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The effect of polypropylene fibers on graphite-natural hydraulic lime pastes

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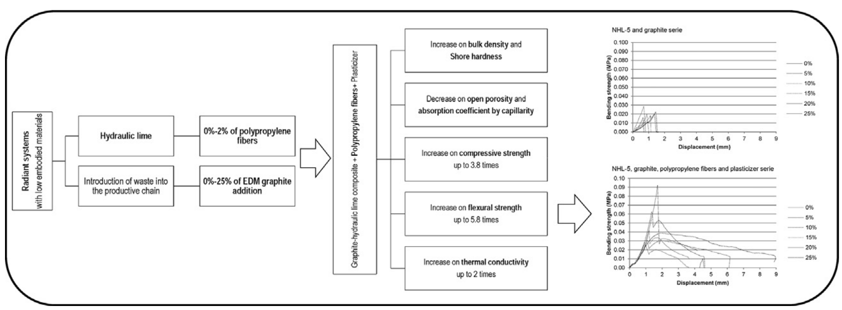
HIGHLIGHTS

- Polypropylene fibers improved the graphite-hydraulic lime pastes.
- Fibers increased ductility and toughness of graphite-NHL pastes.
- Series 3 showed the best performance of graphite-NHL pastes.
- Flexural strength increased up to 5.8 times compared to plain pastes.
- Thermal conductivity increases up to 2 times compared to plain pastes.

GRAPHICAL ABSTRACT



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ABSTRACT

A reduction in greenhouse gas emissions has given rise to the search for low-embodied energy materials. Based on this assumption, natural hydraulic lime can be an alternative binder to cement, while the introduction of waste as inert material can be used to reduce the environmental impact of sand. A graphite-NHL composite had been previously analyzed but it showed both a low resistance to cracking and a brittle performance. Hence, in this paper, the effect of polypropylene fibers in this composite has been studied in order to enlarge this composite while improving its performance. Several series of natural hydraulic lime pastes based on NHL5 were prepared with a percentage of fiber ranging from 0% to 2% and graphite from 0% to 25% by weight substitution of natural hydraulic lime. Both the fresh state and the hydric, mechanical and thermal properties were analyzed. Fibers increased the ductile-like behaviour and toughness considerably, as well as its porosity. However, their combination with waste graphite and plasticizer considerably improved the properties of the plain pastes.

1. Introduction

Natural hydraulic lime is a traditional binder which has been used for centuries around the world. In recent decades, interest in its use has increased because of its mechanical strength, modulus of elasticity as well as water vapour permeability. It has a shorter curing time than air lime according to current expectations, however, they showed lower mechanical strength and higher water vapour permeability than cement. Additionally, natural hydraulic lime has become an alternative to cement due to its low embodied energy and the reduction in greenhouse gas emissions. However, there was little knowledge of natural hydraulic lime performance which is why the research carried out in the last decade has been into mortars with natural hydraulic lime (NHL) [1–8] and with hydraulic lime [9], as well as in grouts [10–14].

One of NHL main drawbacks is the cracking brought about by hardening due to drying shrinkage, as well as its brittle performance during hydration [15]. This problem can be tackled through

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the addition of fibers, more commonly used in the cement industry [16–20]. Nevertheless, very little research has been carried out into their effect on lime pastes and mortars. Polypropylene fiber was the most common type of fiber researched in such a way that Chan and Bindiganavile [21,22] used it in the NHL2 mortar with a content of up to 0.5% by volume. The use of glass fibers and basalt fibers at 1% and 2% wt was researched at NHL3.5 mortar by Iucolano et al [23] for restoration purposes. As a continuation of the former, Santarelli et al [24] researched three types of basalt fibers in different NHL3.5 mortars; while Liguori et al [25] analyzed the effect of glass fiber in an NHL3.5 mortar with different percentages of tuff and zeolite. Gil et al [26] researched the effect of 1% wt of fibers from end-of-life tires on hydraulic mortars. In addition, Izaguirre et al [27] researched CL90S-type air lime with calcareous aggregate at 0.06% and 0.5% of the total weight of the mortar. While, Di Bella et al [28] analyzed the effect of polypropylene fibers on an air lime mortar with natural zeolites at 0.2% weight compared with sisal and kenaf.

On the other hand, a gradual increase in the ecological footprint in recent decades implied the exhaustion of the natural sources. Therefore, an increase in the efficiency of the resources through a reduction in the environmental impact and the recycling of waste has now become one of the main priorities. It implies multiple benefits in the reduction in environmental impact: air, water, soils and greenhouse-emission gases. To this end, in 2005, the first European Commission communication was published in which strategies for the sustainable use of resources were defined [29]. It was ratified in the COM 13:2011 in which both their strengths and weaknesses were analyzed [30]. However, the key point of waste reduction was the "circular economy package" proposed by the European Union. It was connected to the European Communication COM 397 in which a proposal for a European Directive was set out [31]. Different researchers analyzed the effect of by-products such as silica fume [8,32], blast furnace slag [32,33] and fly ash [14].

