POST INSTALLED REBARS – PULL-OUT CAPACITY DURING FIRE

NACHTRÄGLICH EINGEMÖRTELTE BEWEHRUNGSSTÄBE – TRAGVERHALTEN BEIM HERAUSZIEHEN UNTER BRANDBEAN-SPRUCHUNG

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SUMMARY

The chemical adhesives bonding materials used for Post Installed Rebars (PIRs) are known to be sensitive to temperature. Hence, the bond strength provided by these bonding materials reduces drastically with increasing temperature which can cause safety related issues. The paper presents a design procedure for PIR under fire which also considers the heat transfer through reinforcing bar. The design procedure consists of three steps: 1) Conducting a 3D transient heat transfer analysis of the structural assembly; 2) Computing the pull-out capacity of PIR using simplified procedure and 3) Computing the demand/load on the rebar by conducting thermal stress analysis. The predicted time to failure for a beam-wall connection using the presented design procedure is in good agreement with the experimental results. Thus, demonstrating the effectiveness and usefulness of the design procedure.

ZUSAMMENFASSUNG

Die für nachträglich eingemörtelte Bewehrungsstäbe (Post Installed Rebars (PIR)) verwendeten chemischen Klebstoffe sind erfahrungsgemäß temperaturempfindlich. Daher nimmt die Verbundfestigkeit mit steigender Temperatur drastisch ab, was zu sicherheitsrelevanten Problemen führen kann. Dieser Aufsatz beschreibt einen Bemessungsansatz für nachträglich eingemörtelte Bewehrungsstäbe bei Brandbelastung, welcher auch die Wärmeübertragung über den Betonstahl berücksichtigt. Das Verfahren besteht aus drei Schritten: 1) Durchführung einer 3D instationären (transienten) Wärmeübertragungsanalyse der Bauwerksstruktur; 2) Ein vereinfachtes Berechnungsverfahren der Auszugsleistung von nachträglich eingemörtelten Bewehrungsstäben; 3) Berechnung der Lasten auf die

Bewehrung mittels einer thermischen Belastungsanalyse. Das dargestellte Bemessungsverfahren zur Bestimmung der Versagenszeit einer nachträglichen Verankerung mit Bewehrungsstäben, stimmt mit den Versuchsergebnissen gut überein.

KEYWORDS: Post installed rebar, fire safety, bond strength, high temperature

1. INTRODUCTION

In recent times, the use of Post Installed Rebar (PIR) technique in various structural engineering applications has increased. Various application includes connecting different structural elements, adding new concrete sections to the existing structure etc. Chemical adhesives are preferred over the traditional cement grout because of its ease of application and very short curing time. There are a lot of such systems readily available in the market with technical approvals. At ambient temperature these PIR systems have been demonstrated to have strengths similar and, in some cases, better than the classic cast-in systems.

In general, the load carrying capacity of anchorages reduces when exposed to fire. But, the pull-out capacity of PIR shows a rapid degradation when exposed to fire. This drastic reduction is because of the polymeric adhesive material whose properties changes significantly over a short temperature range. Hence, these circumstances can cause safety related issues [1]. The paper presents and demonstrates using a case study, a simple design procedure which can be used for determining the fire rating of PIR connections.

2. DESIGN PROCEDURE

The bond-strength degradation of PIR with temperature is highly product dependent, as it depends on the composition of the adhesive material (inorganic/organic/vinyl ester/epoxy) [2, 3]. Hence, an objective design procedure shall be one which uses least product dependent parameter. Moreover, the problem of designing PIR connections under fire also has a structure aspect, while the demand imposed on the PIR is dictated by the structural system. Hence, the design procedure can be divided into two sections: a) computing the pull-out capacity of PIR and b) computing the demand imposed on PIR.

2.1 ASSUMPTIONS

In order to keep the design procedure relatively simple, the following assumptions are made:

1. The effect of the thin polymeric mortar layer between rebar and concrete, on heat transfer is assumed to be negligible.
2. Perfect thermal contact is assumed between concrete and reinforcing bar.
3. It is assumed that the product dependent variation of bond strength with temperature has already been experimentally evaluated in accordance with the European Technical Document [4] and is available to the designer.

