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Lightweight plasters containing plastic waste for sustainable and energy-efficient building

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HIGHLIGHTS

- Environmentally-friendly plasters with 100% waste particles replacing virgin materials.
- Lightweight mortars for plasters by using PET waste particles from post-consumer blown bottles.
- Plasters with the maximum content of organic particles and with lime replacing cement.
- Plasters with promising functional properties and sufficient mechanical performance.

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ABSTRACT

The reduction of energy consumption in construction, the production of thermally insulating materials, as well as the solution of environmental problems by recycling industrial and municipal waste are key challenges for the next future. For this reason several plasters have been studied, in which virgin raw materials such as natural sand and limestone filler were replaced up to 100% by waste polyethylene terephthalate (PET) particles and pulverized Glass Fibre Reinforced Plastic (GFRP) waste, respectively. Moreover, an attempt was made to combine PET waste particles and wood waste (WW) particles in order to improve functional properties of plasters. As supplementary cementitious material silica fume was employed, which is a further industrial by-product obtained from silicon wafer sawing during the production process of solar panels. Finally, in some mixtures even cement was fully replaced by a combination of lime and hydraulic lime in order to further improve the carbon footprint of these plasters. At the end of the optimisation process, environmentally-friendly plasters have been obtained with 100% waste particles replacing virgin materials, which proved to be energy efficient thanks to the low thermal conductivity values achieved, as well as for their remarkable lightness.

1. Introduction

Concerning the reuse of recycled plastic in mortars and concrete, extensive studies have been conducted on used tyre modified concrete and mortars [1–3], as well as on the reuse of other plastic wastes in lightweight aggregate concrete (LWAC), such as: polyurethane foam waste [4,5], PVC scraps [6], high density polyethylene (HDPE) [7], thermosetting plastics [8], shredded and recycled plastic waste [9–11], expanded polystyrene foam (EPS) [12,13], and polycarbonate [14].

In this paper an attempt was made to prepare lightweight mortars for plasters, by adding to the mixtures PET waste particles coming from post-consumer blown bottles. Polyethylene terephthalate (PET) is one of the most common consumer plastics used and is widely employed as a raw material to realise products such as blown bottles for soft-drink use and containers for the packaging of food and other consumer goods. PET bottles have taken the place of glass bottles as storing vessel of beverage due to its lightweight and easiness of handling and storage. In 2007, the world's annual consumption of PET drink was approximately 10 million tons, which presents perhaps 250 milliards bottles. This number grows about up to 15% every year [15]. On the other hand, the number of recycled or returned bottles is very low. Generally, the empty PET packaging is discarded by the consumer after use and becomes PET waste. In the case of thermoplastic products, regeneration can also be feasible. The exponential growth in plastic waste from packaging incited a search for alternative means of recycling [16]. The sorted post-consumer PET waste is crushed, pressed into bales and offered for sale to recycling companies. Recycling companies will further treat the post-consumer PET waste by shredding the material into small fragments. PET waste

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flakes are used as raw material for a range of products. Thus, a large PET waste is available for recycling applications. PET is widely recycled as a material, making a large contribution to the recycling targets required for plastics by the EU directive 2004/12/EC [17]. Nevertheless, a vast amount of PET waste still remains un-used. Indeed, PET is reported as one of the most abundant plastics in solid urban waste [18]. Being a non-biodegradable plastic waste, the disposal of post-consumer PET has huge environmental impacts. When material recycling is not feasible, PET can be incinerated with energy recovery. However, there are active campaigns against waste incineration, generally causing air pollution and contributing to acid rain, and Greenpeace actively worked on these issues.

The use of PET waste in cement-based composites will provide benefit in the disposal of wastes and, in addition, will reduce the environmental damages due to the use of natural mineral aggregates resources. The use of waste plastic as lightweight aggregate in the production of concrete provides both the recycling of the plastic waste and the production of a lightweight concrete in an economical way [15]. There are several recent studies concerning lightweight concrete, which incorporates PET waste products as aggregate particles [19–24].

In this paper a further attempt was made, that of using also wood waste (WW) particles replacing sand. In many countries, the wood industries generate a large amount of waste products. Sawdust is generated from cutting, drilling and milling operations where wood is removed from a finished product. Wood dust consists of very fine particles generated during sanding or other machining operations. They are often collected in filter bags or dust collectors. The physical and chemical properties of wood dust vary significantly depending on many factors such as wood species and industrial processes. On average, the wood sawing results in 5–10% by weight of dust [25]. In some cases, wood waste contain some degree of contamination reducing the net value of the material and requires further processing in order to meet end market specifications. Each of these factors can generally influence the possibility to recycle wood waste. Moreover, the generation of energy from burning wood wastes may give rise to problems related with the greenhouse effect. Some research projects carried out in the past used wood ash wastes as a replacement for cement in concrete or mortar mixtures [26,27], without showing a great improvement in mechanical properties. In this paper, sawdust was used, which came from a company in which wood is worked to produce wood packing. Sawdust is made of fir (the main component) as well as poplar and beech, and it was collected from sawing. Small amounts of paint, insecticide, fungicide are present inside the sawdust and they forbid a safe reuse of this wooden waste as fuel. Consequently, the possibility to reuse sawdust in mortars can be environmentally-friendly.

