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Investigation of punctiform, plane and hybrid joints of textile-reinforced concrete parts

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Abstract

The application of textile-reinforced concrete allows manufacturing of thin-walled, high-strength components. Efficient joints are vitally important for the integration of precast concrete components into structural frameworks. Within the scope of a recent research project, basic punctiform, plane and hybrid joint geometries have been tested. The goals of this study are to avoid any reduction in strength compared with undisturbed components. This paper describes investigations on the tensile strength and failure pattern of different joint geometries. Different types of joints and failure are discussed and an auspicious joint offering nearly the load capacity of the undisturbed specimen is introduced.

Keywords: Textile-reinforced concrete; Joints; Hybrid joints

1. Introduction

Textile-reinforced concrete allows for an extensive expansion of the application field for concrete in structural tasks [1]. The innovative material broadens the range of design by increasing the load bearing capacity as well as improving durability [2]. The alkali-resistant textile structures are made of corrosion-resistant high-performance filament yarns. A replacement of the ordinary steel reinforcement by these textile structures allows for the manufacturing of particularly thin and high-strength (prefabricated) elements, since a minimum concrete cover is no longer required. The basis for innovative applications, from an architectural as well as an engineering point of view, is provided by interdisciplinary collaboration of 11 research institutes within the DFG-funded "Collaborative Research Centre 532" at RWTH Aachen University.

A material-appropriate joining technique plays a decisive role, particularly with regard to the set-up and assembling of lightweight framework structures made of prefabricated concrete components [3]. Within the scope of this study, the following joints of thin textile-reinforced specimens have been considered:

- detachable, punctiform joints with bolts,
- permanent, plane adhesive joints, and
- detachable hybrid joints with bolts and inserted jackets.

Similar hybrid joining techniques have already been applied successfully to fibre reinforced polymer (FRP) components: due to the low shear resistance and low strength transverse to the direction of pultrusion, a strengthening of the connection area is required for such FRP components. Thus several experimental investigations were performed to increase the resistance of bolted connections by local strengthening using either inductive bonded collar jackets or bonded adaptive cold-formed fittings. Since those strengthening techniques show high and sufficient ultimate resistance [4,5], the hybrid joint approach has been adopted

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for fibre reinforced concrete as well. Nevertheless the design rules derived from those test results on FRP cannot be applied to textile-reinforced concrete without taking into account the specific characteristics of this material. Particularly the load transfer from the tension weak concrete cover into the reinforcement layer needs a closer inspection.

The primary objective of the parametric studies described in the following is the determination of the strength parameters of the different types of joints. Concerning the structural design of the connection it has to be assured that the ultimate resistance of the whole structure is not reduced.

2. Test specimens and test set-up

The test specimens are reinforced with two layers of alkali-resistant glass textiles. These consist of 2400 tex rovings (1 tex = 1 g/km) with an 8 mm-grid in the direction of load as well as perpendicular to it. This corresponds to a degree of reinforcement of approximately 2.1% in both directions. A more detailed description of the reinforcement material is given in [6]. The used matrix has been developed within the Collaborative Research Centre as a fine grained concrete with a maximum grain size of 0.6 mm. This matrix is a flowable fine concrete mixture with a compressive strength of approximately 85 N/mm^2. The addition of silica fume and fly ash to the mixture reduces the amount of alkali ions and calcium hydroxide in comparison to pure Portland cements. The pH value of this mixture is 13.5. The composition of the concrete mixture as well as its structural and mechanical properties are published in [7].

The different types of joints are tested under centric tensile load, the deformations are measured using displacement transducers fixed to the specimen, Fig. 1.

The punctual force is transferred into the test specimen via high strength bolts, held by a rigid steel frame structure. For the tests on plane adhesive joints, the force is transferred via the adhesive layer and where applicable via additional elements (e.g. mounting links). For all tests, the area of disturbance of the concrete specimens is not covered and allows for an unhindered development and survey of the particular fracture mechanism.

3. Punctiform joints

For the joining of textile-reinforced concrete components with bolts, adequate through borings must be provided in the components. The simplest way of creating the holes is by countersinking holes subsequently through the fully cured concrete specimen. As some of the tensile force transmitting reinforcement rovings are cut through by drilling, this type of joint is not particularly appropriate for the fibres. Alternatively the bolthole wall is strengthened with a metal jacket which is either subsequently pasted into the hole or directly set into the concrete formwork.

