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Innovative techniques for concrete reinforcement with polymers

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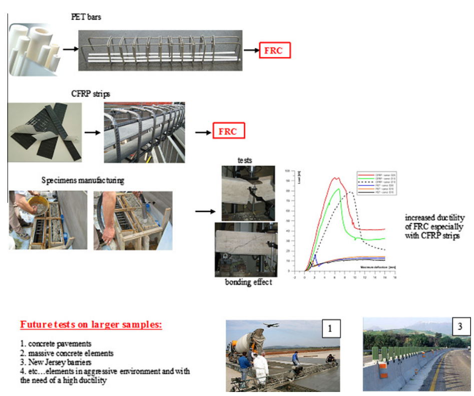
HIGHLIGHTS

- Concrete reinforced with PET bars and CFRP strips shows a higher ductility.
- PET bars and CFRP strips are inserted inside the concrete casting to make beam specimens.
- Bending tests are performed with a point load in the middle-span of each specimen.
- Comparisons of the results show a better behaviour of specimens with CFRP strips.
- Future tests with an equal area of reinforcement.

GRAPHICAL ABSTRACT



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ABSTRACT

In this work the results of a series of preliminary tests on concrete beam specimens reinforced with PET and CFRP are shown and discussed. The novelty in the tests lies in the use of a waste material with promising results. The reinforcement is made with PET and CFRP are arranged as continuous bars and strips, respectively. They are positioned inside the specimen, in the same position of the steel bars in a reinforced concrete element. For both cases it is noticed that they limit the presence of cracks and, especially, avoid and/or reduce the corrosion processes in reinforced concrete structural elements. In particular, the concrete-fibers adhesion and the global behavior of these fiber reinforced concretes is analyzed in order to evaluate the possibility of future investigation. However, the results of the tests showed a better behavior for specimens reinforced with CFRP strips.

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1. Introduction

Concrete is a building material whose main drawback is its very low tensile strength, so low that it is often completely neglected in the calculus models. If concrete is today by far the most widely used building material in the world is thanks to reinforcement bars that make up for its poor tensile strength and brittle behavior. Steel reinforcement is often utilized but also reinforcement made with other materials are used [1–3]. Among these, polymeric materials are gaining success in recent decades. The use of such reinforcement has been also codified in a standard from FIB (Federation Internationale du Beton) [4]. National and international research is focusing, in particular, on the use and re-use of waste polymeric materials [5–16]. In this way it is possible to combine the advantages in terms of a better behavior of the mixture with those derived from the exploitation of large quantities of waste that would otherwise be used in landfill, incineration and recycling. The recycling of waste materials, in fact, is one of the most important problems nowadays and in the future that people must try to solve in every possible way.

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The present study mainly concerns the use of polyethylene terephthalate (PET) and Carbon Fiber Reinforced Polymers (CFRP) in concrete. Tests have been performed utilizing them as reinforcement for concrete, showing for them good characteristics of adhesion with concrete. Previous pull-out tests confirmed this property for PET [17], while for CFRP most tests principally aimed to determine the adherence between the polymer and the bonding material utilized to externally stick the fiber reinforcement to the surface of the concrete element [18,19]. Modeling has been proposed for such confining effect of FRP [20]. Also investigation on the axial behavior of confined and unconfined concrete beams exposed to aggressive environment has been performed [21]. Some studies refer to the bonding produced by CFRP in beams damaged for corrosion of the steel bars [22,23]. Actually, they are analyzed on restored beams to get the level of confidence in using FRP for strengthening corroded beams.

In this paper, in accordance with the concept of environmental sustainability, the aim is to utilize CFRP strips and PET bars as reinforcement in substitution of steel in concrete elements subject to bending forces. The principal novelty of the present study is the use of a waste material such as PET with promising results. In this case the small steel long bars present in the reinforcement cage of the concrete element have a very low contribution to the strength capacity of the section, they are inserted with the aim of keeping the stirrups in place.

Bond deterioration between steel reinforcement and concrete is one of the main reasons for structural degradation of corroded r.c. beams [24,25]. Both flexural capacity and ductile behavior are impaired by corrosion induced bond weakening.

