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Effects of natural fibres reinforcement in lime plasters (kenaf and sisal vs. Polypropylene)

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HIGHLIGHTS

- Mechanical and durability properties of several lime plasters were studied.
- Effect of synthetic or natural fibres was investigated.
- The use of natural fibres is functional to the reduction of tensions.
- The sisal and kenaf fibres can be a valid alternative to polymeric ones.

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ABSTRACT

Nowadays the tendency to realize environment-friendly products is becoming more widespread to ensure sustainable and smart development.

The synthetic fibres, frequently used, are harmful to the environment because they are non-degradable and non-renewable. Their use has resulted in an increase of oil consumption. Therefore, the possibility of replacing them with natural fibres becomes increasingly concrete confirmed by the researches and investigations carried out.

In this work three lime based plasters were prepared and analysed to evaluate the influence on their performance of different fibres used as reinforcement. In particular each plaster was realised by adding to the mortar the same amount (i.e. 0.2% w) of polypropylene, sisal (*Agave sisalana*) and kenaf (*Hibiscus cannabinus*) fibres, respectively. Then, compressive and bending strength, resistance to freeze/thaw conditions and to marine environment (by performing salt spray test) of lime plasters were investigated.

On the basis of experimental results, natural fibres can be considered as a valid alternative to polypropylene ones as reinforcement of lime plasters. In particular, the decrease of mechanical properties due to freeze/thaw cycles is comparable under flexural load condition for all plasters analysed in this work, while the decrease of compressive strength, shown by plasters reinforced with sisal fibres, is lower than other ones. Moreover, thanks to their higher hydrophilicity, the plasters reinforced with natural fibres present low weight loss after ageing time in salt spray environment than ones with polypropylene.

1. Introduction

Lime-based mortars have been used for centuries as stone binders in ancient buildings: i.e., the Egyptian used lime in the chambers of the pyramids (around 2000 B.C.). During the 20th century, the use of lime disappeared due to the fast development of Portland cement. Nevertheless, over the past several decades, the need to develop environmental-friendly products has generated new interest in using lime as a building material [1].

Hydraulic lime or a combination of hydrated lime and pozzolan are widely used in the production of exterior plasters. These plasters are designed primarily for the protection of load bearing structures against environmental effects. At the same time, they are supposed to present an aesthetic quality of a building. Hence, their durability is of critical importance for any building structure [2].

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Because those surfaces are exposed to extreme weather conditions, cracking and delaminating are most common non-structural defects. Unlike structural deterioration, these defects are caused physically by temperature variations, heat expansion and shrinkage, erosion by water, freezing and thawing. They can also be caused by hygric swelling or shrinking due to water/moisture wetting and drying cycles [3].

In particular the shrinkage represents an important cause that leads to cracks formation and consequently to decay of external plasters.

If cracking occurs for effect of the rapid evaporation of the water from the plaster in the first few hours after casting (i.e. when the plaster is in a plastic state), this phenomenon is known as plastic shrinkage cracking. In these conditions, internal tensile stresses, higher than the low tensile strength of the lime based plasters, occur causing a widespread cracking.

On the other hand, drying shrinkage cracks are the result of moisture loss after the plaster has hardened.

In order to improve the tensile strength of lime based mortar minimizing plastic shrinkage, one of the most effective methods consists in the use of fibres as reinforcement.

In fact, the use of short fibres randomly distributed within the matrix improves its resistance to cracking and consequently leads to better performances in terms of toughness and durability. The presence of fibres can also increase the resistance of the plaster to impact, abrasion and fatigue.

Also in the field of cement-based mortars, the use of different kind of products based on natural fibres [4,5], admixtures [6,7] and even metallic particles [8] is widely accepted to minimize plastic shrinkage cracking.

As regards lime based mortar fibres commonly used for these purposes are polymeric or synthetic ones, e.g. polypropylene, polyamide and polyacrylonitrile based [9,10]. In particular polypropylene fibres represent the ideal additive for concrete mixtures in order to reduce plastic shrinkage, cracking and improving surface properties of the concrete.

Nowadays, one of the current trends of the building industry is to develop "green materials": the use of natural fibres as reinforcement of lime plasters plays a leading role in this transition toward renewable materials [11]. Generally, the application of natural fibres is attractive for four main reasons: their specific properties, their price, their health advantages and their recyclability [12]. The fact that these natural fibres offer a low density and good specific properties is an important benefit. Furthermore, the fibres are renewable and have a CO_2-neutral life cycle, in contrast to their synthetic opponents [13].

In this paper, mechanical and durability properties of lime plaster reinforced with synthetic fibres (i.e. polypropylene) are compared with those of plasters reinforced with two kind of natural fibres: i.e. sisal and kenaf fibres.

