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POTENTIALS IN CONNECTIONS BETWEEN STEEL AND CONCRETE WITH SPECIAL EMPHASIS ON TEMPERATURE INFLUENCES

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ABSTRACT

Modern construction technology requires new types of constructions materials and new construction elements both for existing as well as for new structures. Adequate interaction between elements and bond between reinforcement and concrete are major issues for concrete and for steel-concrete composite structures. High requirements have to be fulfilled both for fastening and connecting elements as well as for the bond interaction of reinforcements on anchoring (force transfer) capacity, ductility, deformation capacity, safety, long term properties, durability, fire resistance, applicability etc.

Bond research is again in the focus of interest owing to the appearance of new types of reinforcements (e.g. non-metallic reinforcements) and new types of concretes. New materials provide new aspects to the anyhow complex picture of influencing factors and failure modes. Bond performance has effects both on ultimate behaviour (flexure and shear capacities) and serviceability behaviour (cracking, tension stiffening and deflections).

In some areas of bond and interactional behaviour (especially high temperatures) still limited information is available. The reason is the complexity of experiments. Therefore, a particular emphasis is given herein to consequences of high temperatures.

Present paper intends to review some of the new potentials in anchoring solutions as well as for bond.

1 Introduction

The series of conferences on *Connections between Steel and Concrete* provides an excellent forum for presenting developments on connections of all kinds including (i) fastenings/anchors, (ii) bond in general and (iii) steel-concrete composite structures.

Eligehausen and Fuchs called our attention as current and future research projects for fastening technique in their Keynote at the 2nd ConSC2007[1]: optimization of the design methods for fastenings, behaviour and design of fastenings with anchor reinforcement, fire resistance of fasteners, fastenings under seismic excitations, strengthening and retrofitting of structures, new fastening techniques, influence of concrete composition on the behaviour of chemical anchors, durability of chemical anchors, connections with post-installed rebars, fastening in solid and hollow masonry.

On the other hand, the following developments were addressed for *composite structures* by the Keynote of Kuhlmann at the 2nd ConSC2007[2] as: composite girders and slim-floor girders, composite slabs, composite columns, composite joints and frames, composite bridges.

Present paper intends to give an overview on potentials and new developments of connections mainly to above (i) and to (ii) with special emphasis for temperature influences on them, respectively.

1.1 Interaction between anchors and concrete, behaviour and modelling

Anchoring methods and anchoring systems are continuously further developed. A new element is shown in Fig. 1 as a special example. This is short (about 300 mm long) GFRP bar, where the overall length is too short to develop enough anchoring capacities at both ends. Therefore, multi diameter heads were created with increasing diameters outwards to provide improved development of anchoring forces.

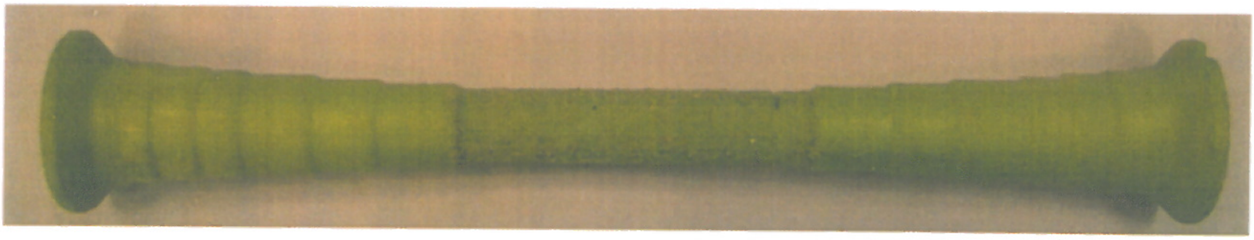

Figure 1: New type of GFRP bar with end-anchors at both ends

A significant part of research is dealing with the strengthening of reinforced concrete (RC) members with externally bonded fibre-reinforced polymer (FRP) composites has been generated to date e.g.[3, 4, 5, 6, 7]. Researchers have consistently identified a limitation of the approach to be debonding of the FRP in generally a brittle manner. In addition, debonding has been found to typically occur at strains considerably lower than the strain capacity of the FRP material e.g. [7, 8]. In a bid to better utilise the FRP material and provide a safer strengthening solution, anchorage devices may be installed. Devices such as FRP anchors, U-jackets and nailed plates have proven to be effective in suppressing debonding failures and they have enabled strengthened members to achieve greater deformability in cases [9, 10, 11].

Whenever the strengthening fibres are not pre-impregnated by resin, the anchoring capacity can be developed within a short distance by creating special end solutions like in Fig. 2.