Depending on the type of borehole layout and the edge distance of the hole, three different types of failure are observed [8]. Considering small edge distances, the failure type does not depend on the type of borehole layout. The tensile test specimen fails by a cracking of the concrete between hole and front edge of specimen, where the failure occurs transverse to the main tension direction caused by a tension failure of the transverse reinforcement. The correlation between edge distance and ultimate load turns out to be approximately proportional. If the edge distance is increased, local failure occurs by a shell-shaped concrete crushing in front of the jacket or lateral failure occurs by a tension failure of the longitudinal reinforcement, signalised by a distinctive lateral crack next to the hole. In this context local failure is initiated by exceedance of the local concrete compressive strength; lateral failure is initiated by an exceeding of the tension capacity of the net section (cross-sectional area reduced by the hole) which is governed by the tension capacity of the longitudinal reinforcement. With an increasing edge distance the load level remains constant for these kinds of failure.

The tests show that if the bolt is in direct contact with the concrete, i.e. no jackets used, a maximum of 60% of

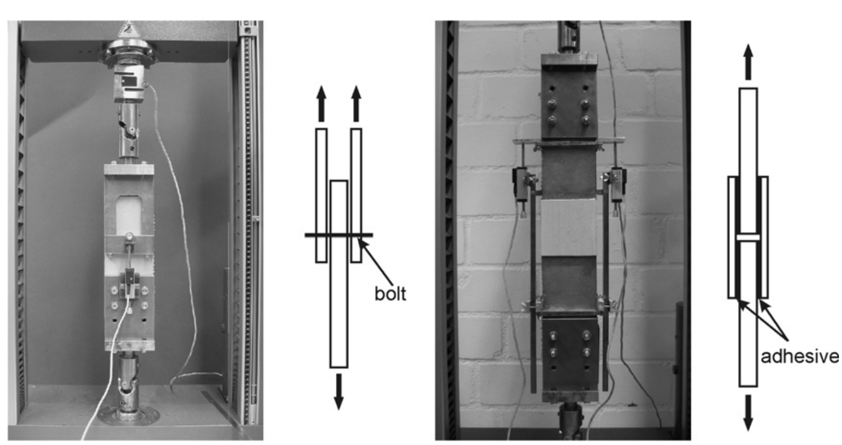

Fig. 1. Test set-up for punctiform and plane connections.

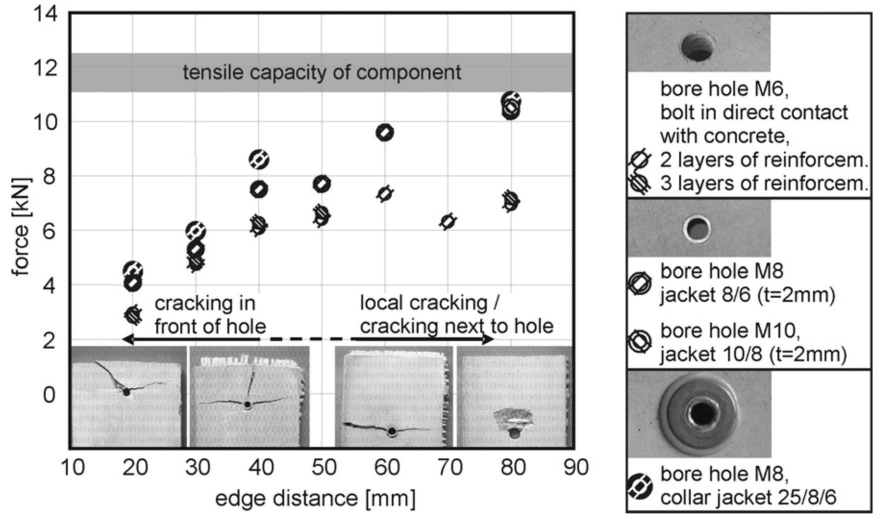

Fig. 2. Ultimate loads of bolted components with and without jacket.

the average load carrying capacity of the undisturbed specimen (tensile capacity of component) is reached, independent of the borehole's diameter, see Fig. 2. A reinforcing of the holes with brass jackets (thickness = 1 mm) leads to an increase of the specimen's load carrying capacity up to approximately 90%, independent whether the jackets are set in concrete or pasted into the hole subsequently. This leads to the conclusion that the reduction of local stress peaks is mainly caused by the improved contact conditions between bolt and hole wall. The ultimate loads for both types (with and without embedded jacket) versus different edge distances are shown in the diagram of Fig. 2.

