Textile Reinforced Concrete Facades

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Summary

The characteristics of the new composite material textile reinforced concrete (TRC) are investigated at the Aachen University in the Collaborative Research Center 532 sponsored by the Deutsche Forschungsgemeinschaft (DFG). Based on the results of these investigations some first applications of TRC have been developed. In a pilot project exterior cladding panels made out of TRC have been used for the extension of the laboratory hall of the Institute of Structural Concrete, Aachen University. The manufacturing of facades out of TRC offers many advantages. The textile reinforcement is corrosion-resistant and only a thin concrete cover is required so that the construction of thin-walled elements is possible. In this paper the dimensioning, production and fixing of the facades made of TRC are described.

Keywords: cladding panels; curtain wall; facade elements; textile reinforced concrete; composite material.

1. Introduction

Textile reinforced concrete (TRC) is a new composite material. The development of TRC is based on the fundamentals of glass fibre reinforced concrete with short fibres. Similar to ordinary reinforced concrete structures the fibres are aligned in the direction of the tensile stresses which leads to an increase in their effectiveness. The characteristics of TRC are investigated in several research projects [1][2][3]. The load bearing capacity of TRC is one task of these investigations as well as the durability. At this time with the results of these investigations the load bearing capacity of TRC can be approximately calculated.

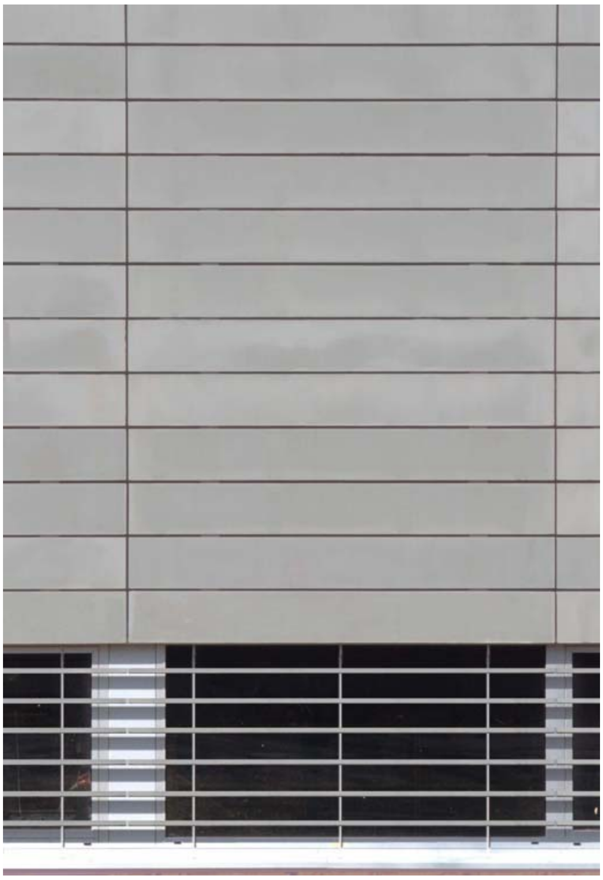
By replacing the ordinary steel reinforcement through a corrosion-resistant textile reinforcement, filigree cladding panels with a broad range of design options can be created. Profile thicknesses, previously known only from steel construction and composite fibre plastics structures, can be achieved with a textile reinforcement as well as high quality homogenous surfaces. These advantages lead to an entirely new application potential for concrete as a building material, especially for facade construction. The small wall thickness that can be realised and the resulting lower dead load also eliminate the need for complex facade anchors, as used in reinforced concrete construction.

2. Textile reinforced concrete cladding panels

2.1. General Remarks

Cladding panels made of TRC are used for the first time for the extension building of the Institute of Structural Concrete, Aachen University. The existing hall with a span of 12.0 m has been extended by four axes of 5.4 m each, resulting in an additional usable floor space of 21.6 m x 12.0 m. On the longitudinal side of the hall, curtain wall panels are used instead of hitherto natural stone, which would have been the typical choice. The upper part of the facade is cladded with panels. The design of the curtain wall panels is shown in Fig. 1. At this time the sun-protection in Fig. 1 (b) is only added by a computer. It will consist of textile reinforced concrete lamellae and will be attached during the next time.