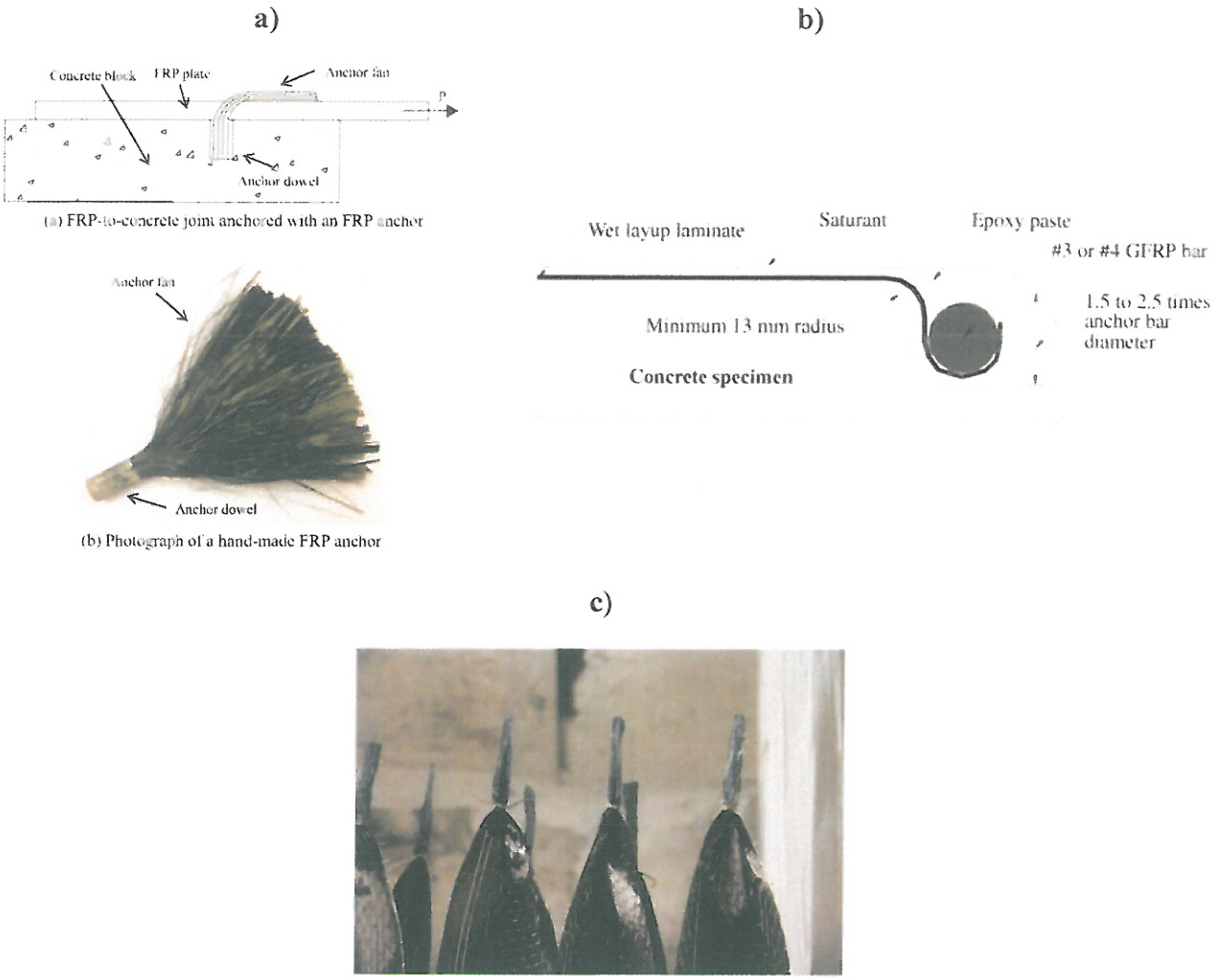

Figure 2: New ideas for anchoring FRP [to a):Ref. [12] and to b): Ref. [13]]

There are several reasons to pursue research and application of FRP anchors in comparison to anchors made of more traditional materials such as metal, namely, (i) FRP anchors can be applied to wide shaped FRP-strengthened members such as slabs and walls, (ii) FRP anchors are corrosion resistant, (iii) the flexible nature of FRP anchors results in limited bearing pressure induced between the anchor and adjacent FRP plate which minimizes plate splitting failure, and (iv) the FRP anchor can be installed at the same time as the FRP plate thus ensuring a monolithic plate and anchor strengthening unit.

Several post-installed anchors (Figure 3) are available with different ways of force transfer mechanisms in order to enable force applications owing to technological reasons or any other reasons. The fastenings can transfer the load to the base material via the following mechanisms: mechanical interlock, friction or bond. Furthermore, the most recent techniques use combined bond and friction (e.g. bonded expansion anchors). In case of expansion anchors, the load is transferred by friction. Generally, an expansion sleeve is expanded by an exact displacement or torque. Chemical fastenings are anchored by bond. Bonded anchors can be divided into two subgroups: capsule or injection systems. The bond material can be either organic, inorganic or a mixture of them. In this case the loads are transferred from the steel (normally a threaded rod, rebar) into the bonding material and are anchored by bond between the bonding material and the sides of the drilled holes [14, 15, 16, 17, 18, 19, 20, 21, 22].

