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Multi-parametric characterization of a sustainable lightweight concrete containing polymers derived from electric wires

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HIGHLIGHTS

- A lightweight concrete obtained mixing cement, water and polymer waste was analyzed.
- The residual polymer was obtained by the recycling of electric wires.
- Chemical, mechanical, thermal and acoustic tests were performed.
- The results showed the possibility to use the concrete for floor screeds.

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ABSTRACT

The present paper reports the results of the experimental investigation of a sustainable lightweight concrete containing polymers derived from the recycling of the sheets of electric wires. After the removal of the copper, the plastic insulating sheet is ground into small size granules. Firstly the chemical and physical properties of plastic granules are investigated and their applicability in concrete is studied. Measurements of dynamic stiffness, impact sound pressure reduction and thermal conductivity show that the developed concrete can be successfully used for thermal and acoustic insulating lightweight screeds to be applied above the concrete structural slabs in floors.

1. Introduction

Nowadays it is almost impossible to imagine a world without concrete, a material with infinite applications that can be produced in order to satisfy almost every technical specification in the building and transportation sector. For its excellent characteristics on average one ton of concrete is produced each year for every person in the world [1]: this clearly explains the incredible amount of material produced and the resulting environmental impacts. The production of each ton of Portland cement releases almost one ton of carbon dioxide into the atmosphere and worldwide the cement industry alone is estimated to be responsible for about 7% of all generated CO_2 [2]. Furthermore cement production is very energy demanding: it uses approximately 1% of all energy produced in the United States [3]. Of course it is not conceivable to limit the use of concrete but there are several ways to reduce its environmental impact towards a higher sustainability in order to obtain a "green" concrete [4,5]. One of the most used is to replace as much as possible Portland cement with alternate components, possibly obtained by recycled materials or by-products of industrial resources. Among those the most used are fly ash, ground granulated blast furnace slag, recycled concrete, silica fume, post-consumer glass, end of life tyres, recycled plastics or other natural materials [6,7].

As far as the use of recycled polymers in concrete, their application is quite problematic because of the poor bond between the plastic particles and the cement matrix with a consequent decrease of the concrete strength [8,9]. On the other hand other properties can be enhanced: (i) being an excellent thermal insulator, the inclusion of plastic inside the concrete considerably improves the thermal resistance [9]; (ii) the decrease of the concrete stiffness leads to an improved insulation against impact sounds [10]; (iii) the sustainability of the final material is definitely higher compared to that of a traditional concrete also considering the large amount of plastic waste that needs to be disposed each year [11]. All these aspects are currently crucial for the building sector considering the increasing demand for high-performance sustainable

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materials to be used in low energy or nearly Zero-Energy Buildings [12].

Even if the final strength of the concrete containing plastic waste is reduced and structural applications are often precluded, an optimal application for this material can be found in the building sector with the creation of lightweight slabs to be used in alternative or in addition to a common floating floor system applied above the structural concrete slab.

The present paper studies one of these solutions containing plastic waste coming from the recycling of electric wires mixed with cement and water in order to create a lightweight concrete: the acoustic, thermal, chemical and mechanical properties are analyzed and the results are presented. Thanks to new formulations of the tested material, the results presented in previous publications by the same authors [13,14] are here updated and discussed.

2. Description of the lightweight concrete

Electric wires are made of a conductive material, commonly copper, covered with a plastic insulator. Copper is of course the most valuable material to be recycled from end-of-life electric wires while the insulation sheet is often considered a low-value waste of copper recycling.

The sheets are ground and passed through calibrated sieves in order to obtain granules of homogenous sizes. Then the polymer granules can be mixed with concrete and water in the correct proportions to obtain a lightweight concrete. Its main application should be in the building sector and as a subfloor applicable manually or with pumps.

