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# Effect of external basalt layers on durability behaviour of flax reinforced composites

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ABSTRACT

Aim of this work is to evaluate the influence of external layers of basalt-mat on the durability behaviour of flax reinforced epoxy composites. To this scope, long-term ageing tests were performed on two different laminates in critical environmental conditions. The first laminate, named Flax, was constituted by stacking ten layers of bidirectional flax fabrics. The second one, named Flax–Basalt, was produced by replacing two external flax layers with two layers of basalt mat for each side of the laminate. Both laminates were exposed to salt-fog environmental conditions, according to ASTM B 117 standard, for 60 days. Five samples per laminate were removed from salt-fog spray chamber and mechanically tested. In particular, quasi-static flexural tests and Charpy impact tests were performed according to ASTM D 790 and ISO 179 standards, respectively. The fracture surfaces of both laminates were evaluated by using an optical 3D microscope. Moreover, five samples per laminate were removed periodically and weighed to evaluate the water absorption. The experimental results showed that the hybridization with basalt fibres can be considered as a practical approach for enhancing the durability of natural fibre composites under salt-fog environment conditions.



## 1. Introduction

The physical and mechanical properties of fibre reinforced polymer composites (FRP), e.g. the glass transition temperature, the elastic modulus, the failure stress, the ductility and the impact strength vary as a function of time, temperature and ambient conditions. Severe environmental conditions affect the strength of both matrix and fibre as well as the fibre–matrix adhesion, thus leading to an overall decrement of performances of the composites.

For this reason, design engineers need to know safe and economic values of the characteristics of those materials to adequately dimension the structures for their life-cycle [1].

To this aim, a comparison between experimental results obtained in laboratory and after actual exposure has been made [1–4], but there is still great uncertainty on the long-term evolution of material performances. Hence, the knowledge of the FRPs behaviour under aggressive environmental conditions has not a solution free of problems since the action of moisture in fibres may induce damage and the effect of moisture and temperature may reduce their expected durability.

In the last few years, the use of natural fibres as reinforcement of composite materials, as an alternative to the synthetics, has received growing attention, owing to their specific properties, price, advantages for health, and recyclability.

In particular, flax fibre is an inexpensive and easily available bast fibre, widely used as reinforcement in polymer matrix composites for different engineering application: i.e. construction, automotive, marine etc.

Cevallos and Olivito [5] studied the effects of fibre type, fabric geometry, physical and mechanical properties of fabrics and volume fraction of fibres on the tensile stress–strain response and crack propagation of cementitious composites (i.e. natural hydraulic lime grouting mix as matrix) reinforced with flax and sisal fabrics. In particular, they highlighted that the fabric geometry and the volume fraction of fibres have the greatest effects on the tensile behaviour of these composite systems. Moreover, Olivito et al. [6] used flax fibres in addition to sisal ones as reinforcement in cementitious composites for masonry structures. In particular, they used a natural hydraulic lime-based mortar mix with a low content of water-soluble salts and a lime-based grouting mix containing

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natural pozzolans and carbonated filler as matrices. The experimental results showed that both sisal and flax fibres have good adhesion with the lime-based grouting matrix, making them capable of producing composites with ductile behaviour and suitable mechanical performance for strengthening applications in masonry structures.

Meredith et al. [7] studied the applicability of natural fibre composites for high performance structural applications. In particular, composites were manufactured using woven flax and regenerated cellulose (i.e. Cordenka) fibre pre-impregnated with epoxy resins in order to determine their static and dynamic properties. The authors showed that these natural fibre composites can be used in structural applications but additional work is required about fibre–matrix bonding to maximize their properties.

Yan et al. [8] evaluated the quasi-static compression behaviour of empty and polyurethane-foam filled flax fabric reinforced epoxy composite tubes. In particular, the effects of foam-filler, tube thickness, triggering and the combination of triggering and foam-filler were studied. The test results indicate that foam-filled tubes have better crashworthiness than empty tubes in total absorbed energy, specific absorbed energy and crush force efficiency. Moreover, the presence of triggering has no significant effect on total absorbed energy and specific absorbed energy of the empty tubes.

Furthermore, the lateral crushing behaviour of these tubes was studied as function of tube thickness, tube inner diameter and foam filler [9]. The comparison with existing tubes shows that natural flax/epoxy tube can be considered as good alternative to aluminium tube and glass/carbon composite tube as energy absorbers. Moreover, it was found that the specific energy of the empty and foam filled flax/epoxy tubes in lateral crushing is significantly lower than those in axial crushing. The same authors [10] analyzed the axial compressive and flexural behaviour of coir fibre reinforced concrete confined with flax fibre reinforced polymer. The experimental results showed that in compression, the strength, energy absorption capacity and ductility increased remarkably with an increase of tube thickness whereas in flexure, composite beams exhibited high load carrying capacity, energy absorption and ductility. Yan and Chouw [11] compared the axial compression behaviour of glass/carbon and flax fibre reinforced polymer confined coir reinforced concrete showing that the confinement effectiveness of the proposed cylinders is close to or comparable to the glass/carbon confined concrete. Furthermore, the flexural behaviour (i.e. three and four point bending) of plain concrete and coir fibre reinforced concrete beams externally strengthened by flax fabric reinforced epoxy polymer composites was studied [12]. In particular, it was shown that the peak load, flexural strength, deflection and fracture energy of both plain concrete and coir reinforced concrete enhance with increasing of confinement layers.

