Composites Part B 77 (2015) 74–83

Contents lists available at ScienceDirect

Composites Part B

journal homepage: www.elsevier.com/locate/compositesb

Mechanical performance of natural fiber-reinforced composites for the strengthening of masonry

Rosamaria Codispoti [a,*], Daniel V. Oliveira [b], Renato S. Olivito [a], Paulo B. Lourenço [b], Raul Fangueiro [c]

[a] University of Calabria, Department of Civil Engineering, Rende, CS 87036, Italy
[b] ISISE, University of Minho, Department of Civil Engineering, Guimarães, Portugal
[c] 2C2T, University of Minho, Department of Civil Engineering, Guimarães, Portugal

ARTICLE INFO

Article history:
Received 3 November 2014
Received in revised form
6 February 2015
Accepted 4 March 2015
Available online 12 March 2015

Keywords:
B. Fibre/matrix bond
B. Mechanical properties
D. Mechanical testing
Natural fibers

ABSTRACT

The growing concerns regarding the environmental impact generated by the use of inorganic materials in different fields of application increased the interest towards products based on materials with low environmental impact. In recent years, researchers have turned their attention towards the development of materials obtained from renewable sources, easily recoverable or biodegradable at the end of use. In the field of civil structures, a few attempts have been done to replace the most common composites (e.g. carbon and glass fibers) by materials less harmful to the environment, as natural fibers.

This work presents a comprehensive experimental research on the mechanical performance of natural fibers for the strengthening of masonry constructions. Flax, hemp, jute, sisal and coir fibers have been investigated both from physical and mechanical points of view. The fibers with better performance were tested together with three different matrices (two of organic nature) in order to produce composites. These experimental results represent a useful database for understanding the potentialities of natural fibers as strengthening systems.

1. Introduction

Composite materials represent currently one of the most suitable and efficient solutions as reinforcement and repair systems for civil structural applications. Simultaneously with this successful development, the construction sector is required to cope with problems related to environmental respect, as well as to compatibility between the reinforcement and the substrate, and durability of the materials. The growing ecological awareness and international environmental regulations have encouraged the investigation on bio-composite materials. Consequently, natural fibers reinforced composites are deserving more and more attention. The performance of natural fibers reinforced polymer (NFRP) composites in strengthening applications has been already compared to the fibers reinforced polymer (FRP) composites, as evidenced by Ku et al. [1]. The potential development of natural fiber composites has been investigated in different kinds of engineering and domestic products [2]. Moreover, studies on bio-composites have been developed not only with the use of polymer matrix, but also with the use of cementitious materials as an interesting alternative to polymers, in order to produce natural fiber reinforced cementitious matrices (NFRCM) composites [3,4]. In addition to mechanical analysis, chemical analysis have also been carried out on natural materials [5–7]. Recently, bio-fibers have been investigated for flexural strengthening of reinforced concrete (RC) beams; sisal and jute fabrics reinforced polymer composites (SFRP-JFRP) have been compared to carbon fabric reinforced polymer composites (CFRP) and glass fabric reinforced polymer composite (GFRP). RC beam strengthened by SFRC showed highest amount of ductility, JFRP strengthening have shown highest deformability index and proved that jute FRP composites have a huge potential as a structural strengthening material [8,9].

The use of renewable materials with low environmental impact represents a key factor for the sustainable development of the building industry. On the other hand, historical masonry is characterized by moderate compressive and shear strengths, very low tensile strength and low to moderate stiffness. Therefore, a suitable

* Corresponding author. Tel.: +39 0984 496947; fax: +39 0984 496924.
E-mail addresses: rosamaria.codispoti@unical.it (R. Codispoti), danvco@civil.uminho.pt (D.V. Oliveira), renato.olivito@unical.it (R.S. Olivito), pbl@civil.uminho.pt (P.B. Lourenço), rfangueiro@civil.uminho.pt (R. Fangueiro).

http://dx.doi.org/10.1016/j.compositesb.2015.03.021
1359-8368/

strengthening system for masonry structures should possess a similar stiffness for mechanical compatibility with the substrate, while exhibiting enough tensile capacity. Within this context, the use of natural fibers seems quite appealing, more than the use of high performance fibers (e.g. carbon fibers), which present a too high stiffness, hardly compatible with the substrate, and a non-exploitable tensile strength. Additionally high performance fibers are more costly and present many disadvantages related to a high embodied energy and CO_2 production [10,11]. This paper is focused on the analysis of the mechanical properties of natural fibers and associated composites, while their physical properties are briefly addressed. The aim of this research is the analysis of natural fibers in order to produce suitable composite materials particularly for strengthening of ancient masonry structures. Mechanical characterization tests were carried out on matrix and fibers materials, the last ones both as single yarns and fabrics. Afterwards, different production methods were considered to manufacture NFRP and NFRCM, and their performance has been analyzed in detail from the mechanical point of view.