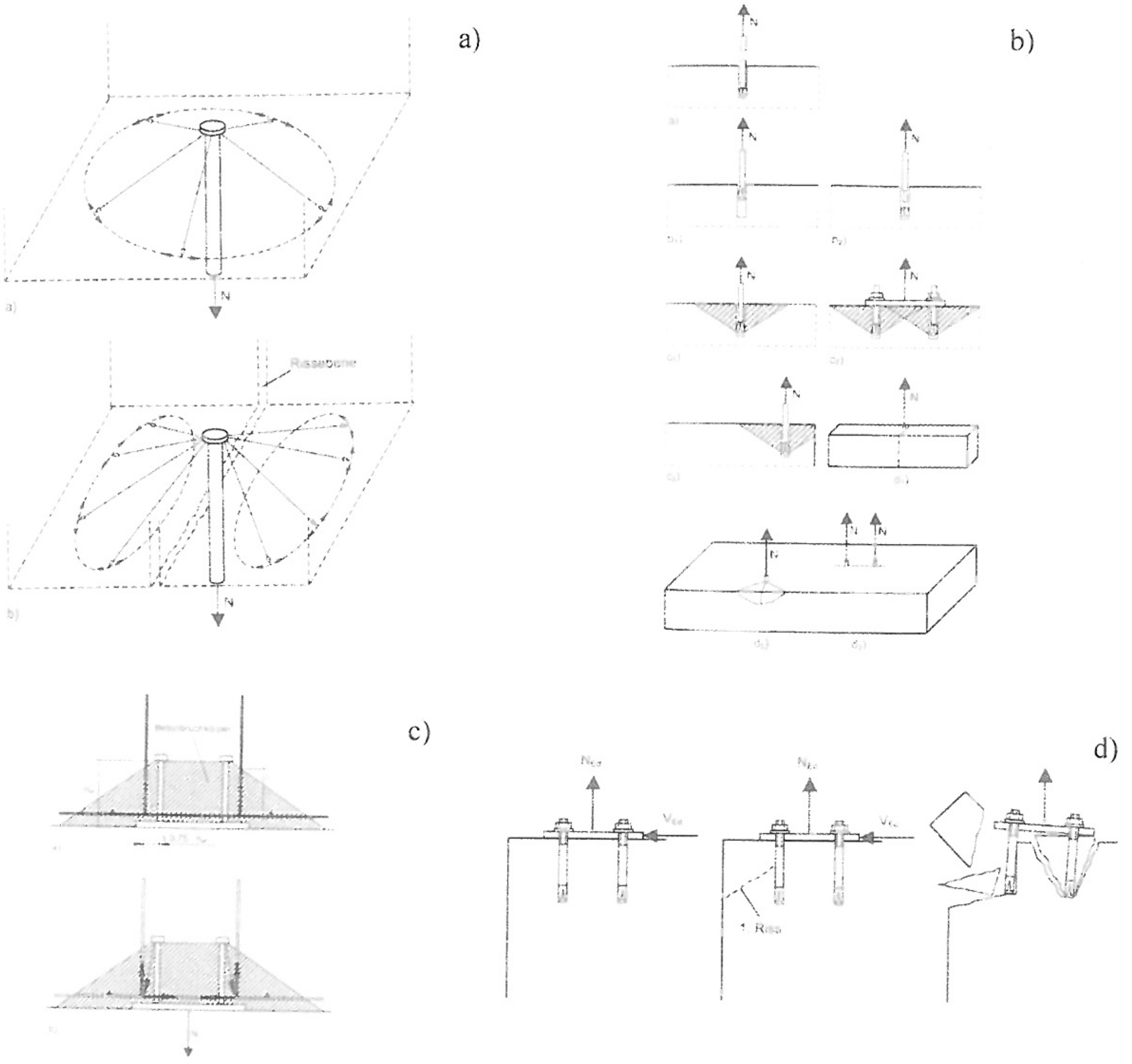

Figure 3: Overview of behaviour of anchors in concrete [23]

a) Load balancing with or without cracks [24]
b) Failure modes [18]
c) Force increase in reinforcement due to anchors [23]
d) Corner failure a multiple anchor [23]

The load balancing for fastenings is visualized in Figure 3.a with or without the presence of a crack in concrete within the section of the anchor. Figure 3.b indicates how the force that is generated by the anchor in concrete balanced by the steel reinforcement. Figure 3.c gives the main types of failure modes in concrete. Figure 3.d indicates the complex behaviour of an anchor group close to a corner.

Load bearing of fastenings can be determined by taking the minimum of ultimate loads corresponding to different failure modes.

Steel failure depends on the tensile strength of the steel rod. Steel capacity can be calculated from the ultimate steel strength (f_u) and the cross-sectional area (A_s) [14, 15, 16].

The properties of concrete cone failure mostly depend on embedment depth (h_{ef}) and concrete strength (f_{ck}). Cone failure is the optimal failure type, because concrete strength is completely utilized. Partial cone failure is a common failure type of bonded anchors; in this case the bond between the bond material and concrete is partly damaged. This means a transitional failure type between cone failure and pull-out [14, 16].

Pull-out failure has to be discussed separately for bonded and expansion anchors. Pull-out failure of mortar bonded anchors means bond failure between mortar and concrete, while pull-out failure excluding mortar means bond failure between the steel fastening and the bonding material. The bond strength ($\tau_{u,k}$) depends on the certain product, but its value is included in the corresponding approvals.

Pull-out failure in case of expansion anchors is possible under tension, including or excluding the expansion sleeve (pull-out/pull-through).

Splitting failure is caused by the critical edge-, spacing distances. Load bearing capacity can be influenced by distances from edges and by spacing distances; these effects can be taken into account by reduction factors [14, 16].

The use of precast concrete elements in construction has increased over the last decades. It arises from the innovation of new construction methods and usually advances beyond standard rules of design. These individual elements must be transported to the building site and affixed in the corresponding place thereby connecting them with the main structure or with other auxiliary elements. Anchor elements previously incorporated in the precast pieces serve to perform this function. Every load that affects these elements is transferred through their anchorages and makes them an essential part of the structural support system. Thus, the proper design of these elements is essential [25].

If fasteners are subjected to repeated actions, the fatigue resistance must be verified. Since, the fatigue behaviour of steel is well known for fasteners, a special attention should be devoted to the fatigue of concrete. The concrete fatigue can be decisive in case of high cycle fatigue loading, particularly if the load amplitude is selected such, that it is below the endurance limit of steel. In case of fasteners, no endurance limit can be observed, which corresponds to the expected concrete fatigue behaviour [26].

The durability of the prestress anchor bolt is strongly affected by the time-dependent behaviour of concrete. A concrete with a mix proportion giving the lowest possible shrinkage and creep is recommended in order to limit the decrease in the prestress. Moreover, these anchors are submitted to fatigue stress which can increase the concrete packing. [27]

Our experimental results on bonded anchors after fire exposure are presented in Ch 2.2.

After temperature loading the material characteristics could be significantly changed [28, 29, 30, 31, 32]. In case of bonded anchors glass transition temperature of the adhesive is important. Bond strength is considerably reduced if the temperature goes beyond glass transition temperature of the adhesive.

Metallic post-installed and undercut anchors were experimentally studied by Bamonte, Gambarova [31] in thermally damaged concrete. The shank diameter was 10 mm. The effective depth was 80 mm. The anchors were installed into the previous heated surface. The observed peak load was linearly decreasing by increase of the previous temperature load [33, 34, 35]. The failure mode is also affected by the temperature. At room temperature failure of the steel shank took place.

Ožbolt, Kožar, Eligehausen and Periskič [36] indicated by FEM analysis that the largest reduction of the load bearing capacity is obtained for anchors with relatively small embedment depth. By heating of concrete the resistance is generally decreasing, however, when the concrete member is heated than cooled down, the resistance can increase and it can even be larger than the resistance of the anchor in unheated concrete [36].