The test results are supplemented by a hybrid joint test series using a collar jacket 25/8/6 (cf. chapter 5).

4. Plane joints

4.1. Characterisation of adhesives

The tensile capacity of plane joints of textile-reinforced concrete components mainly depends on the mechanical properties of the adhesives used. By a selection of appropriate adhesive systems, high-strength as well as elastic bonded joints may be carried out. For this reason, high-modulus adhesives on basis of epoxy resin as well as more flexible systems on basis of polyurethane are tested.

Initially the wetting behaviour on both untreated and brushed or blasted surfaces is examined. Due to residues of formwork lubricant on the fine concrete surface the untreated surfaces show the worst wetting properties. The best wetting property is achieved by sandblasting and subsequent compressed air cleaning of the surface, which results primarily from an exposure of the concrete texture by removing the upper loose layer of cement. Furthermore the specimen is provided with a defined surface roughness as a result of this process [8]. Since this procedure also provides the highest reproducibility, all further bondings are carried out on blasted specimens.

Subsequent to the wetting tests, the mechanical properties of the different adhesives are examined by means of static short-time tests under tensile and shear loading, see Fig. 3. Without the application of a primer, the failure of the polyurethane bondings on blasted concrete surfaces is an almost complete adhesive one, which means that the failure occurs when the adhesive layer separates from the concrete surface. The determined values of ultimate strength show only a low scattering less than 5%. The use of primer results in a cohesive failure within the adhesive layer, which means that the failure initiates from inside the adhesive material. However, the use of primer does not lead to a significant increase of the maximum adhesive strength.

For the epoxy resin bondings cohesive failure occurs in the near surface concrete layer. Since a wide scattering of failure loads is observed on this failure type, the determination of the mechanical properties of the adhesive layer is also carried out using rigid, standardised metal specimens. The maximum achievable strength of the adhesive layer after complete hardening of the adhesives is shown in Fig. 4. The progression of strength of different adhesives is analysed over a period of several days, because bonded joints have to remain in a fixed state until the adhesive shows a sufficient cohesive strength. The testing of plane bonded textile-reinforced concrete specimens is carried out after the complete hardening of the adhesive layers can be guaranteed.

4.2. Adhesive joints of textile-reinforced concrete specimens

Based on the adhesive characterisation, different single-lapped and double-lapped joint geometries are tested. For these purposes, test specimens with two layers of reinforcement and a basic geometry of 250 mm × 100 mm × 10 mm are produced. To generate a double-sided joint, textile-reinforced concrete plates (100 mm × 100 mm × 5 mm) are bonded to these specimens, see Fig. 5.

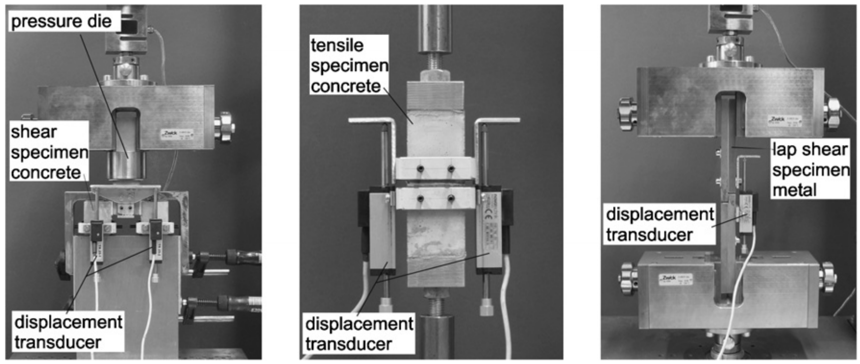

Fig. 3. Mechanical characterisation of the adhesive layers on concrete and metal surfaces.

