Textile Reinforced Concrete – Applications and Bond Specifics

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Summary

Using test results it is shown how thin layers of concrete with textile reinforcement can be used as strengthening for RC-members. The enhancement of bending capacity is demonstrated with flexural strengthened RC-plates. Properties of serviceability are also improved, in particular the reduction of deflections and crack widths. The detailed problem of force transfer from the textile reinforced strengthening layer to the existing concrete of RC-members is explained. The interrelation between the transferable bond force and the associated bond length is shown. A simple model for dimensioning the flexural strengthening of RC-plates is presented and necessary model extensions are pointed out.

Keywords: reinforced concrete, strengthening, fibre, textile reinforced concrete, bond

1. Introduction

Textile reinforced concrete is a relatively new and sophisticated composite material. It comprises of a cementitious matrix and AR glass fibre reinforcement. In difference to the steel reinforcement, the single AR glass fibres in the textile can have almost any direction and therefore can be nearly perfectly adopted to the direction of the applied load. An extremely effective reinforcement is therefore feasible. The textile reinforcement is built in as a multiaxial fabric. The fibres can be arranged on top of each other, in different directions in a maximum of four layers. High strength fine grained concrete with a maximum aggregate size of 1 mm is used as a matrix.

New, very thin concrete elements are considered to be applications for the new material. This is possible due to the very low diameter of the reinforcement. The diameter of the fibres in the textile reinforcement is usually one or two dimensions lower then the diameter of steel reinforcement. Also no minimum thickness of concrete cover is now necessary to sufficiently prevent corrosion of the reinforcement. Both of these advantages allow the development of concrete elements with a thickness of only one centimetre. Low thickness may not only be helpful for new concrete elements, but also makes possible the strengthening of already existing concrete structures. The strengthening by textile reinforced concrete noticeably increases both the ultimate load bearing behaviour as well as the serviceability. This will be shown in the paper using experimental results of strengthened slabs.

2. Flexural Strengthening of Reinforced Concrete Plates

2.1. General Remarks

RC-members require strengthening for many reasons, for instance because of an increase of live loads. One possibility is the flexural strengthening of plates. The following criteria must be kept in mind during the design of the textile reinforcement:

- the load bearing capacity of the strengthened plate,
- the criterion of the minimum reinforcement,
- the necessary anchorage of the textile reinforced concrete layer.

A biaxial fabric with a weight per unit area of 210 g/m² was applied to the test plates for the flexural strengthening. The AR-glass fibres in the main load direction have a fineness of 1100 tex (that means 1100 g/km in length) and have a distance of 7.2 mm. The cross section area of one of these fibres is about 0.39 mm². The percentage of reinforcement in the perpendicular direction is nearly 25 % of the longitudinal reinforcement.

Plates with a thickness of 10 cm and an effective span of 1.60 m were used as test specimens. The ultimate load bearing capacity of the plates has been tested in 4-point-bending tests. Each plate had a percentage of reinforcement of 0.2 % or 0.5 %.

The textile reinforced concrete strengthening is applied layer by layer. Alternate layers of fine grained concrete, applied with a spatula, and the textile reinforcement will be applied to the plates. Before the new concrete can be applied, the old RC-member has to be cleaned by sandblasting from any fine grains on the surface. This is necessary so that a bond can be formed between the old concrete and the strengthening layer.

