Construction and Building Materials 64 (2014) 451–459

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

An analytical model for sandwich panels made of textile-reinforced concrete

Ali Shams [a,*], Josef Hegger [a], Michael Horstmann [b]

[a] Institute of Structural Concrete, RWTH Aachen University, Germany
[b] Kempen Krause Consulting Engineering Firm, Aachen, Germany

HIGHLIGHTS

- TRC sandwich panels are an attractive option for use as modern building envelopes.
- Using TRC leads to reduced concrete usage and slender panels.
- Construction with TRC meets the demands of sustainable building concepts.
- Derivation of new calculative models for thin-walled TRC-sandwich panels.
- Suitable connectors are required to enhance the load-bearing capacity.

ARTICLE INFO

Article history:
Received 3 December 2013
Received in revised form 9 March 2014
Accepted 2 April 2014
Available online 5 May 2014

Keywords:
Textile reinforced concrete
Sandwich panel
Analytical model cracking
Composite action
Load-bearing behavior

ABSTRACT

Textile-reinforced concrete (TRC) is a composite material that consists of high-strength, fine-grained concrete and non-corrosive textile reinforcements, which are mainly fabricated of AR-glass or carbon fibers in order to design filigree and lightweight concrete structures. In order to investigate the load-bearing behavior of sandwich panels with thin TRC-facings and resilient insulation cores applied for self-supporting façades, a series of tests have been performed at RWTH Aachen University. The present paper summarizes the results of the experimental investigations and presents an analytical model that enables a realistic calculation of the load-bearing-deflection behavior of the panels tested in Aachen.

1. Introduction

Structural concrete has been one of the most widely used building materials, though it has shown disadvantages in terms of durability and vulnerability to corrosion. In order to protect the steel reinforcement against corrosion, a concrete cover is required. However, concrete covers according to current design codes, e.g. [1], can lead to structures with clumsy appearances. This is accompanied by the distinctive architectural trend to prefer the design of more slender structures. Motivated by the desire for filigree and lightweight elements with high durability, textile-reinforced concrete (TRC) has been steadily developed in recent decades, thereby opening up a new field of application for concrete. For example, lightweight façades with high structural capability and high durability can be realized with sandwich panels through a combination of TRC as a material for the rigid facings and a rigid polyurethane (PU) foam as a connecting link. However, no prevailing design model for ordinary structural concrete panels is valid for calculations involving TRC panels, due to the loss of stiffness and the load transfer between the facings and core because of the cracking of the facings at higher load levels. In order to derive a reasonable load-bearing behavior model for the composite panels, the aforementioned conditions must be taken into account. This paper presents selected parts of the performed investigations on the load-bearing behavior of sandwich panels and a suitable model to assess the deformation and load transfer that considers the cracking of the facings.

2. Material properties of the sandwich components

2.1. Textile reinforcement

The most commonly used material for current TRC applications are filaments made of alkali-resistant glass (AR-glass, filament diameter 14–27 μm) or carbon. Hundreds or thousands of these filaments are bundled into rovings, which is then finished to a laid scrim, i.e. a mesh-like reinforcement structure (see Fig. 1).

* Corresponding author. Address: RWTH Aachen University, Institute of Structural Concrete (IMB), Mies-van-der-Rohe Str. 1, 52074 Aachen, Germany. Tel.: +49 1797532819; fax: +49 2418022055.

E-mail address: ashams@imb.rwth-aachen.de (A. Shams).

http://dx.doi.org/10.1016/j.conbuildmat.2014.04.025
0950-0618/

Abbreviations

$B_{o,u}$	flexural rigidity of upper/lower concrete facing
w	deflection
B_s	sandwich flexural rigidity
q	global transverse loading
B	whole flexural rigidity
γ	transverse strain
G_c	shear modulus of core material
c	centroidal distance between the upper and lower concrete facings
b	width of cross section
h	thickness of cross-section
$B_{f,u,l}$	flexural rigidity of upper/lower layer (concrete facing)
$E_{f,u,l}$	elastic modulus of upper/lower layer (concrete facing)
$I_{f,u,l}$	moment of inertia of upper/lower concrete facing
$A_{f,u,l}$	cross sectional area of upper/lower concrete facing
P	point load (left hand)
e	distance of the point load P from the left support
P^*	point load (right hand)
e^*	distance of the point load P^* from the left support
l	panel length
x	control variable (distance from left support)
$M_{f,u,l}$	bending moment of upper/lower concrete facing
$\kappa_{f,u,l}$	curvature of upper/lower concrete facing
$\varepsilon_{t1,ul}$	strain in reinforcement
$x_{f,u,l}$	height of compressive zone of upper/lower concrete facing
α_t	static Youngś modulus of the textile reinforcement/concrete ratio
$a_{t,u,l}$	cross-sectional area of textile reinforcement in tensile zone
$N_{f,u,l}$	axial load of upper/lower concrete facing
$q_{f,s}$	shear failure leading load (for uncracked facings)
τ_s	shear strength of core
A_c	cross-sectional area of core material
$q_{f,b}$	bending failure leading load
n_t	number of textile layers
f_t	tensile strength of a fabric in concrete
c_e	distance between the centroidal axes of upper/lower concrete facings