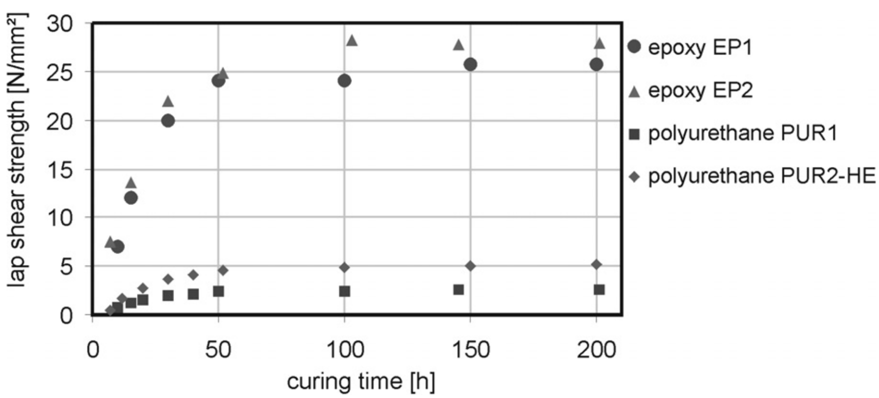

Fig. 4. Development of strength of the adhesive systems tested.

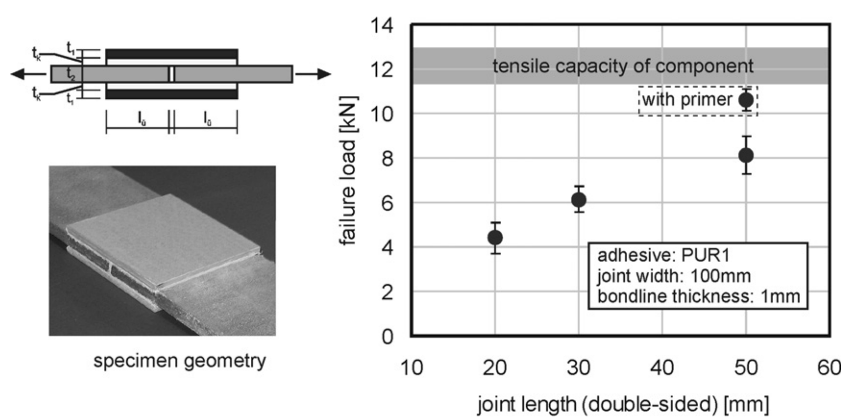

Fig. 5. Tensile capacity of double-lapped joints.

If sufficiently large adherent surfaces are provided, the application of comparatively flexible adhesive systems on PUR basis makes it possible to reach the component's ultimate capacity as shown in Fig. 5. The adhesive layers are able to reduce stress peaks. They guarantee a homogeneous transmission of force and show a favourable behaviour in the case of deformations and cyclic loads. Failure occurs in the tensile-reinforced member within a distance of 3 mm to the edge of the assembling zone, as the stress peaks cannot be eliminated completely. However, under exposure to high static permanent loads and temperatures, the advantages mentioned above come along with large deformations and a reduction of strength [9].

In such cases, highly cross linked adhesive systems, e.g. epoxy resins, are alternatively applicable. Due to the higher bond strength and Young's modulus this results in particularly smaller necessary adherent surfaces and less deformations compared to the flexible PUR-adhesives. However, a rigid bonding shows the risk of early ultimate failure of the specimen due to an increase of stress peaks at the edges of the laps [10]. In this case, joining geometries with the adhesive layer positioned in the reinforcement