(a) View



(b) Detail

Fig. 1 Curtain wall construction

Using fine-grained concrete with a maximum particle size of approximately 1.0 to 2.0 mm, smooth surface finishes as well as sharp-edged profiles and joints could be achieved. The results are concrete surfaces with a completely new look.

2.2. Dimensioning

The calculation of the required textile reinforcement is based on the information from the knowledge of the Collaborative Research Center 532 in Aachen. The dimensions of panels are 268.5 x 32.5 x 2.5 cm^3 (Fig. 2). The reinforcement layer in longitudinal direction ranges about 4 mm from the surface of the panel. This leaves a concrete cover of at least 3 mm.

In the horizontal direction the panels are clamped at four points (Fig. 3). In the vertical direction they are supported by two thrust bearings, the other bearings only admit horizontal forces. Thus, no stresses due to temperature changes are generated by the support conditions

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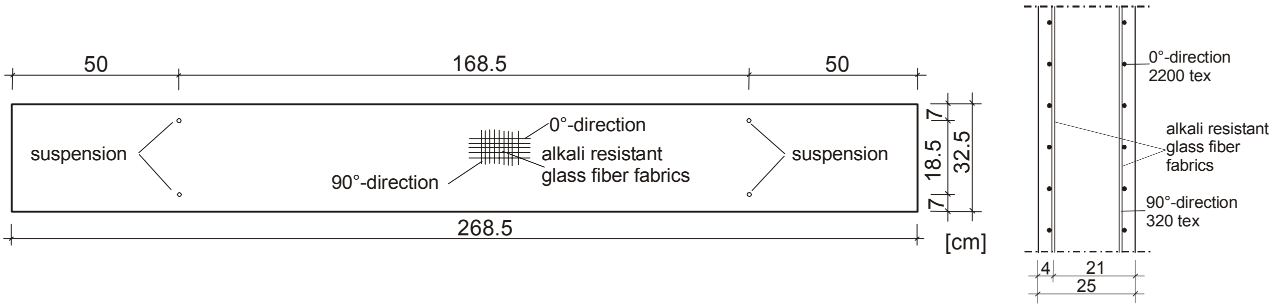