For the experimental investigations described in this paper, three different fabrics (F1–F3) made of AR-glass have been applied as reinforcement. Since the filaments have diameters of a few micrometers, and therefore miniscule spaces between the filaments, the concrete mixture is unable to penetrate the inner rovings. Thus, the core filaments are not activated for load transfer. The impregnation of the textiles with, for example, an epoxy resin enables a homogenous cross-section in which nearly all of the filaments are activated for load transfer, since the resin has the ability to penetrate into the rovings and connect the filaments. The geometric and mechanical properties of the used fabrics are given in Table 1.

2.2. Fine-grained concrete

The properties of the textile reinforcements lead to special demands on the concrete mixtures. In order to enable the penetration of the fabric mesh, the maximum grain size is limited to about 2 mm, and a low viscosity is required. Concrete 1 (Table 2) is a premixed concrete containing 2% by mass of AR-glass short fibers, widely used as a GFRC (Glass Fiber-Reinforced Concrete) for the fabrication of ventilated façade systems.

Concrete 2 is a mixture based on Concrete 1 with less added cement, short fibers, and silica fume. At the same time, the portion of sand with diameters above 0.7 mm is increased. The changes in the mixture result in a higher compressive strength and lower shrinkage values. The main properties of the hardened concretes are summarized in Table 3.

The compressive strength was determined according to DIN EN 196-1 [3]. The axial tensile strength was calculated based on stain-controlled tensile tests on concrete cylinder specimens with a diameter of 50 mm and a height of 100 mm, according to [4], while the elastic modulus was evaluated by tests on specimens as per DIN 1048-5 [5]. The shrinkage values were found following the procedure from the German Committee for Reinforced Concrete (in German DAfStb), issue 422 [6].

2.3. Rigid foam core

Polyurethane (PU) foam is a suitable material to produce sandwich panels with high stiffness, high load-bearing capacity, low thermal conductivity, and excellent insulating properties. The load-bearing capacity and the shear and elastic moduli increase with increasing foam density. On the other hand, the thermal conductivity and sound insulation are affected adversely. For the four-point bending tests conducted, rigid polyurethane foams of different densities, as shown in Table 4, were used.

4. Summary of experimental investigations

3.1. Bending tests on sandwich beams

To investigate the load-bearing capacity of sandwich panels with textile-reinforced facings, a total of 24 beam tests were performed. Appropriate parameters were varied in 4 series of four-point bending tests, set up as seen in Fig. 2, to investigate the influence of three overarching factors on the load-bearing capacity: geometry (including such variables such as span length, flat/profiled facings, and the thickness of flat facings), materials (different fabrics, foam, and concrete materials), and the reinforcement ratio.

During the deformation-controlled tests, the strain of the tensile zone and the deflection at mid-span of the beams were measured with LVDTs. Further information about the test set-up and production methods can be found in [2,7–9]. As outlined in [7], a sufficient adhesive strength in the joint between the core and the concrete facing—a key factor affecting the load-bearing capacity—can be achieved by pressing a notched core into the freshly cast concrete facing. All the panels discussed in this paper have been produced by this method. The experimental programs, as well as results of select representative beam tests are listed in Table 5.

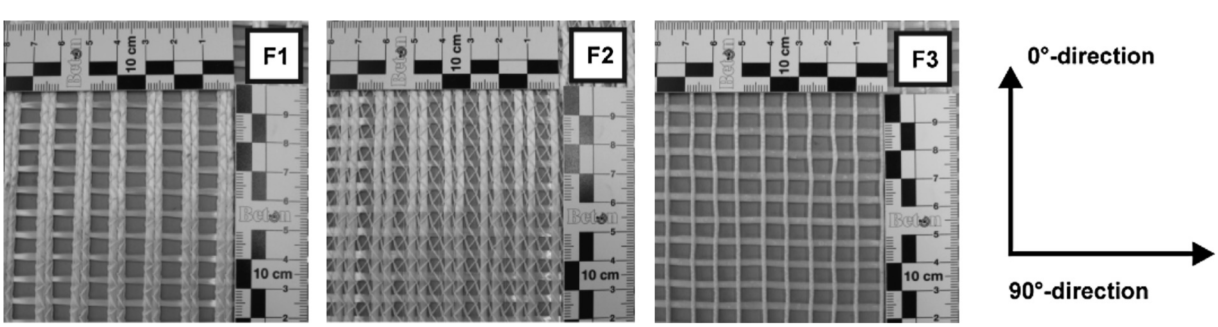

Fig. 1. Applied fabrics 1–3 (left to right).