Construction and Building Materials 116 (2016) 235–244

Contents lists available at ScienceDirect

Construction and Building Materials

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

Damage in glass-concrete composite panels

Luigi Biolzi, Sara Cattaneo *, Pietro Crespi, Nicola Giordano

Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy

HIGHLIGHTS

- Progressive failure analysis of glass concrete composite panels.
- Simplified analytical model.
- Failure prevention due to concrete shrinkage.
- A case study.

ARTICLE INFO

Article history:
Received 2 November 2015
Received in revised form 10 April 2016
Accepted 26 April 2016
Available online 4 May 2016

Keywords:
Glass-concrete
Composite panels
Shrinkage
Thermal loads
Numerical model

ABSTRACT

The evolution of damage of a glass-concrete façade panel is presented and discussed. The phenomenon is strongly influenced by the mutual interaction between three materials (concrete, steel rebars and glass) having different mechanical and rheological properties.

To assess the possible causes of the observed damages, detailed 3D finite element numerical analyses were conducted considering the effects of thermal loads, due to difference of temperature outside and inside of the building, and the effects of concrete shrinkage. Furthermore, a construction stages analysis was implemented to consider the loading history during the production process of the panel.

The analyses were performed both in linear elastic and non-linear conditions to assess the stress redistributions in the panel due to concrete cracking. In particular, the analyses showed that the shrinkage of concrete was the main reason of the detected damage in a case study, even considering the creep that mitigates the phenomenon leading to a delayed cracking. Finally, a parametric study is presented assuming different factors (concrete rib sizes, different shrinkage laws, as a consequence of the addition of shrinkage-reducing admixtures (SRA), different bond between glass and concrete and different reinforcement ratio). The results of this parametric study suggest interesting remarks about suitable design principles of glass-concrete façade panels.

1. Introduction

The research of high degrees of transparency has become a main concern in architecture following the increase of the application of glass in buildings. Therefore, from being used for simple infill panels, the glass is increasingly used to form complete load bearing structures. Among them, precast glass concrete panels have been employed as skylights, deck lights, stairs, landings, bridges, sidewalks, walls and other original uses. A surprising range of applications is conceivable with a resultant variety of aesthetic results [1].

The glass hollow blocks allow the reduction of supply costs with respect to traditional windows because they join the intrinsic characteristics of transparency with the worthwhile use of a modular element (for transportation, storage and on-site installation) [2]. In addition, the higher specific mass ensures a better sound insulation against impact noises and, the air chamber into the glass ensures a good thermal insulation. Glass is a homogeneous and isotropic material, having a linear elastic behavior up to a brittle failure [3]. The macroscopic strength of glass is dominated by microstructural flaws, which are always present, due to the production processes and subsequent handling. Furthermore, cutting processes negatively affect the mechanical response of glass elements, because of an additional defect production along the element boundaries that locally reduces the tensile strength [4]. The microcracks open in mode I when the tensile stress reaches a critical limit, but they can grow over time even for stress values much

* Corresponding author.
E-mail addresses: luigi.biolzi@polimi.it (L. Biolzi), sara.cattaneo@polimi.it (S. Cattaneo), pietro.crespi@polimi.it (P. Crespi), nicola.giordano@polimi.it (N. Giordano).