1.2 Bond between steel and concrete

Bond performance in reinforced concrete is usually represented by bond stress vs. slip (τ_b-s) relationships evaluated from pull-out tests (Figure 4). In general, the following phases of bond performance can be distinguished: (1) adhesional contact without slip, (2) mechanical interlock with increasing slip (during mechanical interlock micro-cracks [37] form around the reinforcement in the concrete and micro-crushing takes place in front of the ribs of reinforcement), (3) after reaching the maximum stress (bond strength) the small concrete teeth between ribs of the reinforcement are sheared off, (4) finally only friction is provided also for plain as well as for ribbed bars. This residual bond strength for plain bars is about two-third of that of ribbed bars owing to the differences in frictional coefficients for concrete to steel (in case of plain bars) or concrete to concrete (in case of deformed bars). Increase of bond stress plain bars after adhesion is very low and its value remains practically constant during pull-out.

Two types of failure modes are distinguished: (a) pull-out failure if adequate confinement is provided by the concrete cover or by transverse reinforcement of (b) splitting failure with drop of bond stress if concrete cover splits along the reinforcing bar. Eligehausen [38] called the attention for the importance of splitting failure especially for lap splices but also for anchorages.

Bond research has a history of at least 100 years and never seems to stop. The reason is probably the very wide range of influencing factors. Influencing factors of bond can be classified into four main groups:

1. Influences of concrete on bond: concrete compressive strength, concrete tensile strength, concrete cover[39], grading curve of aggregate[40], consistency of fresh concrete[41], fibres in concrete;

2. Influences of reinforcement on bond: relative rib area of bar[41], rib pattern of bar [42] (including inclination and shape of ribs), diameter of bar, coating (epoxy coating for steel bars or sand coating for non-metallic bars), corrosion of steel bars [43], amount of transverse reinforcement [44], stress in the reinforcement;

3. Influence of load history on bond: monotonically increasing loading (including influence of loading rate [45], long term loading, cyclic loading, reversed cyclic loading [46, 47];

4. Influence of position of bar on bond: position of bar during casting, position of bar to the next flexural crack, width of splitting crack along the bar.

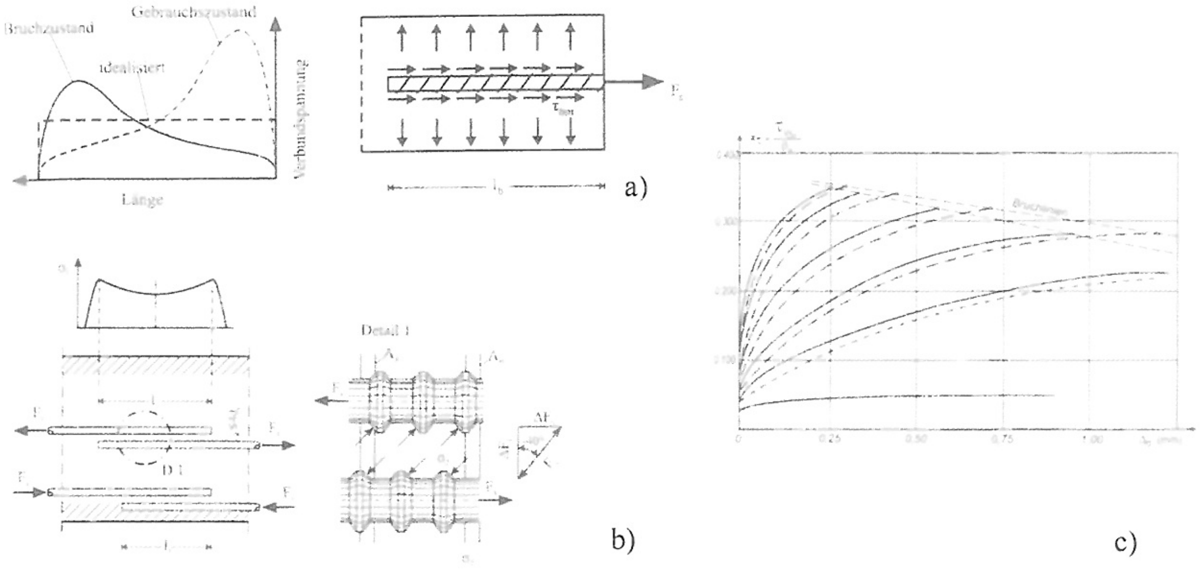

Figure 4: Bond development

a) Bond development over an anchorage [48]
b) Bond development overlap a splice [49]
c) Bond-slip relationships as a function of relative rib area[50]

Above parameters influence bond behaviour in different ways. In specific cases careful analysis is required.

Corrosion induced deterioration of reinforced and prestressed concrete structures stimulated research and application of non-metallic reinforcements. Non-metallic reinforcements are made of Fibre Reinforced Polymers (FRP). High strength fibres of FRP can be made of glass, aramid or carbon with a volumetric fibre ratio of 60 to 70%. Matrix resin is usually epoxy resin. Carbon Fibre Reinforced Polymers (CFRP) show excellent fatigue strength, low relaxation and creep behaviour in addition to high tensile strength and corrosion resistance. FRP have tensile strengths of 700 to 3500 N/mm^2, Young's moduli of 38 000 to 300 000 N/mm^2, failure strains of 0.8 to 4.0%. FRP show no yielding, behave linearly elastic up to failure with brittle rupture.

Surface treatments (such as spiral fibre winding, indentations, periodic ribs, stranded or braided shape or sand coating) are used to improve bond characteristics of FRP (Figure 5). These treatments can increase bond strength of FRP reinforcements even more than that of steel tendons. During pull-out bond failure of non-metallic reinforcing bars the outer layers of FRP reinforcements (periodic ribs, helical wrapping, indentations, etc.) can be damaged which never occurs in the case of steel tendons or reinforcing bars.

Bond strength and bond behaviour is influenced not only by the concrete properties but also the mechanical as well as surface properties of the non-metallic rebars. These differences may influence structural behaviour.