Electrical Discharge Machining graphite powder is a residual material coming from the milling of molds for the Electrical Industry [34]. It is considered a «biologically inert material which produces dust classified as a nuisance» [35], although it is not included in the European List of Waste [36]. In a similar vein, Faria et al [37] analyzed the effect of graphene oxide, a treated waste coming from the metallurgy industry, into an NHL3.5 binder with siliceous sand. As opposed to the latter, the use of waste graphite coming from the Electrical Industry was proposed. In this case, it was used directly without previous treatment. This waste had previously been studied by the authors in a gypsum matrix [34,38,39] as well as in natural hydraulic lime mortars [40]. In the latter, a brittle behaviour of the samples provoked to a reduction in strength.

Hence, this paper has analyzed the influence of polypropylene fibers on batches of NHL mortars and EDM isostatic graphite, both with and without plasticizer, with a different graphite and fiber content ranging from 0% to 25% and 0% to 2%, respectively. The aim of the research is to enlarge the possibilities of revalorization of this type of waste in the building industry as well as improving the ductility and toughness of EDM graphite waste on NHL binder composites.

2. Experimental studies

2.1. Materials

Samples were made up of a commercial natural hydraulic lime NHL5, pure graphite powder waste, polypropylene fibers and, in some cases, a plasticizer.

The natural hydraulic lime was in accordance with the EN 459-1:2001 and provided by the Arrigorriaga factory which belonged to the FYM-Italcementi group. Its bulk density was 769 kg/m^3 while its fineness was 0.9837 m^2/g.

Graphite waste powder, coming from the milling of molds for the Electrical Industry, was provided by IBIDEN™, and showed 440 kg/m^3 of bulk density and 26.3078 ± 0.2622 m^2/g of specific surface and 1.7052 m^2/g in micropore area [34]. Its main particle size ranged from 1 to 10 μm [34].

Furthermore, a commercial polypropylene fiber (PPF) with 900 kg/m^3 of bulk density, 19 mm in length and 3.45 GPa of modulus elasticity was used as reinforcement. It was supplied by Grace™ Construction Products.

Finally, in order to control the water content, a commercial plasticizer-air entraining agent of 1050 kg/m^3 of bulk density, was used. It consisted on an aqueous solution of alkaline products with sulphuric acid and sodium salts as minor components. This was previously used by the authors [40] in which the compatibility of lime + graphite with and without plasticizer was analyzed. In this case, an increase in the zeta potential from −19.6 mV to −36.1 mV was achieved through the use of plasticizer [40].

2.2. Paste proportions

Firstly, two series of batches were prepared in which the influence of the addition of fibers and plasticizer, both at a fixed percentage, was analyzed. It was compared to a control batch in which neither fibers nor plasticizer were included. The w/b was selected based on the already published preliminary research [40] as well as the literature in NHL [2,11,13,21]. The water/binder ratio was kept at 0.60, in order to control the variation in the properties as a function of the graphite, fibers or plasticizer [11]. For the same reason, plasticizer was added at a fixed amount and kept throughout the blends following previous experiences [40]. The addition of plasticizers into the NHL had been previously analyzed by different authors although they used a plasticizer based on naphthalene and polycarboxylate [12].

In the first step, the influence of the fibers on different graphite ratios was studied. In this case, graphite was added as a partial replacement of the natural hydraulic lime at 5%, 10%, 15%, 20% and 25%, by weight. Polypropylene fibers were included at 0.45% by weight of solid components (NHL and graphite) following other previous research [27]. Tests were carried out at 90 and 360 days of curing time. To identify the batches (Table 1), the designation was 1a. Where 1 referred to the series, namely: Series 1, was the reference neither with fibers nor plasticizer; samples which belonged to Series 2 included fibers; and, Series 3 incorporated fibers and plasticizer. Finally, the last letter referred to the graphite content: a is the control batch, with the addition of 0% of graphite, b to 5%, c to 10%, d to 15%, e to 20% and f to 25%.

As the second step, the effect of the fiber content was researched in batches with plasticizer (Table 2). In this case, the graphite content was fixed at 0% (series 0f) and 15% (series 15f). The fiber content was established at 0% (control batch), 0.06%, 0.45%, 1% and 2% by weight of solid components (NHL and graphite). A higher amount of fibers were discarded due to the loss of workability of the batches at 2% of fibers when graphite was added. In addition, plasticizer was added based on the same criteria as that of series 3.

In both cases, the procedure was the same. Graphite was added to the water and homogenized. When a plasticizer was used, it was incorporated into the water after the graphite homogenization. On the other hand, the fibers and NHL were mixed and incorporated into the water at the end. The blends were mixed for five minutes at low speed [12]. With the addition og 25% of graphite, the kneading time was extended by two minutes to guarantee the homoge-