Journal of Cleaner Production 66 (2014) 92–100

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Precast slabs using recyclable packaging as flooring support elements

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ARTICLE INFO

Article history:
Received 23 July 2013
Received in revised form
29 October 2013
Accepted 29 October 2013
Available online 12 November 2013

Keywords:
Precast slab
Recycling
PET bottle
Tetra Pak carton
Aluminum can
Mechanical properties

ABSTRACT

In this study, the substitution of ceramic components by recyclable PET bottles, aluminum cans and Tetra Pak cartons, used as an in fill material for semi-precast slabs, was investigated experimentally. The slabs were produced in full scale, with mean measurements of 1 m (width) × 3 m (length). The compressive strength and elastic modulus of the concrete were determined. The slabs were characterized according to their density and flexural strength. Economic viability analysis was also performed. The flexural strength of the reference slab was 31 kN, while the strengths of slabs using reusable packaging were 36–38 kN. A 20% reduction in mean density is another important advantage, because it reduces the weight for the manufacture, transportation and the total weight of the structure, thus reducing the cost of the structural design while facilitating the construction process. The direct costs of the materials required to manufacture the slabs were equivalent. Comparisons between the prototype slabs with different flooring support components indicate that these are feasible concerning both their fabrication and their structural performance.

1. Introduction

In recent years, irrespective of political, economic or ecological reasons, recycling has been encouraged throughout the world (Stehlík, 2009; Geng et al., 2010; Yuan, 2013). The volume of solid waste generated is increasing, often as a result of poor management of production processes (Seadon, 2010). Currently most of this waste ends up in landfills and only a small portion is recycled (Stehlík, 2009; Almeida et al., 2010). Considering that the problem of waste generation is relatively recent, that its environmental impact is important and that certain solid waste materials available have excellent properties (like PET bottles), in the short to medium term, society must conduct the management of this waste more efficiently to ensure sustainability.

It is undoubtedly the best alternative to reduce the impact that the environment suffers from the consumption of raw materials and the disorderly generation of waste (Fattuhi and Clark, 1996; Sunthonpagasit and Duffey, 2004). The construction market is presented as one of the best alternatives to consume recycled materials. This is because construction activity can be performed in any region, thus reducing costs in transportation (Benazzouk et al., 2007; Angulo et al., 2010). In addition, the materials needed to produce most of the construction components do not require great technical sophistication.

Precast unidirectional slabs can be defined as structural elements with a solid or ribbed section, consisting of longitudinal ribs, arranged in a single direction. They can be formed by precast elements, called beams, normally interspersed with ceramic components, called tiles (Fig. 1) and a "concrete cover" laid *in situ*. Fig. 1 shows different types of prefabricated and molded *in situ* slabs: (a) prefabricated slab with ceramic tile as filler; (b) prefabricated slab with expanded polystyrene (EPS) filler; (c) waffle slab with ceramic blocks as filler; and (d) waffle slab with EPS as filler. In this type of slab, the action of the reinforced concrete beams resists the bending stresses, thus the filler material can consist of virtually anything, provided that it withstands the forces resulting from the compressed concrete cover, i.e. the fresh concrete layer applied on top of the slab, since it functions as temporary formwork.

Packaging available in bulk that is commonly discarded without proper disposal, such as Tetra Pak cartons, aluminum cans and PET bottles, could be used to replace ceramic tiles simply and efficiently (Carbonari et al., 2012). Prior to commercial use, the mechanical strength of these materials must be proven to be compatible with conventional slabs, since the aim should be slabs that have the same unrestricted use as conventional slabs. Faced with the possibility of reusing packaging materials in proximity to their

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0959-6526/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jclepro.2013.10.059

Fig. 1. Types of slabs: (a) prefabricated slab with ceramic tile as filler; (b) prefabricated slab with expanded polystyrene (EPS) filler; (c) waffle slab with ceramic blocks as filler; and (d) waffle slab with EPS as filler.

disposal, communities could organize their collection and storage, with the aim of producing prefabricated slabs for commercialization, thus generating revenue, while contributing to adequate waste disposal.

Research is being conducted that aims to increase the efficiency of these slabs through the use of lightweight concrete or lighter composites (Keller et al., 2007; Schaumann et al., 2008). Lightweight industrial residues, such as polymeric materials, are frequently used as aggregates in lightweight concrete (Ogi and Mizui, 2005). Rubber materials from recycled tires are also extensively used, primarily due to their availability (Pelisser et al., 2011; Sukontasukkul, 2009; Milanez and Bührs, 2009). Regarding concrete slabs, few studies have evaluated the effects of substituting traditional ceramic components with recycled packaging, due to the need to fabricate and evaluate full-scale structural elements.

Considering the factors outlined above, this research presents experimental analysis of precast unidirectional slabs, in which traditional ceramic components (tiles) were substituted by Tetra Pak cartons, aluminum cans and PET bottles. To achieve this, twelve prototypes were cast in real scale, weighed and subjected to flexural resistance tests to evaluate their structural performance. Besides analysis of the technical feasibility of using these types of slab, an economic analysis was performed that considered the consumption of all the constituent materials.

2. Materials and methods

2.1. Manufacturing the slabs

Twelve prototype slabs were fabricated and the specific gravity of all 12 was measured. The slabs used four types of filler element: i) the traditional hollow ceramic blocks, commonly used in construction; ii) Tetra Pak cartons, with a prism-shaped base measuring 0.070 m × 0.072 m and height of 0.200 m; iii) aluminum cans, bound together in pairs with adhesive tape, with each pair measuring 0.24 m in length and 0.066 m in diameter; and iv) PET bottles (510 mL), with no recesses or protrusions, cut and embedded, measuring 0.25 m in length and 0.06 m in diameter.

For each type of packaging component, three prototype slabs were fabricated, in which four, 3 m long precast concrete beams were used. The main armature consisted of three CA-60 steel bars (ASTM A615, 2012), with a nominal diameter of 4.2 mm (Fig.2). Steel bars were used in the compression cap to control cracking and to distribute the stresses caused by concentrated actions. CA-60 steel bars with a nominal diameter of 5.0 mm were used, spaced every 20 cm, with a minimum area of 0.6 cm^2/m. The prototypes were fabricated by placing the precast beam together filled with

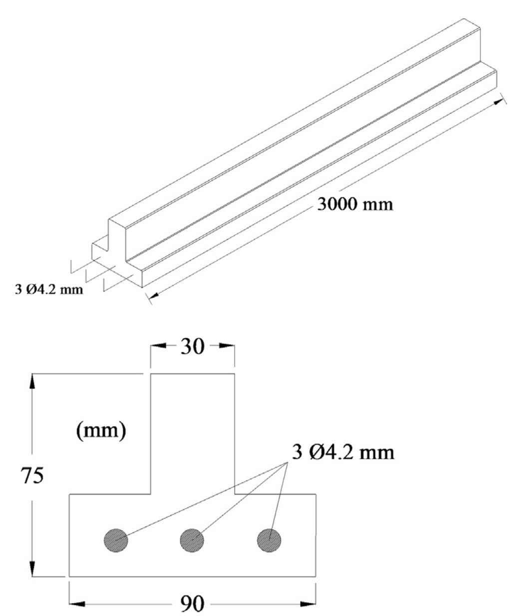

Fig. 2. Layout of the precast beam, showing the cross section.