2.2 DESIGN STEPS

The design procedure consists of the following steps:

1. Conducting a transient heat transfer analysis of the structural system/connection. The temperature dependent thermal properties of concrete and reinforcing steel are the only input materials properties required for this step.
2. The computed temperature variation along the embedment length of the rebar at a time instance is converted to bond strength variation along its length using the product dependent bond strength as function of temperature.
3. The pull-out capacity of PIR at a time instance, is then obtained by integrating the bond strength variation along the embedment length. There are a wide variety of integration schemes available but for simplicity the midpoint rule (or the rectangular rule) has been used in the present study. An illustration of the integration scheme is shown in Fig. 1.
4. The variation of the pull-out capacity of PIR with exposure time is obtained by repeating steps 2 & 3 for different time instances. Hence, the capacity curve is obtained.
5. This step deals with the evaluation of the demand imposed on the PIR. The demand on the PIR changes with time due to the redistribution of internal stresses within the connected structural members, due to the high temperatures. Hence, a structural analysis (thermal stress analysis) needs to be conducted to determine the demand imposed on the PIR. Depending on the complexity of the structural configuration/connection/subassembly being designed structural analysis with various levels of complexity can be performed.

The analysis method might be a sectional analysis [5-7] for relatively simple connections as cantilever beam/slab to wall connection, where the applied moment on the connection is constant. In case of full structures or structural subassemblies, in addition to stress redistribution at sectional level moment redistribution at structural level also occurs due to fire exposure. Hence, for calculating the demand on PIR for such applications, the designer shall have to use more complex structural analysis tools available [8-10].

6. The variation of pull-out capacity of PIR with exposure time as obtained in step 4 and the variation of the demand on the PIR with fire exposure time as obtained in step 5, are plotted on the same graph. The point of intersection of the two curves gives the failure time.

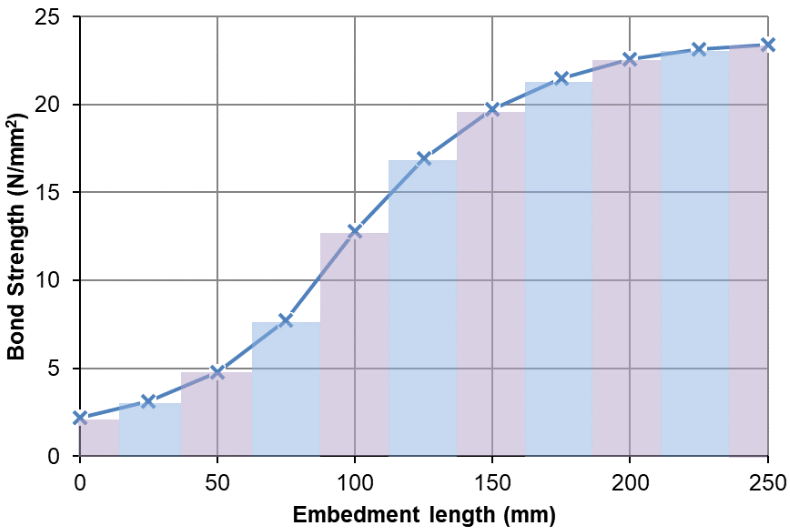


Fig. 1: Integration scheme for evaluating the pull-out capacity (Rectangular rule)

3. CASE STUDY

In order to demonstrate the design procedure experiment performed by Pinoteau et al. [11] is selected. They performed tests on two cantilever beam – wall connections. The 3 m long cantilever beams were connected to the wall using PIRs. The beams were uniformly loaded by placing aerated concrete blocks along its length and some steel dead weights. The total load on one beam was 750 kg, which induced a moment of 19.5 kN-m (including self-weight) at the beam-wall interface. The beams were exposed to standard temperature-time curve as per ISO 834, from 3 sides. Fig. 2 schematically shows the test setup for testing the beam-wall connection.

The beams had a cross-section of 240 x 350 mm and were made of normal strength concrete with a compressive strength of 33 MPa. The reinforcement consisted of 2 – 16 dia. rebars in the tension zone (top) and 2 - 10 dia. rebars in the compression zone (bottom) as shown in Fig. 3. The reinforcing bars had a yield strength of 500 MPa.