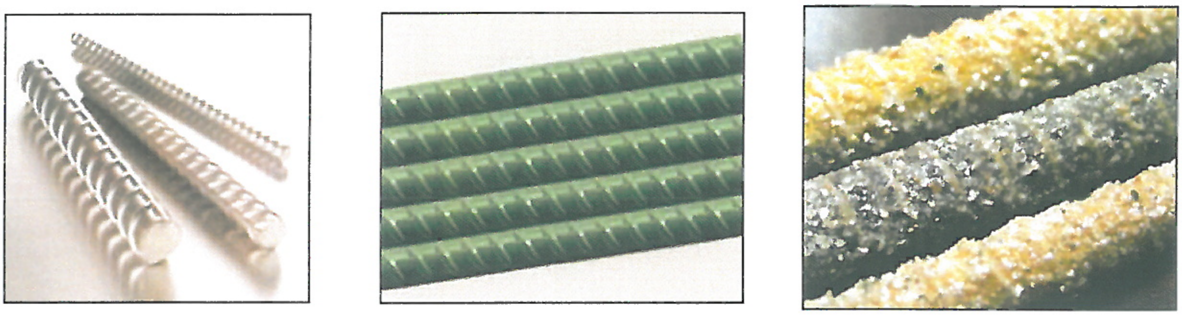

Figure 5: Some types of rebars (stainless steel, epoxy coated, FRP)

Deformation capacity of outer layers defines the slip both at bond strength and at failure. Partial damage of ribs can also cause sudden changes of the τ_b-s relationship. Sand coating is resulted in very high adhesion for the reinforcement, however bond strength is reached at limited slip. Residual bond strength is utilised mainly from friction that can be higher or less than in the case of conventional reinforcement depending on the type of fibre, resin and surface configuration. Due to various surface treatments of non-metallic reinforcing bars bond strength can be even higher than that of deformed steel rebars.

New types of concretes (high-strength concrete (HSC), fibre reinforced concrete (FRC) and light weight aggregate concrete (LWAC)) has increasingly become popular within the last few decades.

One of the critical issues is the bond behaviour at high temperatures. During the exposure to high temperatures, concrete undergoes changes in its chemical composition, physical structure and water content. These changes primarily occur in the hardened cement paste. The resulting physical changes and chemical decomposition of major concrete constituents are demonstrated by e. g. cracks, explosive spalling or both [51, 52, 53, 54, 55].

Investigations on the bond strength between concrete and reinforcing steel at room temperature have been carried out over many years, however, only few experiments are available on the effects of high temperature on the bond characteristics.

Our experimental results on bond between steel and concrete after fire are presented in Ch 2.1.

2 Our experimental studies with bond and anchors at high temperatures

2.1 Bond of anchors after fire

In our study one type pf expansion and two types of bonded anchors with adhesives of vinyl ester or vinyl ester with cement were tested in two different concrete grades ($f_{cm}=64.5$ N/mm^2, $f_{cm}=43.4$ N/mm^2). The effective depth of anchors was 50 mm for a diameter of 8 mm. The maximal heating temperatures were 150 °C and 300 °C, respectively. Reference tests were also carried out on specimens stored at room temperature. The anchors were installed in concrete blocks of 300x300x100 mm at room temperature, then the specimens were heated from all sides. The temperature was controlled by type K thermo-elements. The specimens were kept for 24 hours on constant maximum temperature to assure uniform temperature distribution in the elements. Pull-out tests were carried out afterwards at room temperature. The pull-out force was measured with dynamometer, the relative displacement was measured by two LVDTs and their signals were averaged.

2.1.1 Torque controlled expansion anchors

In Figure 6 we have illustrated the maximum measured force as a function of the temperature in case of torque controlled expansion anchors (FBN 50+63).

In case of torque controlled expansion anchors we have observed three different failure modes. In the first case we have observed concrete cone failure. In the second case the anchor head lost its ring and we observed pull-out with concrete splitting (small concrete cone). In the third case we observed steel failure at the minimum diameter of the head. This kind of failure did not cause concrete cone failure. The failure mode depended on the concrete strengths and on the temperature. We have observed steel failure of the anchors in case of relatively high strength concrete at 20 °C and also after previous temperature loading of 300°C. In case of lower strengths we have observed steel failure of the anchor only after previous temperature loading of 300 °C.

2.1.2 Bonded anchors

Peak loads of bonded anchors (FIS A 8-175, anchor, FIS V 360 S, vinyl ester mixed with cement, FIS VT 380 C, vinyl ester) as a function of previous temperature loading were demonstrated in Figure 7.

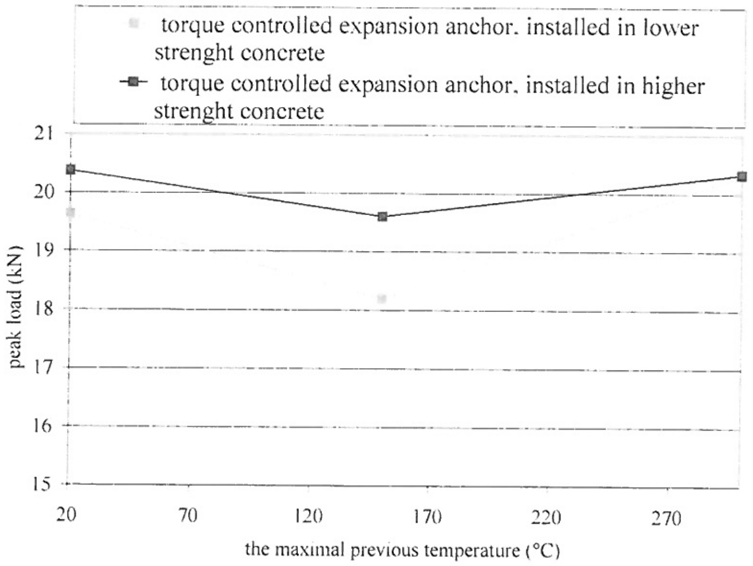

Figure 6: Peak loads of the torque controlled expanded anchors in function of temperature