2.2. Bonding Behaviour of the Strengthening Layer

2.2.1. Bond Problems and Failure Layers

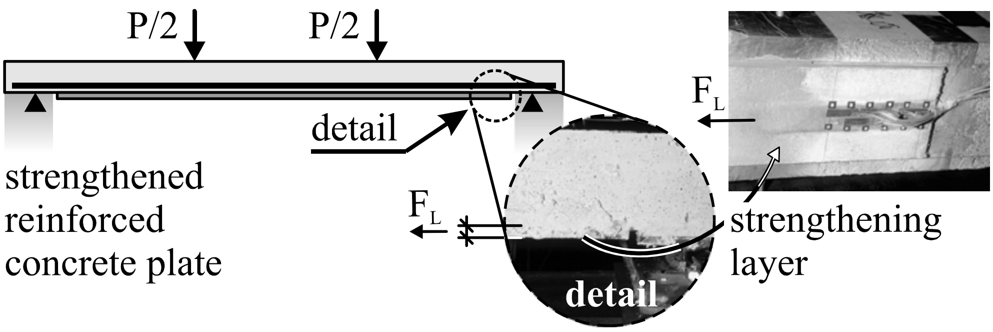

Fig. 1 Anchoring problem

If an old RC-member is strengthened by a new layer, then the tension force that is borne by the strengthening layer has to be transferred back to the old concrete at the end of the strengthened RC-member. A subsequently applied flexural strengthening layer of plates, that is installed in the structure, ends in front of the supports (Fig. 1).

The questions regarding force transfer mechanisms between the textile-reinforced strengthening layer and the old concrete are investigated using separate specimens for bond testing. The aim of the bond tests is to describe the relationship between shear stress and slip, as well as the transferable bond forces and the necessary bond length. Bond models for adhesive bonded steel plates or CFRP-strips can be found in other literature. Strengthening layers made from textile-reinforced concrete show, as opposed to steel plates and CFRP-strips, a pronounced non-linear behaviour of the material due to crack formation [1]. Furthermore, the sandblasted surface of the old concrete and the direct laminating leads to a strong interlocking between the old concrete and the strengthening. Thus, bond failure can only occur in two layers: 1. In the old concrete and 2. As a delamination in the textile layer.

2.2.2. Load Carrying Capacity of Bond

In order to transfer the tensile force from the strengthening layer to the old concrete via the bond joint, a definite bond length is required, which depends for example on the properties of the textile reinforcement. If the available bond length is shorter than the necessary bond length, only a part of the ultimate strength of the strengthening layer can be anchored to the existing concrete of an RC-member. In such a cases, the specimen fails by bond failure in the test.

Fig. 2 shows the ultimate bond forces, related to a plate width of 1 m, and the associated bond length of strengthening layers, which are reinforced with the same textile as is used for the strengthening of the slabs. If the bond stress that has to be transferred becomes higher than the load carrying capacity of the old concrete, the bond will fail in the old concrete. If the bond stress reaches the load carrying capacity of the fine grained concrete in the textile layer before it reaches the load carrying capacity of the concrete, a bond failure will occur as a delamination in the textile layer. The bond properties should become optimised in such a way, that the weak point of the construction is not situated in the newly applied strengthening layer, but in the old construction. This is necessary to use the strengthening to full capacity and can be achieved by an enlargement of the opening width of the textile fabric.