a) view *b) vertical section*

Fig. 2 View and vertical section of the textile reinforced panels

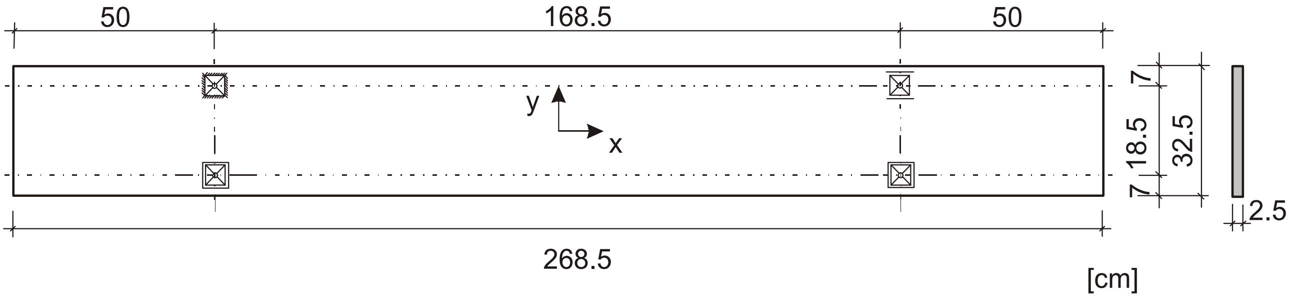

Fig. 3 Bearing of the panel

The facade is subjected to wind load. The wind suction at the corner w_s = -1.0 kN/m². The panels in the inner areas are subjected to only 40 % of the wind load. As a conservative assumption, the maximum bending moments from wind suction are applied to all panels. The dead weight of the panel (g = 24.0 kN/m³ x 0.025 x 0.325 m = 0.20 kN/m) acts in the vertical direction. Basically, the panels are loaded uniaxially. Thus, the biggest moments appear in the longitudinal direction (m_x). Along the centreline and at the side of the panel the maximum bending moments achieve m = 0.24 kNm/m (Fig. 4), in addition to a tensile force due to the own weight of the panels n = 2.8 kN/m. The design of the panels was made under the condition of no cracking under service loads.

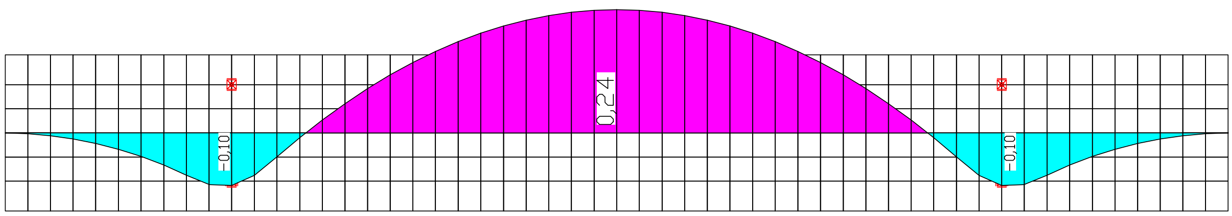

Fig. 4 Bending moments in the panel in [kNm/m]

The tension force t_t to be resisted by the textile reinforcement is calculated as (see Fig. 5):

$$t_t = \frac{m \cdot \gamma_w}{z_1} + \gamma_g \cdot \frac{n}{2} = \frac{24.0 \cdot 1{,}5}{1.79} + 1.35 \cdot \frac{2.80}{2} = 22.0 \ \text{kN/m} \qquad (1)$$

m moment [kNcm/m]
γ_w safety factor for wind load
γ_g safety factor for dead load
z_1 see Fig. 5 [cm]
n normal force [kN/m]

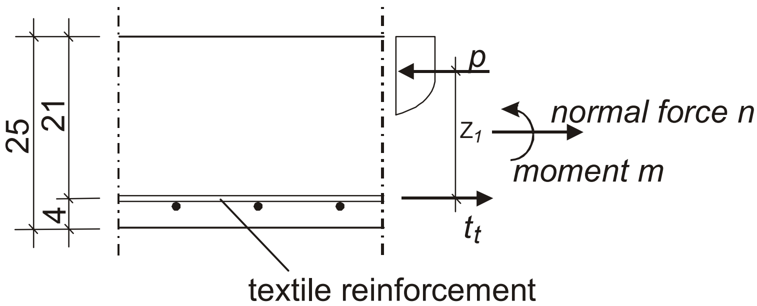

Fig. 5 Inner couple and outer loads moment and normal force

A biaxial laminated fabric made out of alcali resistant glass (AR Glass) fibres with the marking MAG-04-01 (Fig. 6) has been chosen as reinforcement for the panels. This fabric consists of 2200 tex rovings in longitudinal direction (0°) and 320 tex rovings in transverse direction (90°) with a mesh size of 8 mm. Thus, the cross section area in longitudinal direction is a_t = 97.4 mm²/m. In order to account for the reduction in the bond and in the tensile strength of the textile reinforcement, only 80% of the tensile strength of the fabrics was utilized. This reduction coefficient was investigated in former testing. For the textile reinforcement a safety factor γ_t = 1.5 is considered. In tension tests performed at the Institute for Textile Technologie (ITA), Aachen University, the provided laminated AR Glass fibre fabric reached a tensile strength of 563 N/mm². The dimensionally stable fabrics are arranged in two layers close to the surface, thus providing an upper and lower reinforcement layer.

