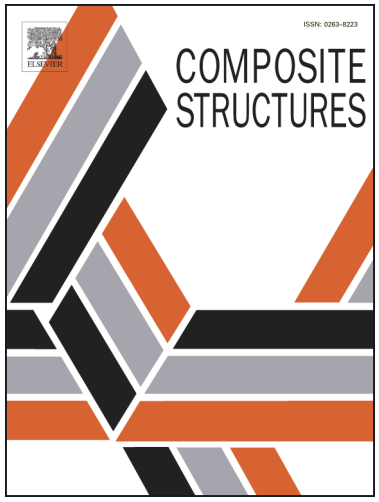

Structural behavior of a lightweight, textile-reinforced concrete barrel vault shell

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Abstract

Textile-reinforced concrete (TRC) as a novel composite material offers a wide range of capabilities and flexibility in the manufacturing of thin-walled, lightweight structures. The application of textile reinforcement in fine aggregate high-performance concrete has enabled the dimensioning of structural concrete in very small thicknesses. This possibility allows for the fabrication of thin-walled TRC shell structures with complex geometries. On the other hand, structural planning and construction require new modeling approaches to comprehend the structural behavior of such forms. In this paper, we present the fabrication procedure of a large-scale TRC vault shell, together with the performed experimental study. The shell structure was tested under a two-step loading scenario to study the load-bearing behavior. The particular focus of the paper is on the analysis of the structural behavior by means of an anisotropic strain-hardening material model specifically developed for the simulation of TRC shells. The prediction obtained using the nonlinear finite element simulation has been compared with the test results to validate the modeling approach. The performed studies are used to evaluate and discuss the structural redundancy included in the applied linear ultimate limit state assessment procedure.

Keywords: Textile reinforced concrete, Carbon concrete, Thin-walled shells, Cementitious composites, Composite structures, Finite Element Analysis, Microplane damage model

1. Introduction

The design and construction of thin-walled shells made of cementitious composites for use in architecture and civil engineering bring about several challenging questions that span the fields of material development, production technology, and safety assessment. The combination of high-performance carbon or glass textile fabrics with a fine-grained cementitious matrix opens up new possibilities for the design of lightweight structures with high degree of material utilization. Because of the flexibility in shape and resistance to corrosion of the textile fabrics, thin concrete shells with shapes tailored to specific boundary conditions can be produced that would not be feasible using traditional steel reinforcement.

Textile-reinforced shells recently constructed at the campus of the RWTH Aachen University were motivated by the need to illuminate the potential of the novel composite material and, at the same time, to examine the suitability of the developed design and production methods for engineering practice. In particular, the manufacturing aspects involved in the construction of the hypar shells serving as roof of the T3 Pavilion [1] were addressed in detail in [2]. The methods applied to characterize the material, including the experimental procedures and structural performance assessment, were described by the authors in [3]. Another carbon concrete shell with a barrel vault shape serving as a roof element over a bicycle stand (Fig. 1) was recently presented in [4, 5] with a focus on the formulated procedure of ultimate limit state assessment.

Reliable dimensioning and assessment rules for a wide range of TRC shell applications can only be formulated with an in-depth understanding of all relevant aspects of their structural behavior. The required insight into the correspondence between the composite material structure, shell shapes, boundary conditions, possible stress redistribution mechanisms, and failure scenarios can be gained using advanced numerical models reflecting specific aspects of the TRC structural shell behavior. We consider the following three phenomena in the material and structural behavior, which are essential for the formulation of a realistic modeling framework to serve as the basis of future code standards and design tools:

- The tensile response of a shell cross section exhibiting strain-hardening effect owing to an evolving fine crack pattern.
- Two-dimensional anisotropic damage owing to matrix cracking and debonding within a shell cross section exposed to combined normal and bending loading.