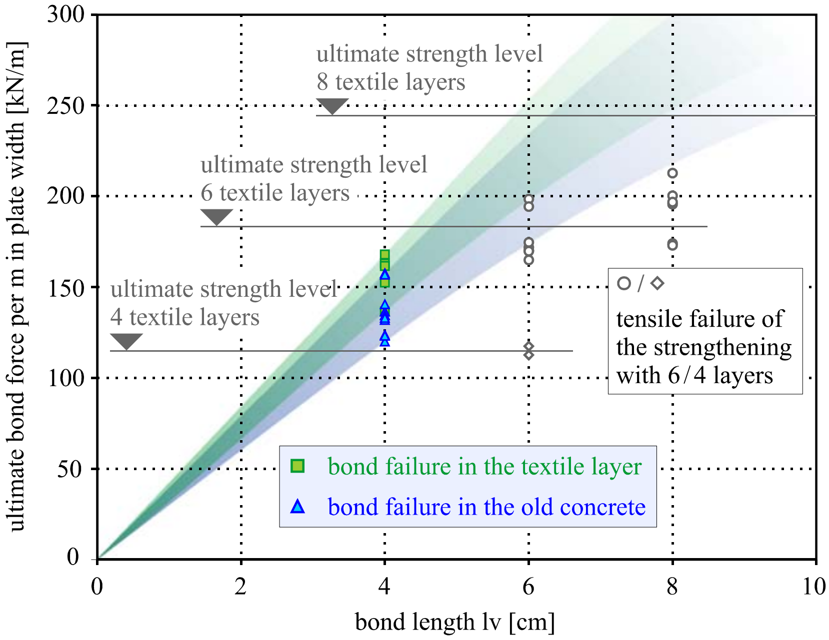

Fig. 2 Ultimate bond force per metre in plate width versus bond length

A necessary bond length, which is able to anchor the ultimate tensile force of the strengthening layer and which corresponds to the maximum bond stress, could be determined for each textile in bond tests, carried out at the University of Dresden. This means that, if the bond length is longer than a definite bond length then the strengthening layer fails by reaching its ultimate tensile load before bond failure can occur. The load carrying capacity of the strengthening can therefore be fully utilized with use of a sufficient bond length. Comparable research, carried out with adhesive bonded CFRP laminates or steel plates, gave only a utilization rate of approx. 10–25 % or max. 50 % respectively [2], [3].

This shows the enormous potential of the new material textile reinforced concrete.

A bond length of approx. 5–6 cm is necessary for the anchoring of the maximum tensile force at a reinforcing ratio of six textile layers in the strengthening (Fig. 2). If the strengthening contains only four textile layers, a bond length of less than 4 cm is sufficient. Thus, a sufficient bond length exists for every number of textile layers, at which the ultimate uniaxial tensile load of the strengthening layer can be anchored to the old concrete of the RC-member. This sufficient bond length can be taken from the diagram in Fig. 2. The small crack distances in the flexural strengthened RC-plates ensure that no bond failure can occur because of the relatively short sufficient bond length.

2.3. Test results of bending strengthening plates

The 4-point-bending test was chosen for testing the plates in order to avoid shear forces simultaneously occurring with bending moments in mid-span. The results were compared with non-strengthened reference plates. During the test series the number of textile layers and the percentage of steel reinforcement were varied.

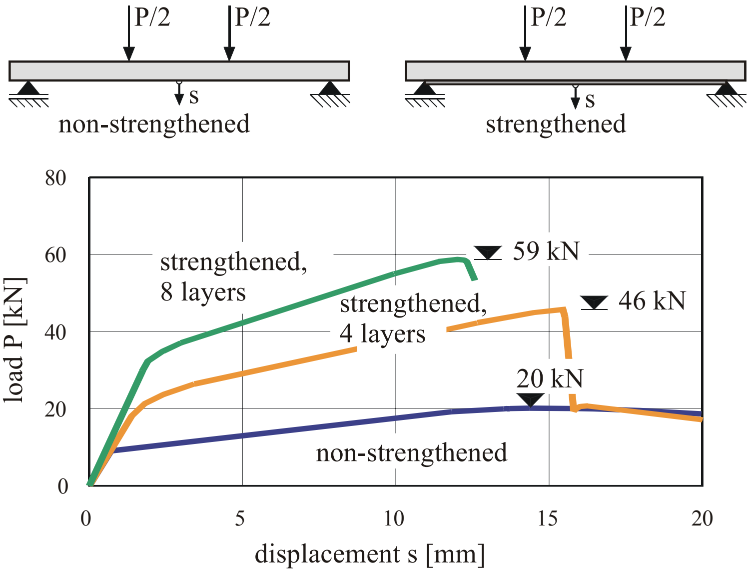

Fig. 3: Load-displacement-diagram

Firstly, the properties of the textile reinforcement were tested with plates whose strengthening layer extended beyond the support line. In existing buildings the support area of the plates cannot be reached and so for this reason, plates were also tested whose strengthening layer ended in front of the support. The ultimate load bearing capacity was approximately equal for both alternatives. Because of the short bond length required the anchorage in front of the support is therefore sufficient.