Sisal fibre (*Agave sisalana*) is one of the most widely used natural fibres and it is very easily cultivated. It has short renewal times and grows wildly in the hedges of fields and railway tracks [14]. Nearly 4.5 million tons of sisal fibres are produced every year throughout the world. Tanzania and Brazil are the two main producing countries [15]. Sisal is a hard fibre extracted from the leaves of the sisal plant. A sisal plant produces about 200–250 leaves and each leaf contains 1000 ± 1200 fibre bundles which are composed of 4% fibre, 0.75% cuticle, 8% dry matter and 87.25% water [14], so a leaf weighing about 600 g will yield about 3% by weight of fibre, with each leaf containing about 1000 fibres.

Kenaf (*Hibiscus cannabinus*) is a warm season, short-day, annual herbaceous fibre plant native of central Africa, and common as a wild plant in tropical and subtropical Africa and Asia. It has been cultivated since around 4000 BC for food and fibre extracting purposes. The plant has a unique combination of long bast (about 35% of the stalk dry weight) with core of short fibres instead of the hollow core. Kenaf belongs to the Malvaceae, a family noteworthy for both its economic and horticultural importance. Kenaf has a high growth rate, rising to heights of 4–6 m in about 4–5 months. It can then yield a dry weight of 6000–10,000 kg/ha year (new varieties may reach 30,000 kg/ha year) [16].

2. Materials

In the mix design of the lime plasters, a hydrated lime was chosen as the main binder. The composition of lime, as determined by X-ray fluorescence analysis, is shown in Table 1.

Natural zeolite (i.e. chabazite-phillipsite-rich tuff) of Naples area (Italy) was added to make hydraulic the lime. The powder was preliminary sieved in order to obtain a granulometry, characterised by the following dimensions: 0–315 μm, with normal distribution. The zeolite presented the following properties: absolute density 2.10 g/cm^3, bulk density 0.70–1.05 g/cm^3, specific surface 33.8 m^2/g, maximum humidity 7%, maximum temperature 350 °C and pH 4–8. Table 2 reported the chemical composition. In particular, being one of the most promising types of natural high-quality pozzolan, natural zeolites are hydrated alumino-silicates that are able to combine with portlandite in the presence of water to produce new reaction products exhibiting a binding behaviour. Therefore, they are widely used as additive in mortar in which portlandite is the major hydration product [17].

Three (calcareous) calcium carbonate based sands were used as aggregates: the first one characterized by small amount of silica and a continuous granulometry in the range of 1.2–2 mm, the second one (called "coccio") with a continuous granulometry in the range of 0.6–1.2 mm, the third one with a continuous granulometry in the range of 0.3–0.6 mm. Furthermore expanded perlite was used as aggregate to obtain an insulating, lightweight and fire retardant plaster. A rheology modifier i.e. (Tylose MH 30000 YP6) was used in this work; it is methyl hydroxyethyl cellulose with the addition of very small amounts of other additives. It appears as a white fine powder difficult to dissolve in water. A starch ether as fluidizer (i.e. Tylovis SE7) was used for improving workability of lime plasters. An interfacial active air entraining agent (i.e. SiliponRN 6031) was used both to decrease the surface tension of the water leading to a better dispersion and to improve the durability of the plasters to freeze/thaw cycles.

Table 3 reported the composition of the lime plaster realised.

2.1. Fibres

Polypropylene fibres, with high density (0.91 g/cm^3) and nominal length of 5 mm, were used to reinforce the plaster. These synthetic fibres are manufactured in a continuous process by extrusion of polypropylene granules. The extruded material is heated, drawn to increase its strength, treated in a finishing bath and cut to the nominal length.

Two natural fibres were evaluated as possible alternative to polypropylene ones as reinforcement of lime plasters: i.e. Sisal (*A. sisalana*) and kenaf (*H. cannabinus*). Table 4 reports the main properties of the sisal and kenaf fibres [18] used.

In the following Plaster-PP, Plaster-S and Plaster-K will be used as designations to identify plasters reinforced with polypropylene, sisal and kenaf fibres, respectively.

Table 1
Chemical composition of lime in mass %.

CaO	97.40
MgO	0.60
SO_3	0.13
CO_2	0.10

Table 2
Chemical composition of zeolite (%).

SiO_2	51.80
Al_2O_3	18.34
Fe_2O_3	3.40
MgO	0.96
CaO	4.73
BaO	0.35
SrO	0.04
Na_2O	0.60
K_2O	4.91
H_2O[a]	15.14

[a] Loss on ignition.