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Early age performance and mechanical characteristics of recycled PET fibre reinforced concrete

Ruben Paul Borg[a,*], Owen Baldacchino[a], Liberato Ferrara[b]

[a] Faculty for the Built Environment, University of Malta, Tal-Qroqq, Msida MSD 2080, Malta
[b] Department of Civil and Environmental Engineering, Politecnico di Milano, Piazza Leonardo da Vinci, Milano, Italy

HIGHLIGHTS

- Fibres are obtained by shredding recycled PET bottles.
- Recycled PET fibres are used as dispersed reinforcement in concrete.
- Effects of fibres on cracking potential due to plastic & restrained drying shrinkage.
- Effects of fibres on mechanical properties of concrete.
- PET fibres can effectively replace industrial fibres.
- PET fibres are effective in structures sensitive to shrinkage cracking.

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ABSTRACT

In this study the performance of concrete reinforced with fibres produced from waste non-biodegradable plastic, polyethylene terephthalate (PET), has been thoroughly investigated. The novelty of the study, to the authors' knowledge, consists in the fact that fibres have been employed as directly shredded from collected waste plastic bottles, with no processing through, e.g., plastic melting and fibre spinning. Moreover, a comprehensive investigation has been herein undertaken, which ranges from the identification of the mechanical behaviour of the fibres to the assessment of their bond with the matrix and of the early age and hardened state properties of the recycled PET fibre reinforced concrete.

Different types of shredded recycled PET fibres, straight and deformed, together with different fibre lengths, 30 mm and 50 mm, have been assessed, for varying percentage addition in concrete. The tensile properties and pull out characteristics of the fibres have been determined. The effects of fibres in mitigating plastic and restrained drying shrinkage cracking were then assessed and, finally, the compressive strength and the flexural performance of the fibre concrete were determined. The cracking potential of fibre-reinforced mortar thin slabs was also assessed.

The use of shredded recycled PET fibres in concrete has been shown to lead to interesting improvements in performance for various fibre concrete characteristics and offers a potential alternative for this material.

1. Introduction

In the field of concrete construction, the use of fibres has been steadily increasing over the past years in an effort to overcome the inborn tensile strength and toughness limitations of plain concrete. The ability to enhance flexural and tensile performance of the concrete matrix, together with the opportunity for improving its durability, pushed boundaries in developing new materials to be used as fibres. As ma matter of fact the introduction of fibres is also known to lead to a reduction in the shrinkage cracking of the concrete matrix, which affects both the aesthetics and the service life of structures.

Concrete reinforced with polymer and steel fibres (fibre reinforced concrete – FRC) belongs to the so-called composite materials. Compared to plain concrete, FRC is characterised by improved crack control, better fatigue resistance and greater tensile and flexural performance. The level of fibre performance depends strongly on the quality and amount of the employed fibres applied, on their shape and dimensions as well as on their bond to the concrete matrix.

* Corresponding author.
E-mail addresses: ruben.p.borg@um.edu.mt (R.P. Borg), liberato.ferrara@polimi.it (L. Ferrara).

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The environmental problems related to the management of numerous different types of waste have led to assess the possibility of their use as constituents in the concrete. Commonly employed waste materials include fly ash, silica fume, dusts from quarry and fillers and recycled aggregates from construction and demolition waste. Fibres derived from waste include metal fibres from recycled tires, natural fibres from agribusiness and different types of recycled plastics [1–5].

The ever-increasing awareness to provide alternative uses for recycled waste materials, especially in the construction field, pushed forward the idea of making use of one of the most common consumer plastics used – polyethylene terephthalate (PET) – to produce fibres for FRC. This would provide a sustainable alternative for this non-biodegradable material, that of being re-used instead of being taken to recycling facilities for processing.

In Europe alone, more than 60 billion PET bottles were recycled in 2012. More than 52% of all post-consumer PET bottles were collected for recycling. This collection rate is much higher than the target rate of 22.5% as stipulated by the waste directive for plastics. This helps recycling plants to work more efficiently and experience a higher utilization rate at their plants. Uses for recycled PET (R-PET) include fibres, which are the largest end-product for such material, used in clothing and textiles industry. RPET is also used for the production of clear sheets and strapping tapes, both used for packaging. In 2008, the passing of EU Regulation 282/2008 on recycled plastic materials and articles intended to come into contact with foods has meant that all EU member states now allow R-PET from approved plants to be used in food contact containers [6,7].