Among other things, in this work Glass Reinforced Plastic (GFRP) by-product was used as filler. GFRP is a composite material made of glass fibres dispersed in a resin, usually polyester, widely used in several fields from building to furniture factory to boatyard. Worldwide, there is a growing use of GFRP due to its lightness, high mechanical performance, possibility of production in any shape, ease of installation and good durability. According to the European Composites Industry Association (EuCIA) in Europe, approximately 1 million tonnes of GFRP is manufactured each year [28]. Its increasing use implies increasing amounts of GFRP produced at different stages of its life cycle. The total combined volume of end-of-life and production waste generated by the glass thermo-set composites market in Europe is expected to reach 304,000 tonnes by 2015 [29] triggering interest in optimising GFRP waste recovery. At present, reuse, recycling and incineration with energy and material recovery, is still not a regular practice. Landfill as non-hazardous waste remains the most popular solution to manage GFRP waste due to the difficulty of separating the glassy part from the polymeric matrix, its intrinsic thermo-set composite nature, the lack of information relating to its characteristics and the insufficient knowledge on potential recycling options. Among the various ways to process GFRP waste, mechanical size reduction does not produce atmospheric pollution by gas emission or water pollution by chemical solvents effluents, and does not require such sophisticated, and expectably expensive, equipment like the ones that are required in the other processes.

Although more solutions that incorporate GFRP waste are needed, some sustainable applications are already available for recycling GFRP waste into value-added construction products [30–33], for example by incorporating GFRP waste into cementitious matrix [34–40]. In particular, Corinaldesi et al. [39,40] showed that the use of GFRP powders, even if penalise mechanical performance, significantly improved both lightness and thermal insulation of cement-based materials, thus indicating a high and promising potential for future developments in the field of mortars for sustainable and energy efficient building.

2. Research significance

The reduction of energy consumption in construction, the production of thermally insulating materials, and the solution of environmental problems by recycling industrial and municipal waste are becoming a relevant problem. Therefore, the development of composite construction materials with low thermal conductivity by using either polyethylene terephthalate (PET) waste particles or wood waste (WW) as well as glass fibre reinforced plastic (GFRP) powder could be an interesting alternative that might solve simultaneously energy and environmental issues.

In particular, in this work some plasters have been studied, in which virgin materials such as natural sand and limestone filler are totally replaced by PET waste particles and GFRP powder, respectively. In the last mixture and attempt was also made to combine PET waste particles and wood waste (WW) particles in order to further improve functional properties of plasters.

Moreover, as supplementary cementitious material silica fume was employed, which is a further industrial by-product obtained from silicon wafer sawing during the production process of solar panels.

Finally, in the last two mixtures even cement was fully replaced by a combination of lime and hydraulic lime in order to further improve the carbon footprint of these plasters, which at the end of the optimisation process are definitely environmentally-friendly also on the basis of the low thermal conductivity values achieved as well as for their lightness.

As last aspect, the risk of sensitivity to sulphates of the hydraulic binders used was also checked in order to evaluate if these plasters can be employed also in ancient masonry for restoration.

3. Experiments

3.1. Materials

As binder, commercial portland-limestone blended cement type CEM II/A-L 42.5 R according to the European Standards EN-197/1 [41] was used.

Alternatively, a combination of lime and hydraulic lime (50–50%) was used. Actually, in Italy hydraulic lime is the most widely employed binder for mortars in ancient masonry. The chemical compositions of cement, lime and hydraulic lime are reported in Table 1. Both the hydraulic binders are characterised by low content of tricalcium aluminate (C_3A). In general, when using hydraulic binders for restoration, the risk of sensitivity to sulphates is expected to be lower when low C_3A or CA-free Portland cement are used, since these materials are supposed to be 'sulpha te-resisting' cements. However, these cements contain a lot of ferrite phase (tetra-calcium aluminoferrite: C_4AF) that may be an alternative source of ettringite in the form of $C_3(A,F)\cdot 3CaSO_4\cdot 32H_2O$. Moreover, these cements might be particularly vulnerable to thaumasite formation for the reaction of gypsum with calcium