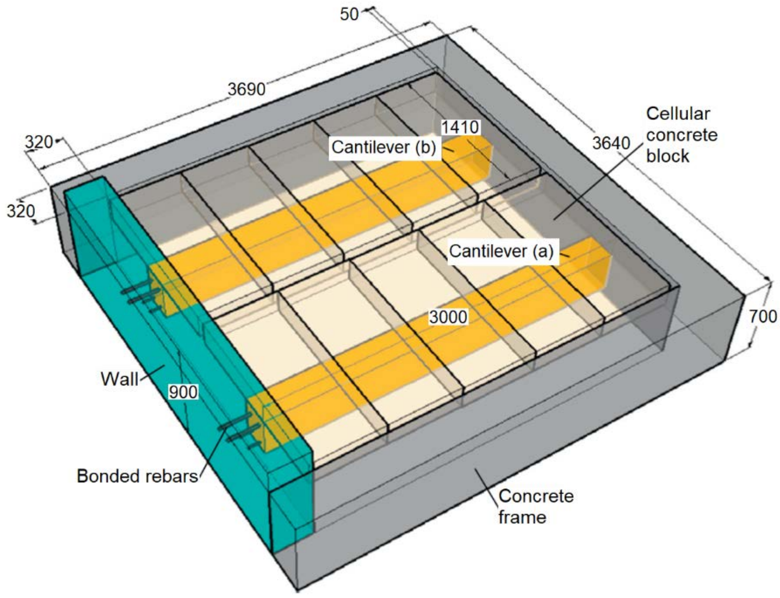


Fig. 2: Beam-wall connection configuration tested under fire [11] (All dimensions in mm)

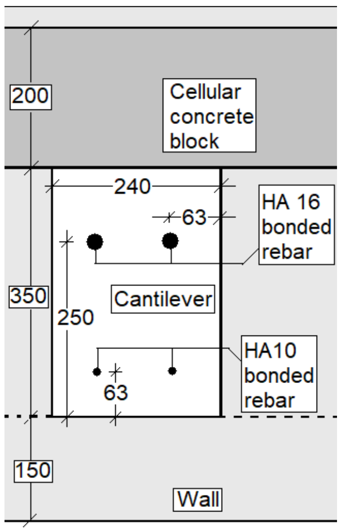


Fig. 3: Cantilever beam cross-sectional details (All dimensions in mm)

The variation of bond strength with temperature for the chemical adhesive used for installing the rebar as reported by Pinoteau et al. [11] is shown in Fig. 4. Equation 1 defines the bond strength degradation model fitted to the experimental data (shown in Fig. 4) and used for computing the pull-out capacity of PIR.

The geometry of the beam and wall was discretised using tetrahedron elements with an average size of 20 – 25 mm. The rebar was also modelled using 8-noded solid elements. The Finite Element (FE) mesh for concrete and rebar are shown in Fig. 5 (a) & (b) respectively. The heat transfer from the hot gases to the concrete surface is modelled considering both convective and radiative components. For the transient heat transfer simulation, the input thermal properties for concrete and reinforcing steel were taken from Eurocode 2 [12] (shown in Fig. 6) and Eurocode 3 [13] (shown in Fig. 7), respectively. The lower bound conductivity and specific heat for dry concrete were used based on the sensitivity studied performed by Lakhani et al. (2013) [14].

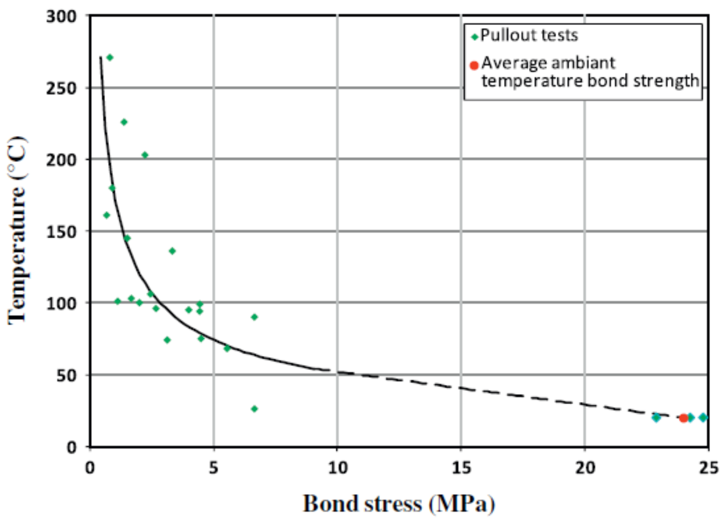
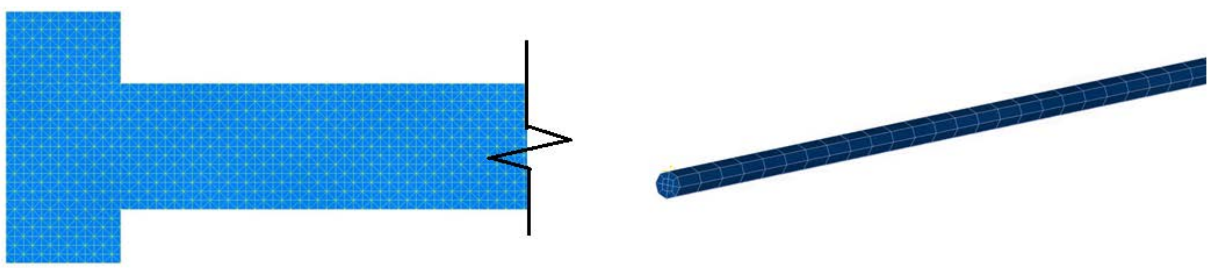