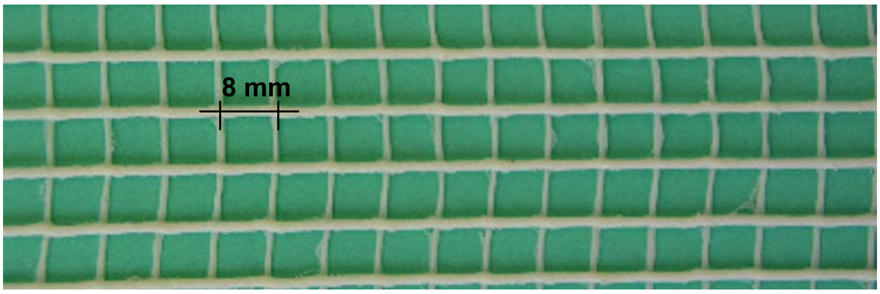

Fig. 6 Textile reinforcement MAG-04-01

The required cross section area of the textile reinforcement therefore is:

$$a_{t,\,req} = \frac{22.0 \cdot 1000 \cdot 1{,}5}{563 \cdot 0.8} = 73.3 \ \text{mm}^2/\text{m} \qquad (2)$$

In the area of the bearings bending moments and normal forces in vertical direction are acting so that a vertical extra layer is needed (Fig. 7).

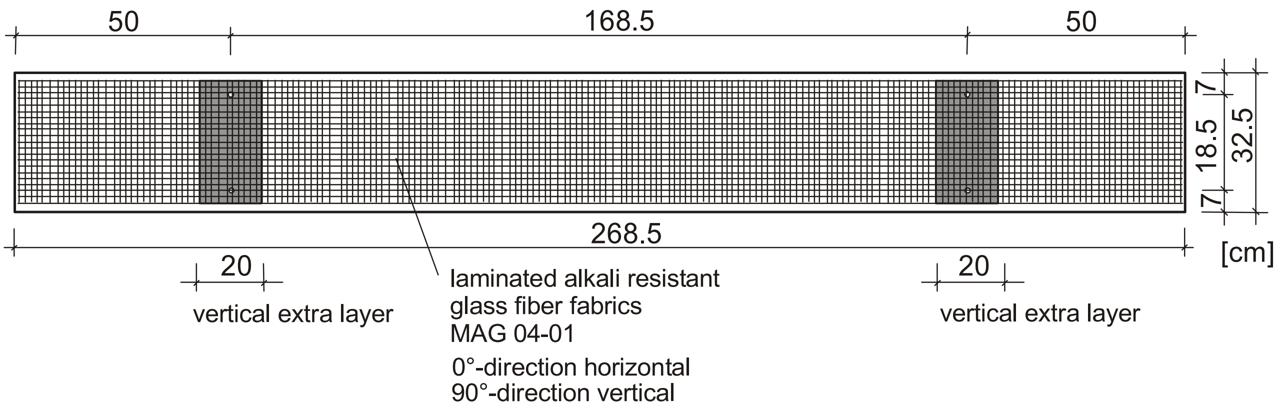

Fig. 7 Arrangement of the alkali resistant glass fiber fabric MAG-04-01

2.3. Fixing technique

An agraffe fixing device of BWM GmbH, Leinfelden-Echterdingen is utilized for the fixing of the curtain wall panels. The vertical aluminium substructure of the device is plugged at the steel-reinforced wall. The textile reinforced curtain wall panels are fastened in horizontal profiles with the screwed on agraffes. The agraffes are fixed to the textile reinforced panels using special dowels. These are positioned in the panel inside cone-shaped boreholes. Pull-out and shearing tests have been carried out in order to check the load bearing capacity of the dowels. The results showed that the dowels can resist more than seven times the load they are actually subjected to in practice.

