded bolt was either positioned at one of the two or between the two anchors of the channel (Fig. 6). Test specimen and setup were in line with TR 020. Note that TR 020 also defines the dimensions of the fixture and, most importantly, the required gap between the fixture and concrete slab to be achieved by means of 10 mm × 10 mm × 10 mm distance cubes.

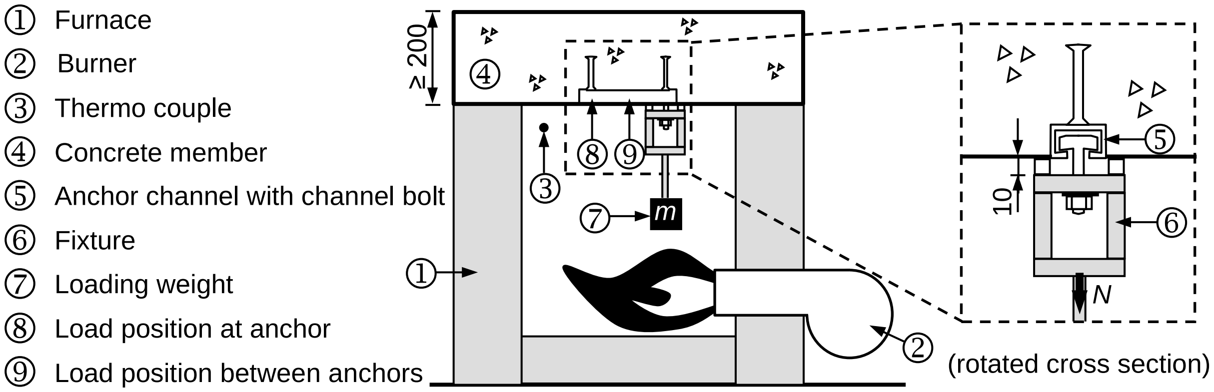


Fig. 6 Test specimen and setup (schematic)

The tests were carried out in two runs. The fuel oil burner heated the furnace according to the ETC which was controlled using the temperature measured by the thermocouples near the top slab. The time to failure was recorded. After completion of the run and cooling down, the failure modes were inspected.

3.2 Test program and results

The fire tests on JORDAHL® anchor channels JTA W 50/30 with T-bolts JB M16 presented here (Table 1) were part of a larger test program. 6 different load levels were tested. Two bolts were loaded identically to check the scatter. Despite different steel-related failure modes, the difference of their time to failure was less than 5%, adumbrating a low overall scatter. No concrete-related failure mode occurred. Note that the categorization of the failure mode has no relevance for the evaluation.

Table 1 Test program and results

Series	Position of load	Load N [kN]	Steel stress σ_s [MPa]	Time to failure t_u [min]	Failure mode
1	Between anchors	9.0	57.3	48	Nut thread
2	Between anchors	7.0	44.6	65	Bolt shaft
3	Between anchors	5.5	35.0	55	Bolt shaft
4	At anchor	5.0	31.9	76	Nut thread
5	Between anchors	4.0	25.5	116	Channel lip
6	Between anchors	2.6	16.6	144	Bolt shaft
7	Between anchors	2.6	16.6	138	Channel lip

3.3 Evaluation

TR 020 provides a guideline on how to derive the resistances R30 to R120 for the tested system. A regression analysis of the steel stress σ_s plotted versus the reciprocal of time to failure $1 / t_u$ (Fig. 7a) allows the determination of the parameters c_1 and c_2:

$$\sigma_{s1} = c_1 + c_2 / t_u \qquad (1)$$

The parameter $c_3 < 1$ is defined to shift the function such that it crosses data point representing the most unfavorable test result:

$$\sigma_{s2} = c_3 \cdot (c_1 + c_2 / t_u) \qquad (2)$$

The most unfavorable test result is the data point closest to the origin in the plot σ_s versus the time to failure t_u (Fig 7b) where the allowable characteristic steel stresses corresponding R60 to R120 may be read:

$$\sigma_{Rk,s,fi(60)} = c_3 \cdot (c_1 + c_2 / 60\text{ min}) \qquad (3)$$

$$\sigma_{Rk,s,fi(90)} = c_3 \cdot (c_1 + c_2 / 90\text{ min}) \qquad (4)$$

$$\sigma_{Rk,s,fi(120)} = c_3 \cdot (c_1 + c_2 / 120\text{ min}) \qquad (5)$$

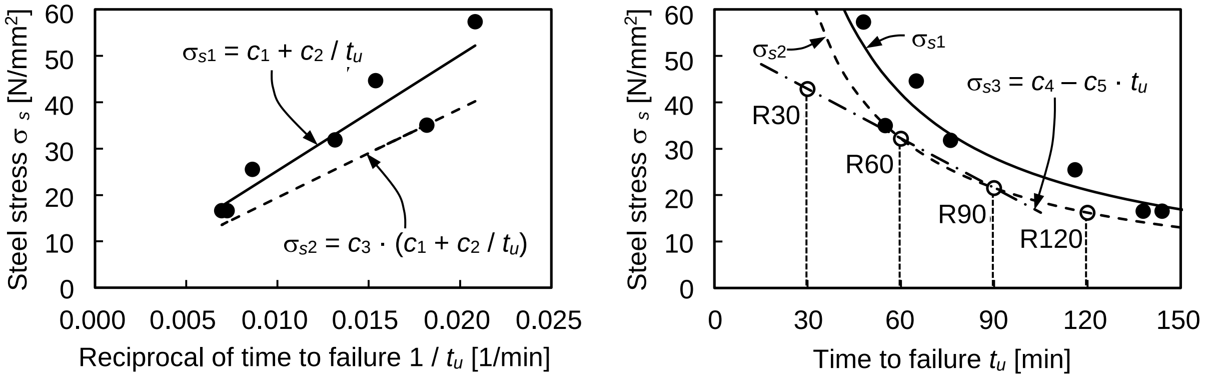
Using the two pairs $t_u = 60$ min | $\sigma_{Rk,s,fi(60)}$ and $t_u = 90$ min | $\sigma_{Rk,s,fi(90)}$ the following linear equation can be derived, defined by intercept c_4 and slope c_5:

$$\sigma_{s3} = c_4 - c_5 \cdot t_u \qquad (6)$$

This equation specifies the allowable characteristic steel stresses corresponding the resistance R30:

$$\sigma_{Rk,s,fi(30)} = c_4 - c_5 \cdot 30\text{ min} \qquad (7)$$

A conventional spreadsheet helps to carry out the necessary operations to determine the parameters c_1 to c_5 (Table 2) and the allowable characteristic steel stresses $\sigma_{Rk,s,fi(30)}$ to $\sigma_{Rk,s,fi(120)}$ (Table 3). The latter is converted into allowable characteristic resistances $N_{Rk,s,fi} = V_{Rk,s,fi}$ based on the stressed area (157 mm for M16). Due to other considerations, e.g. classification concepts, lower values for the allowable characteristic resistances may be specified in the ETA.



a) b)

Fig. 7 Evaluation using a) regression analysis to determine b) allowable characteristic steel stresses

Table 2 Parameters c_1 to c_5

c_1	Regression analysis	0.3347
c_2		2490.3
c_3	Shift to most unfavorable test result	0.7780
c_4	$(\sigma_{Rk,s,fi(90)} - \sigma_{Rk,s,fi(60)})$ / (90 min – 60 min) · (– 60 min) + $\sigma_{Rk,s,fi(60)}$	53.522
c_5	$(\sigma_{Rk,s,fi(90)} - \sigma_{Rk,s,fi(60)})$ / (90 min – 60 min)	0.3551

Table 3 Allowable characteristic steel stresses $\sigma_{Rk,s,fi}$ and characteristic resistances $N_{Rk,s,fi} = V_{Rk,s,fi}$

For fire resistance R30		For fire resistance R60		For fire resistance R90		For fire resistance R120	
$\sigma_{Rk,s,fi(30)}$ [MPa]	$N_{Rk,s,fi(30)}$ $V_{Rk,s,fi(30)}$ [kN]	$\sigma_{Rk,s,fi(60)}$ [MPa]	$N_{Rk,s,fi(60)}$ $V_{Rk,s,fi(60)}$ [kN]	$\sigma_{Rk,s,fi(90)}$ [MPa]	$N_{Rk,s,fi(90)}$ $V_{Rk,s,fi(90)}$ [kN]	$\sigma_{Rk,s,fi(120)}$ [MPa]	$N_{Rk,s,fi(120)}$ $V_{Rk,s,fi(120)}$ [kN]
42.8	6.7	32.1	5.0	21.5	3.4	16.2	2.5

The example test series presented here demonstrate the effort required for fire rating of just one combination of anchor channel and channel bolt, though the fire resistance for intermediate sizes may be calculated by linear interpolation if the ratio of the steel strength corresponding to the larger size and the smaller size is not larger than about 2.

Taking the effort into account, the simplified across-the-board approach appears to be reasonable even though it may be overly conservative – the steel capacity in tension and shear corresponding to the decisive failure mode would be $N_{Rk,s}$ = 31 kN and $V_{Rk,s}$ = 52 kN for the design of JORDAHL® anchor channels JTA W 50/30 with T-bolts JB M16 without fire design. Notwithstanding, the certified characteristic resistances are high if compared with other concrete fasteners.

4. SUMMARY AND CONCLUSION

Fire rating of construction products is important. This holds also for fixations with channel bolts installed in anchor channels which are often used to fasten components relevant for fire safety. First fire tests on anchor channels were carried out in the 1990s according to codified tests with standard temperature curves. Later, the qualification and design under fire were regulated specifically for anchor channels, making fire rating tests mandatory. A simplified yet conservative approach reduced the required tests to a minimum.

As an example for state-of-the-art fire rating, one test series for a single combination of anchor channel and channel bolt, which was part of a large test campaign, is presented in this contribution. The example anchor channels and channel bolts failed in three different failure modes during the fire test. It was observed that, by trend, reduced loads shift the point of failure from the nut (most exposed to the heat) over the bolt to the channel (embedded in the concrete member). The evaluation process to determine the fire resistance (R30 to R120) of the tested system was explained in detail. This exercise demonstrated the effort needed for the fire rating of a single combination of anchor channel and channel bolt, let alone a complete portfolio.

Like any other concrete fastener, anchor channels and particularly channel bolts experience a significant reduction in load capacity for the fire rating which must be taken into account for the holistic fire safety concept.

The views expressed in this paper are the views of the authors only and do not necessarily reflect the views of the Southern University of Science and Technology and Jordahl.

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