http://dx.doi.org/10.1016/j.conbuildmat.2016.04.106
0950-0618/

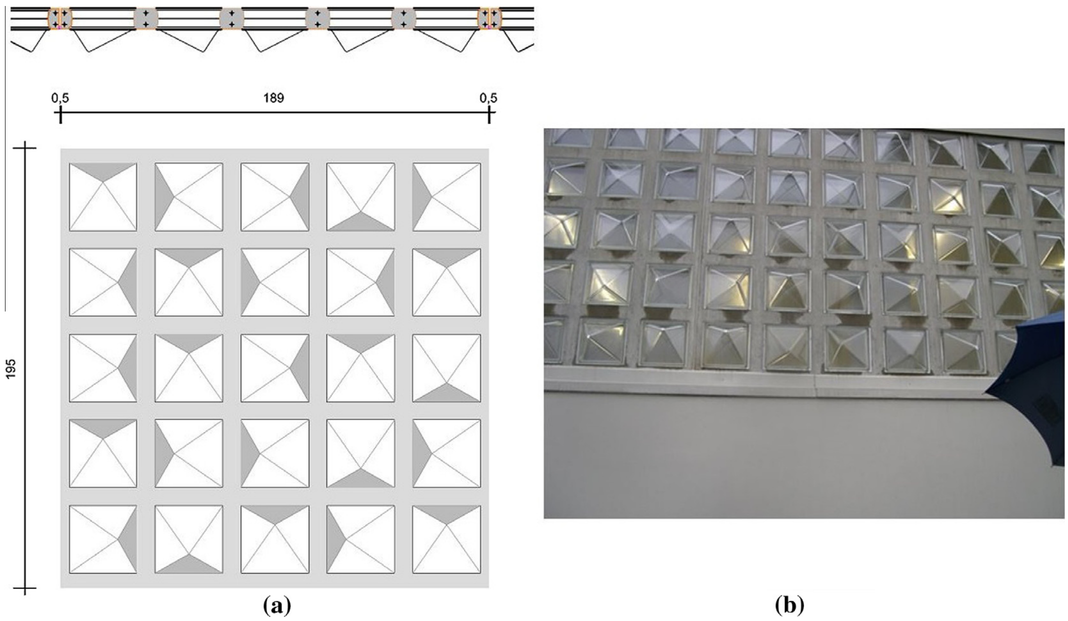

Fig. 1. (a) Panel 5 × 5 (measures in cm); (b) Portion of the façade.

Fig. 2. Damaged glass block and cracked concrete surface.

lower than the critical ones. This phenomenon, usually denoted as static fatigue or slow crack propagation, makes the glass strength dependent upon time and thermo-hygrometric conditions that, in turn, affect the speed of the slow crack propagation. In a composite panel, in addition to glass, there is also concrete, which has a peculiar long-term behavior. All concretes shrink, even the so-called shrinkage-compensating concrete, that is they show a time dependent strain. Concrete shrinkage strain persists to increase with time at a decreasing rate. Shrinkage reaches a final value as time approaches infinity and is dependent on all the factors which affect the drying of concrete, including the relative humidity, the temperature, the mix characteristics (type and quantity of the binder, water content, and water-to-cement ratio, ratio of fine to coarse aggregate, and the type of aggregate), and the size and shape of the element [5,6]. Because of a loss in volume, concrete shrinkage can lead to cracking when concrete is restrained [7]. Evident and/or unreasonably wide cracks usually may be unpleasant and spoil a visible concrete surface; in addition they allow the entrance of moisture thus accelerating corrosion of the reinforcement and leading to durability problems. Concrete shrinkage is an important design issue because it can cause, when restrained by a rigid glass element, an additional state of stress more and more significant in time. This paper is addressed to present and discuss the effects of a problematic combination of different materials, leading to irreversible damages of the glass-concrete composite panels with significant consequences on aesthetic, functional and economical aspects. The results of an extensive and detailed three dimensional finite element numerical analysis are illustrated. Linear and nonlinear analyses to evaluate the consequences of environmental thermal conditions and concrete shrinkage are presented as well. Even if the stress level was small, the creep effect was considered to evaluate whether it could significantly reduce the shrinkage effect. Finally, the influence of the concrete rib size, of the addition of SRA, of the bond between glass and concrete and of different reinforcement ratio were taken into consideration.

2. Observed damage

The problem of damage in glass-concrete composite panels is discussed with reference to an actual application of precast glass-concrete façade panels. The curtain wall, made of glass block concrete elements, was adopted in several façades of a complex building, with all exposures. Since the façades had different sizes, several types of panels were built, containing a different number of glass blocks, ranging from a minimum of 10 (panel size 189 × 86.5 cm) up to a maximum of 65 (panel size 189 × 493 cm).

The geometry of a panel with 25 blocks (5 × 5) and a portion of the façade is shown in Fig. 1.

A damage of the façade panels was observed just after the end of the construction works (about three months after the casting of the panels). In particular, some glass blocks showed a crack