Recycled PET (R-PET) is used for a variety of applications. The clear, higher grade pellets and flakes are primarily used for the food packaging industry whilst flakes which do not make it through the final purification process for food contact, or coloured flakes, find a market in hidden or coloured applications. However, recycling of PET is far from a straight-forward process. Any contamination can result in the downgrading of the material. If materials such as PVC, water, dyes and almost any alien plastic are mixed with PET, they would reduce its properties and quality for certain uses and, to a certain extent, can also make it unusable. Due to the rigorous recycling process that PET has to have, every virgin material experiences a fate known as down-cycling, which results in the plastic being used for lesser quality materials when compared to its original use [8].

Research on the use of R-PET fibres as dispersed reinforcement in concrete and mortars has been ongoing for about a decade with sporadic studies. Ochi et al. [9] also reported a number of applications of R-PET FRC in Japan, including road construction, tunnels, bridge piers and underground storage containers for LNGs.

Ochi et al. [9] and Kim et al. [10] investigated the bond behaviour of R-PET fibres with a concrete matrix, also with reference to the effects of the fibre surface characteristics. Embossed fibres provided the highest bond strength, followed by crimped and straight ones [10]. The effects of fibre surface characteristics on the bond behaviour also resulted in comparable improvement of the resistance to plastic shrinkage cracking, mainly for lower fibre volume fractions. Comparable performance between R-PET and industrially produced polypropylene (PP) fibres was measured, either with reference to bond [9] or with reference to the reduction in the restrained shrinkage cracking potential [10].

As for the effects of the inclusion of R-PET fibres on the compressive strength of R-PET FRC, contradictory results were found in the literature. While Ochi et al. [9] reported a moderate increase of the compressive strength (from 6% to 13%) for fibre volume fractions up to 1%, the increase diminishing or even turning into a decrease for higher fibre volume ratios, Kim et al. [11] reported a moderate (up to 9%) decrease. Both studies agree that R-PET FRC features a lower elastic modulus than the reference plain matrix, decreasing with increasing the fibre content.

The difference in results obtained by the two studies can be attributed to the fact that different material processing of the PET fibres affected their intrinsic fibre properties. It is likely that the fibres used by Ochi et al. [9] had a lower elastic modulus, which in turn would have effectively restrained the tensile stresses with little deformation, thus allowing higher compressive loads to be reached [11]. Coherently with the aforementioned assumptions, the highest increases were measured by Ochi et al. [9] for the less strong concretes.

Pelisser et al. [12] observed that a slight increase in the compressive strength after 28 days took place in the samples having PET fibres whilst a decrease was observed after 150 days, indicating degradation signals of the PET fibres in an alkaline environment, as also confirmed by dedicated studies [13].

With reference to flexural toughness performance, Ochi et al. [9] performed four-point bending test on $100 \times 100 \times 400$ mm unnotched prisms. They measured remarkable post-cracking residual strength and toughness increase, with respect to the parent plain matrix, comparable to the one obtainable with other types of industrial fibres [14], as also confirmed by the deflection hardening behaviour obtained for the highest tested R-PET fibre volume fraction (1.5%).

These findings were also confirmed by Pelisser et al. [12] who, also with reference to flexural performance, highlighted the detrimental effects of the alkaline environment on the degradation of the PET fibres. As a matter of fact the performance measured 150 days after casting resulted worse than the one at 28 days.

The joint need to providing an effective recycling solution for large quantities of post-consumer waste, such as PET bottles, in an island-state community as Malta, and of confirming and widening the quite scant experimental database available in the literature about the engineering performance of R-PET FRC has motivated the investigation detailed in this paper.

To the authors' knowledge the novelty of this study mainly consists in the following two aspects:

- fibres are obtained by simply and directly shredding the waste plastic bottles with no need for pre-processing the plastic e.g. through melting or heat treatment and subsequent fibre spinning;
- a comprehensive investigation has been herein undertaken, which encompasses and complements the previously cited investigation in a unified framework. As a matter of fact, this study starts with analysing the properties of the fibres and their bond with the matrix and proceeds going on with the assessment of their effectiveness, as a function of their type and dosage, in mitigating plastic and restrained drying shrinkage cracking. Finally the measurement of the flexural performance of the R-PET FRC according to the most recent international code prescriptions (Model Code 2010, EN 14651) has been performed.

This kind of a thorough investigation hardly could be found in the literature so far, referenced studies dealing with either one or the other single property, and, but for one study [15] on mortar reinforced with R-PET fibres from shredded bottles, all focused on processed PET fibre spinning production.

2. Experimental programme: materials and testing

2.1. Materials

Two different fibre geometries were employed in this research, straight and deformed. Furthermore, two different fibre lengths were examined, 50 mm and 30 mm, for each fibre profile.