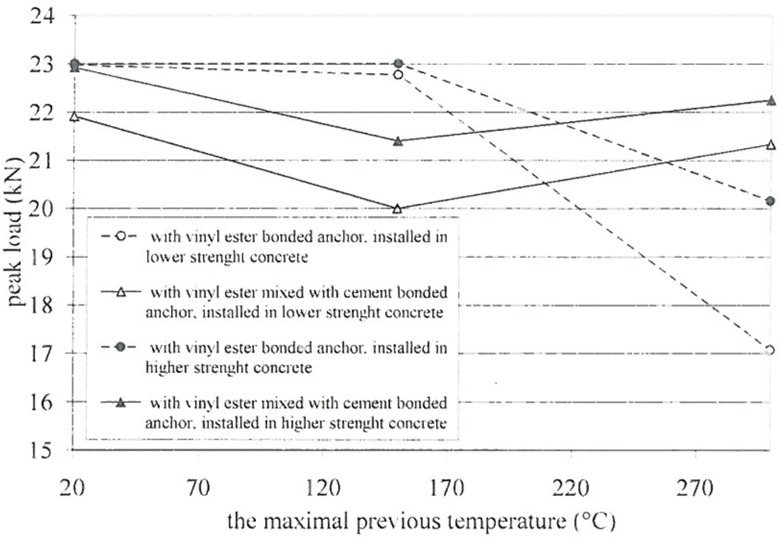

Figure 7: Peak loads of the bonded anchors in function of temperature

By comparing the continuous lines in Figures 6 and 7, we can observe similar tendencies of peak load vs. maximal temperature of previous temperature loading up to 300 °C, for torque controlled expansion anchors or bonded anchors using vinyl ester adhesive mixed with cement. However, these bonded anchors provided slightly higher peak loads.

The failure mode depended also on the concrete strengths and on the maximum temperature load. In case of concrete with relatively high strengths we observed concrete cone failure at room temperature after temperature loading to 150 °C and 300 °C. In case of lower strengths concrete we observed shallow concrete cone with bond failure at all test temperatures.

Vinyl ester adhesive is more sensitive to the increase of the temperature. We observed steel failure at 20 °C independent from the bond strength. After heating up to 150 °C we observed different failure modes. In case of higher concrete strength the failure mode was steel failure. In all other cases concrete cone with bond failure was observed. After heating up to 300°C in all cases concrete cone with bond failure and significant decrease of bond strength were observed.

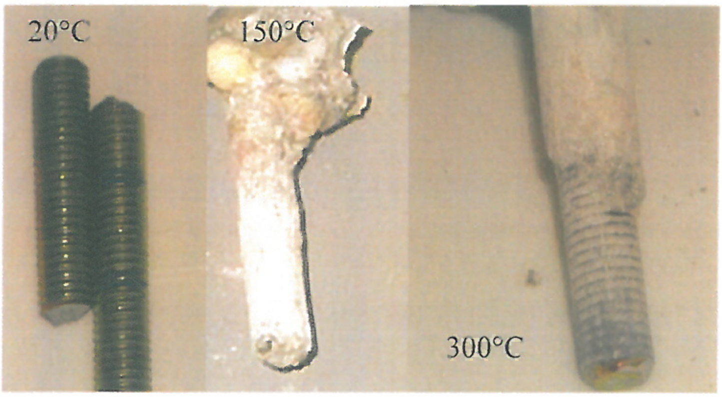

Figure 8: Failure mode in case of bonded anchors with vinyl ester

After the pull out tests we analysed the failed bond surface. We did not observe the damage of the adhesive after temperature loading up to 150 °C. After heating up to 300 °C then cooling it down, the adhesive was significantly damaged (Figure 8).

2.2 Bond of anchors in fire damaged concrete

In our work we analysed the load bearing capacity of anchors placed in thermally-damaged reinforced concrete. Our primary goal was to assist the reinforcement work of reinforced concrete structural members damaged in fire events. One concrete mixture recipe was used to prepare the specimens. 28-days compressive strength of concrete was measured using 150x150x150 mm cubes. The average compressive strength of the concrete used was $f_{cm} = 44.79$ N/mm^2. During the experiment, the specimens were exposed to fire load on one side until they reached the desired temperature, then they were allowed to cool down at laboratory temperature (20 °C). The day after the fire load, typically after 24 hours, when the specimen had been cooled down, the fastener was inserted in the thermally damaged specimen. In order to allow the cross-linking of the adhesive, loading of the fasteners took place after a further 24 hours.

During the experiment, anchors have failed in all cases with a concrete cone failure. These failures illustrate that an adhesive bond can be created between the adhesive and the thermally stressed concrete with a strength that caused a concrete cone failure. During the tests, no specimen showed either a clear pull-out failure or the combination of concrete cone failure and pull-out failure. On the surface of the concrete cones, aggregate particles close to the thermally stressed surface had a reddish discoloration, and the ratio of discoloured particles increased when approaching the embedment depth and with increasing temperature. This discoloration could be explained by the chemical processes that occurred in the quartz gravel. In case of thermally stressed specimens, the crack creating the concrete cone was just running in the cement stone, while aggregate particles remained intact. The aggregate particles could be easily twisted from their positions as a consequence of damage to the adhesion between cement stone and aggregate.

Figure 9 shows the tensile resistance of the anchors, while Figure 10 shows the relative residual resistance values as a function of temperature.

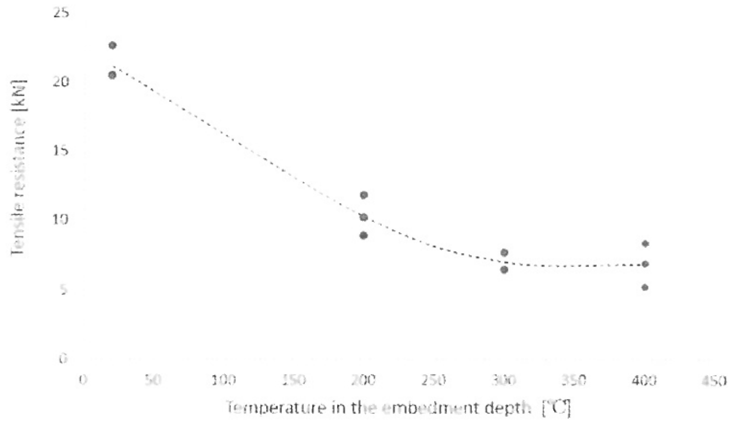

Figure 9: Relationship between the tensile resistance and the temperature in the embedment depth