Fig. 4: Bond stress variation with temperature for the polymeric adhesive used by Pinoteau et al. [11]

$$\tau(T) = \begin{cases} -0.437 \times T + 32.73 & T <= 56.6\ °C \\ \left(\frac{T}{174.06}\right)^{-1.887} & T > 56.6\ °C \\ 0 & T >= 271\ °C \end{cases} \qquad (1)$$

Where: $\tau(T)$ = bond strength at temperature T in MPa; T = Temperature in °C.



(a) Concrete (b) Reinforcement

Fig. 5: Geometric discretisation of Cantilever beam-wall connection (FE mesh)

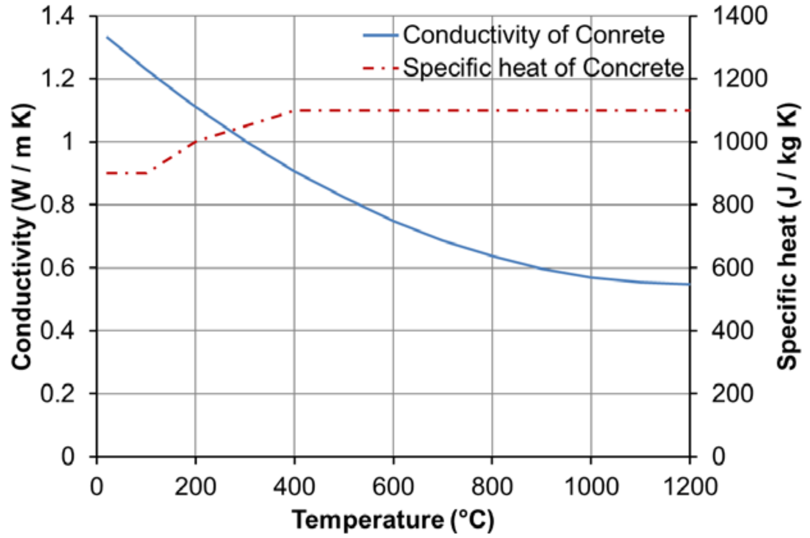


Fig. 6: Thermal properties of concrete as function of temperature

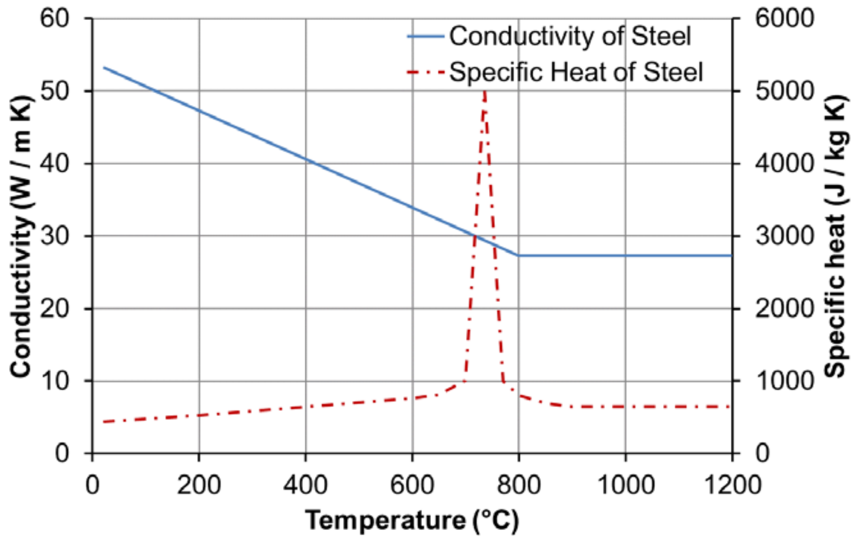


Fig. 7: Thermal properties of reinforcing steel as function of temperature

Fig. 8 shows a comparison between the predicted and experimentally observed temperature variation in one of the cantilever beams (referred as beam b by Pinoteau et al. [11]). It can be seen from Fig. 8, that the predicted temperatures are in good agreement with the experimentally measured temperatures.