Le Duigou et al. [13] prepared a 100% bio-sourced sandwich structure with flax mat/PLLA laminates as skins and balsa core comparing their mechanical properties with those of a traditional glass reinforced polyester sandwich with the same core. They showed that the mechanical properties of the bio-sandwich materials are promising, though slightly lower than those of a traditional sandwich.

Flax fibre also possesses some drawbacks (e.g. hydrophilic nature, low and highly variable mechanical properties, and poor adhesion with several different polymeric matrices). In particular, due to its susceptibility to moisture absorption, its ageing resistance in humid environments is limited and its application is restricted to non-structural or semi-structural interior products. To overcome this problem, chemical pre-treatment of natural fibres can be carried out to improve fibre/matrix interface, thereby increasing moisture durability. However, the treated fibres were found to behave poorly when exposed to weather. Therefore, an optimum blend ratio of chemical additives must be employed to achieve a balance between strength and durability requirements for natural fibre composites [14]. Dhakal et al. [15] compared the effects of water immersion ageing on the mechanical properties of flax and jute fibre reinforced composites. They showed that the percentage of moisture uptake and diffusion coefficient was higher for jute-reinforced specimens compared with flax. The mechanical characterization showed a higher susceptibility to water immersion of jute composites rather than flax ones. In particular, flax samples lost almost 40% of strength and 69% of modulus after immersion in a de-ionized water bath at 25 °C for a period of 961 h whereas the jute wet samples lost 60% of strength and 80% of modulus, respectively.

Hybridization of flax fibres with stronger and more corrosion-resistant fibres can also improve the stiffness, strength, as well as moisture resistant behaviour of the composite. Using a hybrid composite containing two or more types of different fibres, the advantages of one type of fibre could complement what are lacking in the other [16]. Hybrid composites containing flax fibres have been widely studied in the last decade [17–22]. Nevertheless, at the best of our knowledge, very few studies concern the hybridization of flax fibres with mineral fibres as basalt ones [23,24].

Due to their good properties such as chemical stability, non-toxicity, non-combustible, resistant to high temperatures, thermal and acoustic insulation besides to mechanical properties better than those of E-glass ones, basalt fibres began to be used as a brand new reinforcing material for concrete [25–27] and polymer [28–33] composites as well as for hybrid composite laminates [34,35]. The high resistance of basalt laminates exposed both to cycles of artificial ageing and to outdoor environment was shown by Alaimo et al. [36].

Moreover, basalt-based materials can be considered environmentally friendly and non-hazardous even if the current production technology for continuous basalt fibres is very similar to that used for E-glass manufacturing. The main difference is that E-glass is made from a complex batch of materials whereas basalt filament is made from melting basalt rock with no other additives and, as a consequence, with an advantage in terms of cost.

The present paper aims to evaluate the influence of external basalt layers on the durability of flax reinforced epoxy composites. To this scope, two months ageing tests were performed to evaluate the durability of flax reinforced composites and hybrid (i.e. Flax–Basalt) composites exposed to salt fog environment. In particular, the water uptake of the above laminates was measured. Moreover, the laminates were tested by carrying out every 15 days quasi-static flexural tests, and Charpy impact tests.

## 2. Material and methods

All the laminates investigated were realized with a single lamination using the vacuum bagging technique, cured at room temperature for 24 h and then post-cured at 50 °C for 8 h.

In particular, the flax reinforced composites (in the next “Flax”) were constituted by ten layers of bidirectional flax fabric (Fig. 1a) in a matrix of epoxy resin (i.e. SP 106 by Gurit) mixed with own hardener. This kind of flax fabric is an unbalanced plain weave fabric with areal weight equal to 150 g/m$^2$ and cost per unit of area of 6 €/m$^2$, usually used to make curtains. The hybrid composites (in the next “Flax–Basalt”) were manufactured by replacing two external layers of bidirectional flax with two layers of basalt mat (randomly oriented fibres, with areal weight of 100 g/m$^2$ and cost per unit of area of 9 €/m$^2$, supplied by HG Europe, Italy) for each side of the laminate, as showed in Fig. 1b.

Mat layers are widely used as external layers of composite laminates both to achieve better surface finishing and to protect the