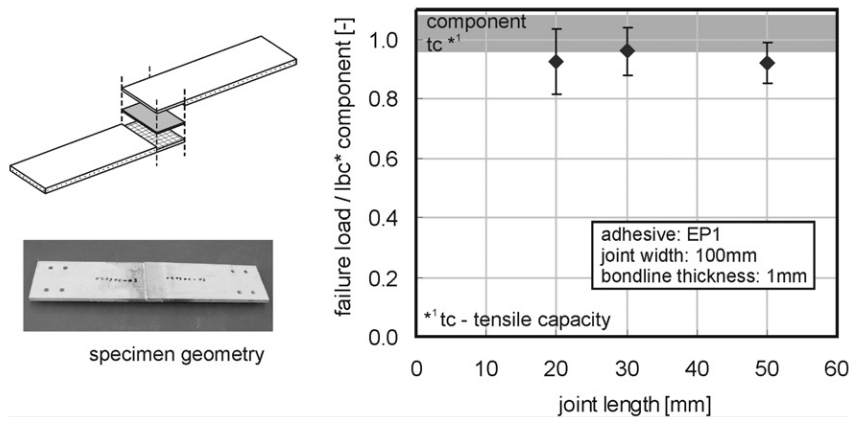

Fig. 6. Tensile capacity of bonded stepped specimens in comparison with undisturbed single components.

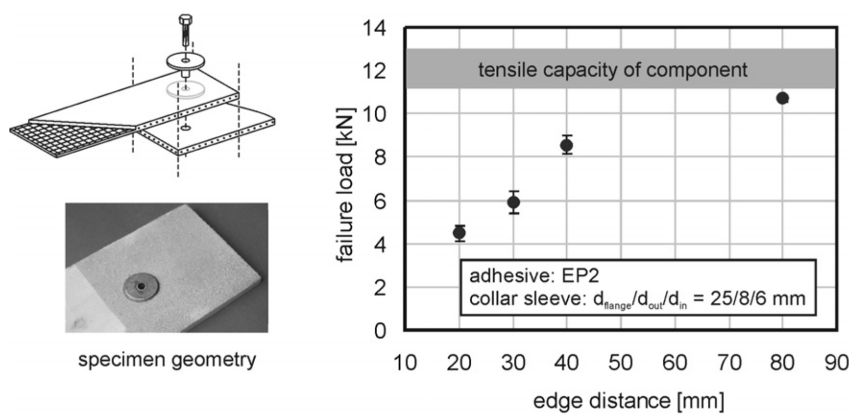

Fig. 7. Tensile capacity of hybrid joints with pasted-in "collar jackets".

zone should be intended. The tensile capacity of joints of stepped specimens in comparison with the tensile capacity of the undisturbed single component is shown in Fig. 6. Due to the high mechanical strength of the epoxy resin adhesive, the tensile capacity of the undisturbed single component is reached for all tested overlapping lengths. Again, failure occurs within a distance of 3 mm to the edge of the assembling zone in the textile-reinforced member, showing a distinctive crack perpendicular to the loading direction.

5. Hybrid joints

Particularly with regard to the on-site installation and handling of prefabricated components made of textile-reinforced concrete, hybrid joints are tested as well in addition to bonded plane joints. For the test specimens the same basic geometry as already established for the adhesive joint tests is used. Hybrid joints combine the advantages of an easy assembly and disassembly on the one hand, and the two-dimensional transmission of force on the other hand [11,12]. This joining geometry involves so-called "collar jackets" which are inserted into subsequently drilled holes as shown in Fig. 7. The collar flange surfaces are bonded to the concrete surfaces by rigid epoxy resin adhesives.

Compared to punctiform bolts or rivet joints, the application of collar jackets leads to a further increase of the tensile capacity. The tension stresses concentrated in the region next to the hole, perpendicular to the loading direction, are reduced by the collar of the jacket. Due to its high stiffness, the jacket distributes these stresses two-dimensionally in a homogenous way through the high-modulus adhesive to a larger area of concrete.

6. Summary and prospect

Within the scope of the Collaborative Research Centre 532, RWTH Aachen University, the potentialities of textile-reinforced concrete have already been demonstrated by different filigree load carrying structures. For the integration of single components into the overall structure, the joining technique becomes a key question. Bonded, plane joint geometries can reach the tensile capacities of undisturbed regions by selection of suitable adhesives and an appropriate joint design. Based on the acquired grounds of basic punctiform joints of textile-reinforced components, simple hybrid joining geometries can be realised. Hereby the advantages of an appropriate two-dimensional force transmission and an easy assembly are combined.

The loss in strength of joints under complex long-term loading or in case of fire will be the subject of future investigations. With regard to the specified service life of constructions, sufficient durability has to be proofed.

Acknowledgement

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