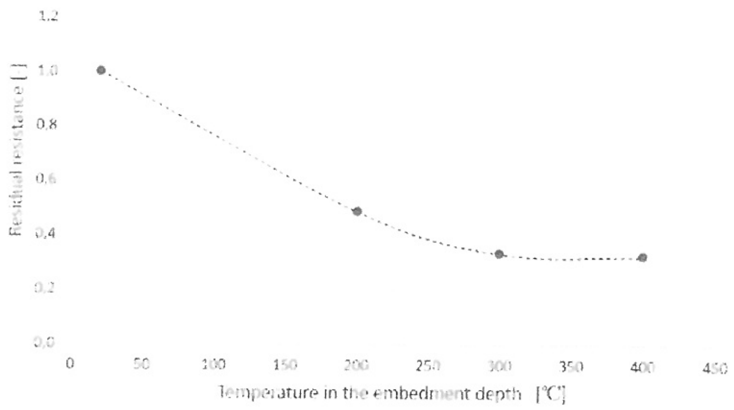

Figure 10: Relationship between the residual resistance and the temperature in the embedment depth

We used the tensile resistance of anchors fixed with epoxy resin as a standard: it drops to 49% compared to fasteners that have not been exposed to fire when temperature reaches an average of 200 °C-in the embedment depth; it drops to 33% when temperature reaches 300 °C in the embedment depth, and to 32% when temperature reaches an average of 400 °C in the embedment depth.

The force-displacement curves of pull-out tests performed on the standard specimens described a brittle failure (Figure 11). The initial rapid force uptake, after reaching the maximum load, was followed by a rapid failure with small displacements. The force-displacement curves of pull-out tests performed on the thermally stressed specimens showed a gradual decrease in load bearing capacity. It can be observed that the curves are more and more flattened as the temperature increases, which means that failure is accompanied by increasingly greater displacements. It is interesting to note that the maximum recorded force had nearly the same displacement value in all four cases (~1 mm).

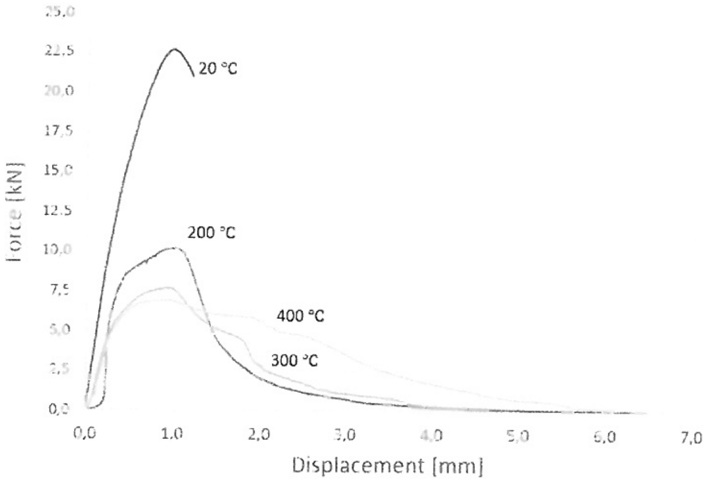

Figure 11: Typical force – displacement curves

2.3 Bond between steel and concrete after fire

Bond behaviour between concrete and reinforcing bars was studied under various levels of elevated temperatures. Five different concrete compositions were used. Hundred five pull-out specimens (Ø120 mm, 100 mm) were prepared. After removing the specimens from the formwork, they were stored in water for seven days then kept at laboratory conditions until testing. The specimens were 28 days old when tested.

We carried out an experimental study to analyse the bond characteristics after being subjected to high temperatures. Test variables were:

- maximal temperature (20 °C, 50 °C, 150 °C, 300 °C, 400 °C, 500 °C, 600 °C, 800 °C)
- type of aggregate (quartz gravel, expanded clay)
- type of fibres (polypropylene fibers, hocked-end steel fibers).

The water cement ratio was constant: w/c=0.43. The amount of cement, water, aggregate, fibres and plasticizer are given in Table 1. The consistency of concrete was measured by flow table tests and resulted 450 to 500 mm.

Table 1: Experimental concrete mixes (* polypropylene fibers, **hocked-end steel fibers)

	Mix 0	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5
cement (kg/m^3)	350	350	350	386	386	350
water(kg/m^3)	151	151	151	181	181	151
aggregate (kg/m^3) 0-4 mm	912 quartz sand	912 quartz sand	912 quartz sand	1024 quartz sand	1015 quartz sand	912 quartz sand
aggregate (kg/m^3) 4-8 mm	485 quartz gravel	485 quartz gravel	485 expanded clay	302 expanded clay	390 quartz gravel	485 quartz gravel
aggregate (kg/m^3) 8-16 mm	544	544	544	-	-	544
plasticizer kg/m^3)	1.4	1.4	1.4	5	5	1.4
fibres (kg/m^3)	-	1*	1*	-	-	35**

The pull-out specimens had a diameter of 120 mm and height of 100 mm. Slip was measured with two LVDTs at the unloaded side.

Figure 12 indicates the measured relative residual bond strength values of concrete as a function of maximal temperatures up to 800 °C. Pull-out test were carried out at room temperature after heating and cooling the specimens. The following conclusions can be drawn:

1. The relative bond strength reduction was higher than the relative compressive strength reduction in all cases.

2. Most considerable reduction of bond strength took place between 400 °C and 500 °C. This reduction can be explained by the decomposition of portlandite at 450 °C.

3. The relative bond strength of lightweight concrete with expanded clay (Mix 2 and Mix 3) was higher up to 400 °C but lower above 500 °C compared to concrete with quartz gravel aggregate.
4. The relative bond strength of fibre reinforced concrete (Mix 1 and Mix 2) was lower up to 400 °C but higher to 500 °C and higher temperatures as in the case of concrete with quartz gravel aggregate.