2. Natural fibers as a strengthening material of civil structures

Natural fibers are classified into three major categories according to their origin: vegetable, animal and mineral [12,13]; each of these categories is divided into several sub-categories. Substantially, there are thousands of different fibers in nature. Each fiber is characterized by different properties due to non-uniformity of its structure; also their mechanical, physical and geometric properties are influenced by many factors: hydrophilic nature, moisture content, defects, structure, cell dimensions, and morphology of the plant. One of the drawbacks found in natural materials is the variability of their mechanical properties, remarkably higher than those of the inorganic fibers, like carbon or glass fibers. In civil engineering applications, the natural fibers mostly analyzed and studied as reinforced fibers are those vegetable, especially bast fibers (jute, flax and hemp), even if to a lesser extent, also seed (coir) and leaf fibers (sisal) [14–16]. In addition the vegetable fibers are commonly a useful resource for the development of innovative materials, due to their advantages when compared to the ordinary synthetic fibers, facing up to the current requirements and demands of the construction field. These fibers can be grown and made within a short period of time, and consequently this supply can be unlimited as compared with traditional glass and carbon fibers for manufacturing advanced composites. Their overall energy consumption during collecting, recycling, refining and remolding processes is reduced in respect to the man-made fibers. Moreover, natural fibers have many interesting properties, such as low cost, low density, comparable specific tensile properties, non-abrasiveness to the working tools, non-irritation to the skin, less health risk, renewability and biodegradability [17–19].

In the vast field of bio-fibers, flax and hemp fibers are particularly suited to be used as reinforcement in composite materials, not only from the mechanical behavior point of view, but also because they are already being commercialized by the biggest international companies. Composite materials are commonly constituted by continuous long fibers immersed in specific matrices [20]. Natural fiber reinforced polymers (NFRP) and natural fiber reinforced cementitious matrices (NFRCM) have been manufactured in laboratory for the present research, and consequently natural materials have been investigated both in the form of yarns and fabrics. In terms of the matrix, experimental tests have been conducted both on polymers and inorganic matrices.

3. Experimental tests on components

3.1. Single yarns

The study of the tensile behavior of single yarns has been conducted by carrying out direct tensile tests. Five types of natural materials have been examined: flax, hemp, sisal, jute and coir. Given the wide variety properties of the single yarns, a number between 10 and 15 specimens for each material has been prepared, for a total of eleven different types of yarns, see Fig. 1. The yarns are rather diverse in terms of density, thickness of diameter and orientation in the fabrics (weft or warp).

Each specimen was cut, measured and weighed in order to compute its physical properties, namely linear density (Tex) and tenacity (N/Tex), according to the ISO 1889:1997 [21]. The results are listed in Table 1; in particular three different yarns of jute and hemp (taken thread out from three unidirectional fabrics), three typologies of sisal yarns (of which sisal^{1a} and sisal^{1b} are respectively the yarns in the warp and weft direction of a bidirectional fabric and sisal^{2} are identified the yarns of an unidirectional fabric), and one type of coir and flax yarns were analyzed.

The study of the mechanical properties of the single yarns has been done by carrying out tensile tests, in accordance with ISO 2062 [22]. All tests have been conducted in a normal atmosphere on specimens previously acclimatized, by means of a high precision universal testing machine (Fig. 2) and conducted under displacement control at a rate of 5 mm/min. Before each test, a pre-load of a 1.5 N was applied.

All the results obtained from tensile tests on single yarns are shown in Table 2, in terms of deformation at peak load ε_{peak}, tensile strength f_t, and modulus of elasticity E. Analyzing the results obtained, it was possible to observe clear differences linked to the different materials used. Flax is the fiber that presents higher values in terms of tensile strength, followed by the different types of hemp, sisal and jute analyzed. Coir fibers are those least suitable in terms of mechanical properties, consequently they have not been considered as reinforcing fibers for composite materials in the subsequent steps of the experimental work. Some specimens failed near the clamping area and these results have been excluded. In order to analyze the correct strength of the fibers, only the specimens that broke at their middle length (more or less to 100 mm from the clamp) have been considered in the data processing.

Fig. 1. Examples of specimens of single yarns.