The predicted temperature variation along the embedment depth of tension reinforcement (16 dia. Rebar; 250 mm embedment depth) after 60 minutes, 120 minutes and 180 minutes of fire exposure is shown in Fig. 9. Embedment length/depth zero implies the junction at the beam – wall connection and as the length/depth increases the point goes deeper into the wall.

Using the predicted temperatures along the rebar length and the bond strength degradation given by Eq. (1), the capacity curve for the PIR can be computed as explained in Section 2. The variation of bond strength along the embedment depth of tension reinforcement at 60 minutes, 120 minutes and 180 minutes of fire exposure is shown in Fig. 10.

The pull-out capacity of the PIR is obtained by integrating the bond strength variation along the embedment length at various time instances. The computed capacity curve is shown in Fig. 11. It can be clearly seen that, although the tension reinforcement (embedment into the wall) are in the relatively cooler joint region, the pull-out capacity of the PIR reduces drastically with increasing fire exposure time. This can be attributed to the heat flow which occurs along the rebar length.

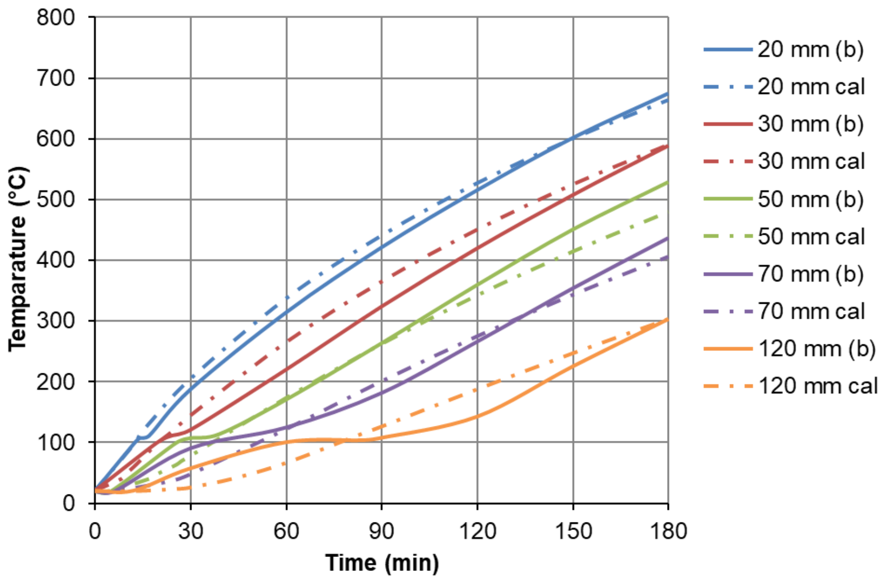


Fig. 8: Temperature variation in the cantilever beam
(The distance specified are along the middle of the beam cross-section measure from the bottom exposed face; solid lines – experimental values and dotted lines – predicted values)

The demand on the tension reinforcement in the beam-wall connection is evaluated using the sectional analysis approach proposed by Fitiany and Youssef (2009) [5]. It should be noted that the designer is free to use any of the available analysis tool to compute the demand on the rebar. For computing the demand in the presented case-study the reinforcing steel was considered to be cold-rolled and concrete was considered to be made of siliceous aggregates. The temperature dependent stress-strain constitutive law for concrete and reinforcement was taken from Eurocode 2 [12].

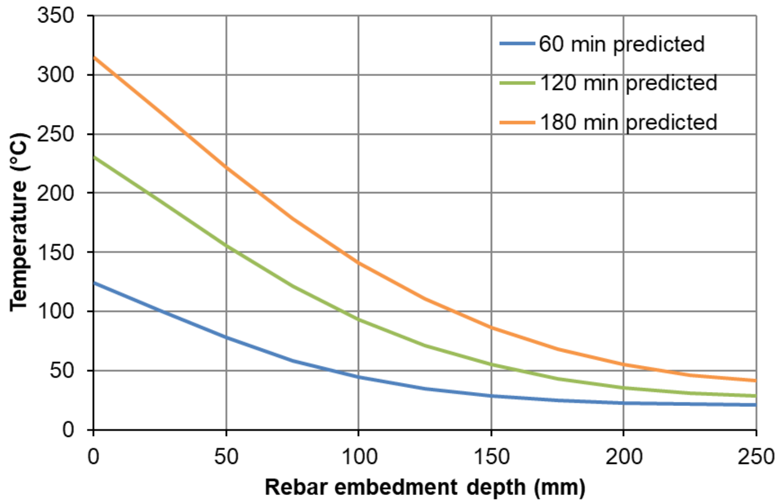


Fig. 9: Temperature variation along the embedment length of tension reinforcement in the cantilever beam