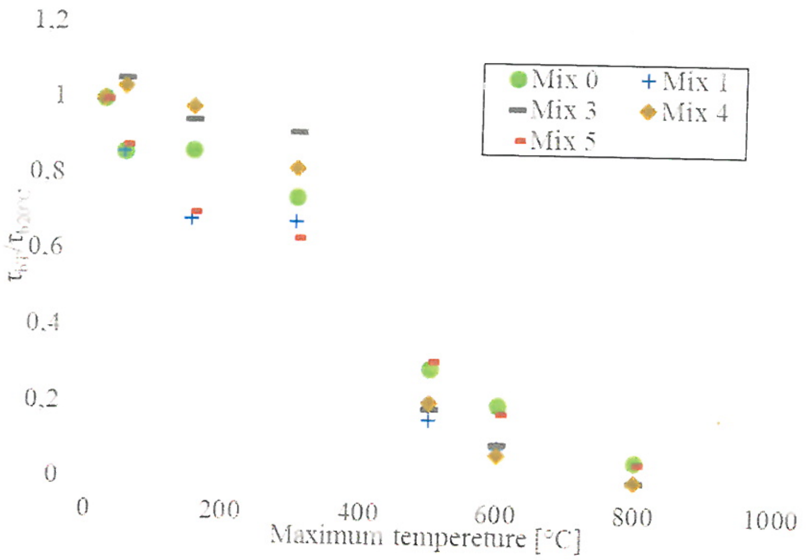

Figure 12: Test result on bond strength measured on ribbed reinforcement (each point gives the average of 3 measurements)

Bond strength –slip diagrams for Mix 0 as a function of temperature are represented in Figure 13.

The following conclusions can be drawn:

1. With increase of temperature the bond stress decreases and the slip values increase.
2. After 20 °C, 50 °C and 150 °C temperature loading, the bond strength-slip diagrams show the same tendencies. The strength reduction is less than 20 %.
3. After 600 °C and 800 °C temperature loading, the tendencies of bond strength-slip diagram change. This could be explained by the missing of chemical bond (decomposition of portlandite). The strength reduction is 80 % after 600 °C temperature loading, and 93 % after 800 °C temperature loading.

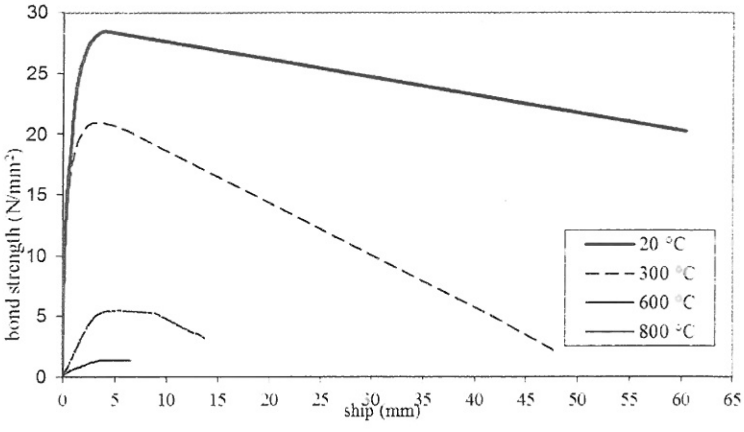

Figure 13: Bond strength- slip diagrams as a function of temperature (Mix 0)

3 Conclusion

Interaction between structural elements or structural materials can be provided by fastening elements or directly by bond, respectively. Fastening elements and bond have to fulfil multiple requirements on force transfer capacity, deformation capacity, ductility, durability, fire resistance in addition to easy application.

Present paper intended to review some of the new potentials in anchoring solutions as well as for bond. New types of concretes as well as new types of reinforcements provide new technical solutions as well as characteristics that have to be controlled.

Specific parts of this paper give new test results on bond of anchors as well as bond between steel reinforcement and concrete after fire:

Bond of anchors after fire: The anchors were installed in concrete blocks which were previous heated up to 150 °C or 300 °C. Reference tests were also carried out on specimens stored continuously at room temperature (20 °C). The failure mode depends in all cases on concrete strengths and the maximal previous temperature. Torque controlled expansion anchors and bonded anchors using vinyl ester adhesive mixed with cement have similar tendencies of peak loads vs. maximal temperature of previous temperature loading up to 300 °C. Vinyl ester adhesive is more sensitive to the increase of the temperature. The peak loads after the previous temperature loading up to 300°C were significantly reduced by bonded anchors using vinyl ester adhesive.

Bond of anchors in fire damaged concrete: In our work we analysed the load bearing capacity of anchors placed in thermally-damaged reinforced concrete. Our primary goal was to assist the reinforcement work of reinforced concrete structural members damaged in fire events. The load capacity of anchors created with epoxy adhesive decreased with increasing temperature during thermal loading. When plotting the tensile resistance in function of the temperature, it can be said that:
- if temperature reaches 200 °C in the embedment depth, then tensile resistance drops to 49%,
- if temperature reaches 300 °C in the embedment depth, then tensile resistance drops to 33 %,
- if temperature reaches 400 °C in the embedment depth, then tensile resistance drops to 32 %,

During the investigation we found no delamination (spalling) of the concrete in any of the specimens, so the results of the test can be used only in cases where spalling does not occur in the reinforced concrete structure during fire.

Bond between steel and concrete after fire: The following conclusions can be drawn from our experimental study on the influence of high temperatures to the residual bond characteristic. Pull-out specimens tested at cold state after heated up to (20 °C, 150 °C, 300 °C, 400 °C, 500 °C, 600 °C and 800 °C). The types of concrete were: C, SFRC, PPRC, LWAC1, LWAC2. Type of steel reinforcement was deformed rebar. Most considerable reduction of bond strength took place between 400 °C and 500 °C in all cases. This reduction can be explained by the decomposition of portlandite by 450 °C. This was valid for all tested concrete types (C, SFRC, PPRC, LWAC1, LWAC2) with all tested reinforcements (deformed rebar). Reduction of bond strength both below 400 °C and above 500 °C are close to linear on different levels.

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