In Italy the national standard UNI 10667-14 [15] defines the requirements of the polymer materials obtained from the collection of industrial and post-consumer waste that can be used as concrete aggregates; in particular the standard gives the specifications for testing several physical parameters (such as composition, shape, size, density and water content) and the corresponding limit values for their application.

The ground polymer granules were tested following the specifications of the standard [15] in order to have a preliminary physical characterization of the loose granules alone.

The percentage in weight of the tested samples of polymer is 99.92% plastic and rubber while the remaining 0.08% is metal, probably not removed in the phase of separation of the sheet from the conductive wire.

Calibrated sieves with openings of 1, 2 and 5 mm were used to measure the granulometry: the size of the granules is always lower than 5 mm, with 13.8% in the range 2–5 mm, 54.5% in the range 1–2 mm and 31,7% with size lower than 1 mm.

The average value of the material density is 774 kg/m^3 and was measured according to the procedures given by ISO 61 [16].

Finally the residual water content evaluated by drying a sample in controlled conditions is equal to 0.62%.

The lightweight concrete (Fig. 1b) can be produced using variable percentage in weight of the following ingredients:

- 60–70% granules of recycled polymers (loose, density = 774 kg/m^3);
- 15–25% Portland cement 325 (loose, density = 1500 kg/m^3);
- 10–15% water (density = 1000 kg/m^3).

The application studied in the present paper is the use of the developed concrete for lightweight slabs to be applied above the concrete structural slabs in addition or in alternative to common floating floor systems used to reduce the transmission of impact noise.

3. Chemical characterization

Since the developed lightweight concrete is designed to be applied indoor in building flooring screeds, the toxicity of the granules was assessed in order to define the healthiness of the final product.

The emissions of VOC (Volatile Organic Compounds) were measured with a gas chromatograph using the solid-phase microextraction method. The measurement procedures are given by the Italian Standard UNI 10899 [17].

The results of the measurements showed the presence of a certain amount of chlorinated hydrocarbons, mainly chloroform, with an amount of 1.4 μg/g. Furthermore a reduced quantity of polycyclic hydrocarbons (mainly toluene) was found, with an amount of about 0.4 μg/g.

The amounts of VOC emissions from the analyzed polymer granules cannot be ignored. However the analyses were performed on the loose granules and not directly on the concrete: so when the composite is mixed to form the screed, it is reasonable that the emission of VOC from the polymers trapped inside the concrete are largely decreased.

4. Mechanical characterization

The ability to bear loads and to keep the thickness unchanged are fundamental requirements of flooring screeds. So mechanical tests were performed on sample layers of the developed lightweight concrete in order to measure its compressibility. The measurement procedures are given by the standard EN 12431 [18]: three levels of load (250, 2000 and 50000 Pa) are applied for a defined period of time (120 s) on a square sample with 200 mm side and the corresponding variation in thickness is recorded (fig. 2a). In particular:

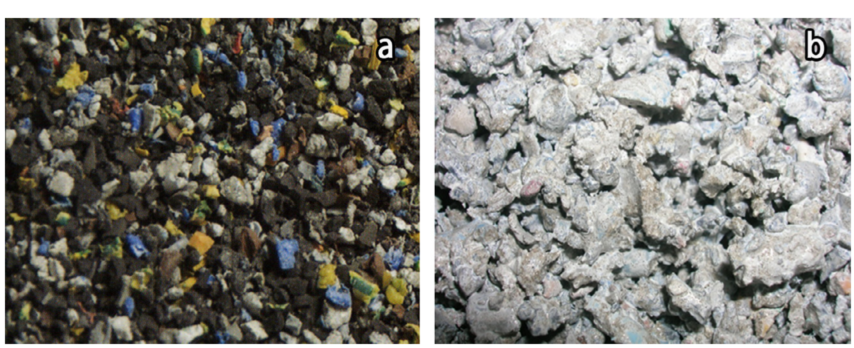

Fig. 1. (a) View of the polymer grains obtained by the electric wires sheets; and (b) view of the concrete matrix.