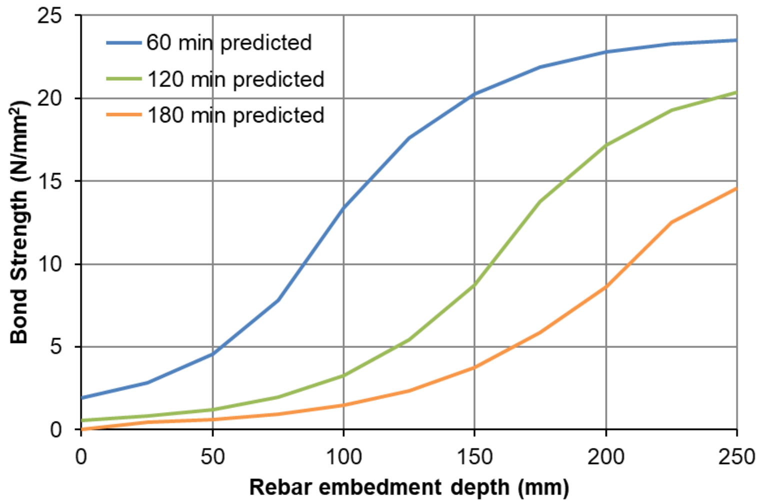


Fig. 10: Temperature variation along the embedment length of tension reinforcement in the cantilever beam

The computed demand on the PIR is shown in Fig. 11. It can be seen that the demand imposed on the PIR increases during the initial 45 minutes of the fire exposure. Although the demand reduces slightly after reaching a peak value, it should be notated that it’s still higher than the demand computed at time t = 0 minutes (initial demand at ambient conditions). Hence, computing the demand curve using structural analysis (thermal stress analysis) is an important part of designing PIR connections under fire. The time to failure for the beam-wall connection investigated can be obtained from Fig. 11, as the intersection point of the capacity and demand curves. The predicted failure time is 172 minutes against experimentally obtained failure time of 178 minutes.

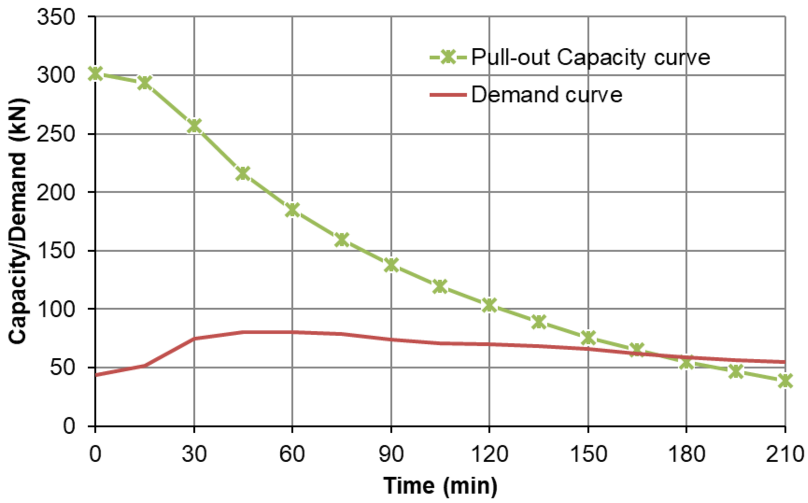


Fig. 11: Temperature variation along the embedment length of tension reinforcement in the cantilever beam

4. CONCLUDING REMARKS

The paper presented a design procedure for designing PIR connections under fire. The proposed design procedure also considers the heat transfer along the re-bar axis, which has been previously ignored by researchers. The application of the discussed design procedure has been demonstrated with the help of a case-study on beam – wall connection. The predicted failure time is in good agreement with the experimentally observed failure time. Thus, validating the design procedure and proving it to be a useful design tool if the temperature dependent behaviour of the polymeric mortar is available.

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