2.4. Production process

The panels were produced lying horizontally. First, a 4 mm thick layer of self-compacting concrete was poured in the formwork. Then the first textile reinforcement layer was placed (Fig. 8), followed by the pouring of the next 17 mm thick concrete layer and the placing of the second layer of the MAG-04-01. Finally the last 4 mm thick concrete layer was poured. The difficulties in the exact positioning of the textile reinforcement layer are one disadvantage of this very simple production process. Thus, the load bearing capacity of the textile reinforced concrete panels has been checked in four- point- bending tests (Fig. 9). As a result of the tests a safety factor $\gamma > 3$ against failure of the panels under service loads was determined.

Fig. 8 Placing of the first layer of textile reinforcement

Fig. 9 Four- point- bending test

2.5. Durability

In cementicious matrices only alcali resistant glass (AR Glass) is applied because the durability of glass in an alcaline environment is not guaranteed. Though the durability of this glass type being better than E-Glas the stability cannot be guaranteed for a duration of some decades. It is an objective to develop concretes with a low alcalinity (pH < 10) to eliminate the damage to the AR Glass, but this is not completely possible using Portland cement. Values lower than pH 12.5 normally cannot be achieved, whereas the alcalinity of carbonated concrete is reduced on values of about pH 8 to 9. After a few weeks the carbonatisation enters several millimeters into the concrete structure [4]. This means that the textile reinforcement of the filigree panels, having only a concrete cover of 4 mm, is placed in an area of low alcalinity, so that significant less damage of the AR Glass can be expected. Furthermore, based on a method given in [5] tensile tests have been carried out on textile reinforced concrete structures (Fig. 10) after seasoning for one week in water with a temperature of 80°C. A comparison of the results with the test-results on specimens without seasoning shows no loss of load bearing capacity through seasoning. A protection effect of the lamination of the arranged textile reinforcement could be a reason for these positive results.

Considering the theoretical and practical investigations the durability of the panels should be given for a long time. Furthermore, regular checks on the facade will be carried out to determine the long-term deformations of the textile reinforced concrete panels.

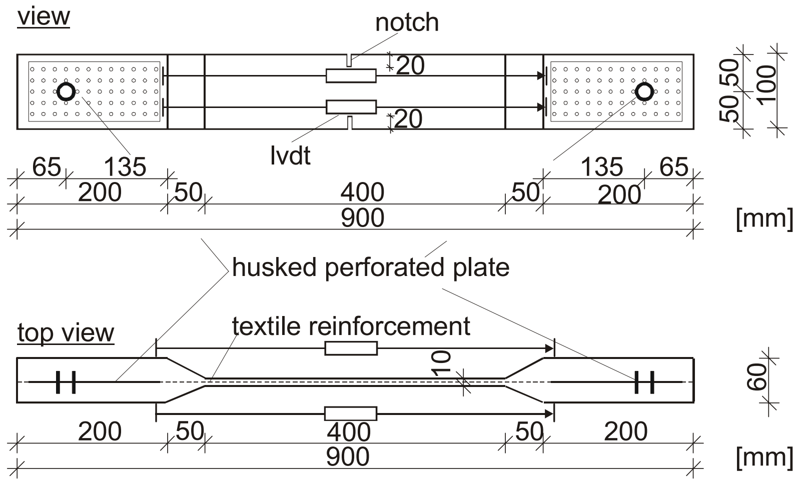

Fig. 10 Geometry and measurement technic of tensile test specimen

2.6. Conclusions and acknowledgements

The successful application of textile reinforced concrete described above illustrates that the structural material TRC is a sound and practical material. The filigree panels are an efficient and economic alternative for reinforced concrete or natural stone facades. They open up new fields for the application of concrete as building material. Common to all solutions is that the beneficial properties of textiles and concrete must be investigated in order to obtain durable components economical to manufacture, to install and to maintain. Further investigations have to be carried out to optimise the laborious production process of textile reinforced concrete structures.

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2.7. References

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