The load-displacement-diagram (Fig. 3) shows the typical behaviour of reinforced concrete in states I (non-cracked), II (multiple cracking) and III (yielding of steel reinforcement) for all plates.

But the rise of the curves is different. In comparison to the non-strengthened plates, the load-displacement-curve of the strengthened plate rises much more sharply. The reason for this is the larger moment of inertia due to the additionally applied strengthening layer in the uncracked state. After the multiple cracking (state III), the steeper rise of the curve is caused by the load bearing properties of the textile reinforcement.

The textile reinforcement improves both the load capacity and also the properties of serviceability. The displacement of the strengthened plates, related to the service load, is smaller than the displacement of the non-strengthened plate. This is caused by the fine crack pattern.

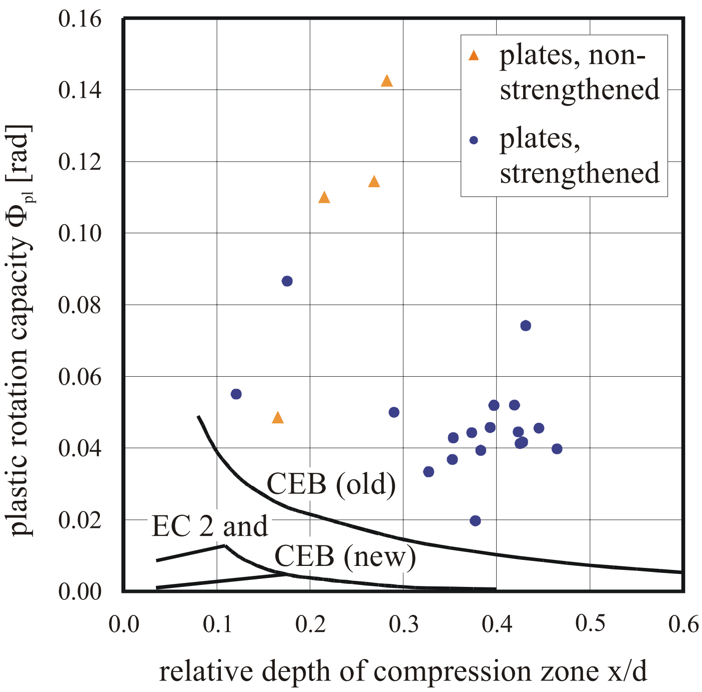

Fig. 4: Rotation capacity versus x/d

To be able to develop a safety concept, the deformability, i. e. the ductility of the textile strengthened plates at the ULS, is very important. Due to the difference in deformation, it is necessary to differentiate between brittle and ductile failure modes, when partial safety factors have to be defined. The measure of the ductility is the plastic rotation capacity.

The measured angle of rotation will be compared with the recommendations of the CEB [4] and the Eurocode 2 in Fig. 4. The rotation capacity of each plate is higher than the specified limit values, i. e. the plates with textile strengthening are ductile enough.

3. Design Model

The well known design model for steel reinforced concrete with the design at the cross section will be extended by an additional tension force for the calculation of the load bearing capacity of flexural strengthened plates (Fig. 5). The model is based on the hypothesis of Bernoulli, that the cross section remains straight during deformation. The bond between the steel reinforcement and the concrete as well as the bond between the textile reinforcement and the fine grained concrete will both be assumed to be rigid.