One of the main problem of steel reinforcement, in fact, is its high corrosivity due to external atmospheric agents, which produce a fast degradation of constructions. It is a very important problem to face for concrete buildings in order to keep them reliable and operative for a long period of time.

This research is only preliminary but it gives new perspectives to the use of FRP for concrete reinforcement with the aim of giving a longer life to concrete structures.

The study presents the results of a series of preliminary tests on concrete specimens reinforced with PET and CFRP arranged inside the element as bars and continuous strips, respectively. Results are shown and discussed to highlight the different behavior and the pro and cons of the two techniques.

2. Experimental procedure

Six specimens in concrete were realized: three specimens were reinforced with PET bars and three specimens were reinforced with carbon fiber pultruded (CFRP) strips. All specimens had the same geometrical dimensions but are manufactured utilizing two different concrete typologies with aggregates of different sizes, as better described in Section 2.1.

2.1. Characteristics of the materials

2.1.1. Concrete

Two different concrete castings were prepared during two different periods of the year, with different environmental conditions.

Concrete type 1: C20/25 concrete [26,27] with a maximum diameter of the aggregates ⩽20 mm and a consistency class equal to S4 from the slump test, at an external temperature of 25 °C.

Concrete type 2: C20/25concrete, with a maximum diameter of the aggregates ⩽10 mm and a consistency class equal to S4 from the slump test; in this case the external temperature was lower, around 20 °C and there was a rather strong wind.

It must be highlighted that the second concrete casting was much more fluid and, therefore, more workable respect to the first one.

2.1.2. PET reinforcement

PET is not much used in Structural Engineering, unless as a material for thermo-acoustic isolation. In Civil and Geotechnical Engineering it is principally utilized as geo-composite cover for drainage.

In the present paper we want to investigate on the possible use of this fiber reinforcement with the same function of steel reinforcement inside a structural element. This kind of research started some years ago at the Technical University of Bari on the use of polymers and waste polymers (i.e. bottles of water) to improve the brittle behavior of concrete.

The possible use of PET for reinforcement of structural elements in concrete is quite new. Its ductility and resistance to chemical attacks from aggressive environment (such as marine environment, industrial environment) make it a possible substitutive of steel in absorbing the tensile stress in structural elements. In addition its high ductility makes it good to be utilized in those cases where impact loads can occur (airport pavements, new jersey, and so on).

PET utilized for the specimens is provided as long bars by the production company, Plastotecnica Emiliana s.r.l., Bologna, Italy. Its mechanical characteristics are shown in Table 1; they have been obtained at a temperature of 20–21 °C.

2.1.3. CFRP reinforcement

CFRP has been utilized in the tests in the shape of strips having the mechanical characteristics provided by SIKA S.p.A, Switzerland (see Table 2). The strips adopted in the tests are of CarboDur type, specifically Sika CarbonDur M.

CFRP strips are utilized as a high resistance reinforcing system for different structural materials such as reinforced concrete, masonry, stone works, steel, aluminum and timber. They have a reduced weight, are easily manageable, and can be directly cut on site to the desired length with a hacksaw. They are usually utilized as reinforcing element for retrofitting of existing structures: bending and shear reinforcement of beams, consolidation of arches and vaults, recovery of columns with the method of hooping. Fig. 1 shows some different shapes of CFRP sheets and strips.

Table 3 collects the principal mechanical characteristics of the materials utilized for the test specimens, steel, PET and CFRP. They have been obtained from the technical data sheets provided by the production companies of each product. The values shown for steel are those codified in the Italian standard [26].

In total 6 specimens have been prepared, three for each kind of reinforcement. All specimens had the same length L = 1.04 m and a 150 mm × 200 mm cross-section. Two specimens have been manufactured with Concrete type 1, called D20 because of the maximum dimension of the aggregates equal to 20 mm; four specimens have been prepared with Concrete type 2, called D10

Table 1
Mechanical properties of PET provided by Plastotecnica Emiliana s.r.l., Bologna, Italy.

Density (g/cm^3)	1.38
Tensile strength (N/mm^2)	90
Elongation at break (%)	>20
Elastic modulus (N/mm^2)	3000
Resilience (KJ/m^2)	KB
Hardness test with ball identer (N/mm^2)	180
Coefficient of friction against steel	0.22
Absorption of moisture in the standard climate (%)	0.2

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