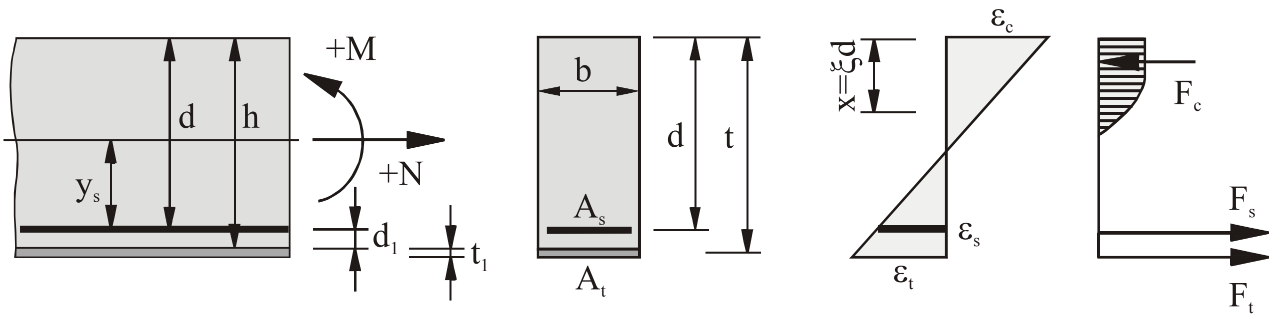

Fig. 5: Internal forces and strains on the cross section

The ultimate load is dependant upon the ultimate strain of the strengthening layer. This ultimate strain is measured with uniaxial tension tests. At present, it has not been conclusively proved that the results from these tests can be used for textile strengthened plates. Many factors affect the ultimate load of the specimens in the uniaxial tension tests [5]. The cracking of the strain specimens in a uniaxial tension test is different from the cracking of the textile reinforced concrete layer, which works as a strengthening layer of a RC-member [6].

For this reason, the equilibrium forces have been calculated with the measured compressive strain on the top of the RC-plates. These calculated ultimate loads can vary up to 20 % from the test results. Possible sources of error, for example the value of steel stresses in the ULS or the differences in the material behaviour between strain specimens and the textile fabric bonded with an old concrete member is being analysed at present [6].

4. Conclusions

The test results indicate that RC-members can be strengthened with textile reinforced concrete. Separate bond investigations prove that relatively short bond lengths are sufficient for the anchorage of the strengthening. In the tests on the flexural strengthened plates, no bond failure of the strengthening layer was observed. The well known design model from steel reinforced concrete cannot be extended to also apply to textile reinforced concrete strengthening layers without modifications. Possible reasons for this and solution approaches have been presented.

5. Acknowledgements

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6. References

[1] ORTLEPP R. and CURBACH M., “Bonding Behaviour of Textile Reinforced Concrete Strengthening”, *High Performance Fiber Reinforced Cement Composites – HPFRCC 4, Proceedings of the Fourth International RILEM Workshop, rilem PRO 30*, pp. 517–527, 2003

[2] ONKEN P., GRUNEWALD G., “Verstaerkung von Brueckenbauwerken mit Faserverbundwerkstoffen”, *Presentation at the 13th Brueckenbau-Symposium*, Dresden, 2003

[3] HOLZENKAEMPFER P., “Ingenieurmodelle des Verbunds geklebter Bewehrung fuer Betonbauteile”, *Deutscher Ausschuss fuer Stahlbeton*, Vol. 473, 1997, pp. 109–209

[4] CEB, “CEB-FIB Model Code 1990”, *Bulletin D’Information*, No. 213/214, Lausanne, 1993

[5] JESSE F., ORTLEPP R. and CURBACH M., "Strength-Reducing Effects in Composites with Continuous AR Glass Fibres", *Proceedings of the 13th Congress of the International Glassfibre Reinforced Concrete Association – GRC 2003*, paper 21

[6] STRITZKE J, CURBACH M, WAGNER A, and BOESCHE A., "Verstaerkung von Balken und Plattenbalken mit textilbewehrtem Beton", *Sonderforschungsbereich 528 – Arbeits- und Ergebnisbericht fuer die Periode II/1999-I/2002*, TU Dresden, pp. 359–404, 2001