Construction and Building Materials 158 (2018) 359–368

Contents lists available at ScienceDirect

Construction and Building Materials

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

Performance of sustainable natural yarn reinforced polymer bars for construction applications

Aladdin M. Sharkawi [a,b,*], Alaa M. Mehriz [c], Ezzat A. Showaib [d], Ahmed Hassanin [e]

[a] North Carolina State University, USA
[b] Structural Engineering Department, Faculty of Engineering, Tanta University, Tanta 31733, Egypt
[c] Department of Structural Engineering, Faculty of Engineering, Tanta University, Egypt
[d] Department of Production Engineering and Mechanical Design, Faculty of Engineering, Tanta University, Egypt
[e] Department of Textile Engineering, Faculty of Engineering, Alexandria University, Egypt

HIGHLIGHTS

- Long yarns made of short flax or jute fibers can be used as composite reinforcement.
- Flax or jute yarns reinforcement remarkably enhanced polymer bar tensile performance.
- Infusion technique provided well resin-impregnated natural reinforced polymer bar.
- Reinforcing composite bars enhanced flexural performance of low-grade concrete slabs.

ARTICLE INFO

Article history:
Received 16 June 2017
Received in revised form 23 September 2017
Accepted 26 September 2017

Keywords:
Natural yarns reinforced polyester bars
Flax fibers
Jute fibers
Reinforced concrete slabs
Sustainable construction applications

ABSTRACT

Performance of polymer reinforced with continuous long natural and man-made fibers was extensively investigated in literature. However, using yarns made of short discrete natural fibers needs to be investigated as a source of sustainable reinforcement for composites. In this study, long yarns made of short flax and jute fibers were selected to reinforce polyester bars. Infusion technique was implemented to produce natural yarns reinforced polyester (NYRP) bars having various fiber volume fraction ratios. Microscopic images showed good fibers distribution and resin-fibers impregnation across the of NYRP bars. In addition, polyester bars reinforced with selected natural yarns lead to remarkable enhancement of their tensile strength, stiffness and ductility. Moreover, concrete slabs reinforced with surface treated NYRP bars performed compatibly until failure. Despite low stiffness of the produced NYRP bars, their use for reinforcing normal and lightweight concrete slabs enhanced their ductility and toughness as well as increased their flexural capacity up to six-fold.

1. Introduction

Due to the low cost of natural fibers and their high specific strength, they are exploited as a replacement for the conventional man-made fibers, such as glass and carbon [1]. In addition, natural fibers are renewable, easily recycled, carbon dioxide neutral, and are locally available in large quantities all over the world and especially at many under development countries [2,3]. Many previous research works examined the suitability of using various long natural fibers as reinforced material for polymeric matrices. However, there are common challenges of using short discrete fibers, in the form of yarn, as composite reinforcement. In addition, suitable manufacturing process is required to achieve high fiber volume fraction in such natural composites to achieve suitable performance.

Manufacturing processes of the natural fiber reinforced polymer sections and the main characteristics of the composite products were among the main previous research objectives. In addition, the suitability of the final composite product-for many construction applications-was investigated. Wang et al. [1] provided a review on the tensile properties of natural fiber reinforced polymer composites. They found that most of the natural fibers, commonly used for reinforcement applications, have much higher strength and stiffness values than those of the common polymeric matrices (e.g. polyester) [1]. Khoathane et al. [4] found that the tensile strength and Young's modulus of composites reinforced

* Corresponding author at: Structural Engineering Department, Faculty of Engineering, Tanta University, Egypt

E-mail addresses: amsharka@hotmail.com, aladdin.sharkawi@f-eng.tanta.edu.eg (A.M. Sharkawi), alaa_mehriz1988@yahoo.com (A.M. Mehriz), eshowaib@yahoo.com (E.A. Showaib), ahassanin2003@yahoo.com (A. Hassanin).

https://doi.org/10.1016/j.conbuildmat.2017.09.182
0950-0618/

List of Symbols

Nm	Length of 1 kg of yarn in km
Vf	Fiber volume fraction
SP	Super Plasticizer admixture

with bleached hemp fibers were increased remarkably with as fiber content was increased. Goutianos, et al. [5] compared the performance of epoxy laminate reinforced with unidirectional flax continuous textile with that of unidirectional glass fiber reinforced epoxy laminate having the same volume fraction. Goutianos, et al. [5] found that, for the same volume fraction, the flexural and compressive strengths of glass reinforced epoxy laminate were about 2.5 and 5 times, that of the continuous flax yarn reinforced epoxy laminate, respectively. Mehmood and Madsen, [6], also compared the tensile strength of flax yarn/thermoplastic polyester composites with glass fiber reinforced composites having the same matrix and volume fraction. Although the later composite showed 5 times higher tensile strength, the flax reinforced composite showed better specific tensile. Sen and Paul [7] provided a durability study of sisal, jute, carbon and glass fiber reinforced polymer composites evaluated under three different exposure conditions. FAO report [8] suggested possible applications of natural fibers as structural composites and accordingly in the development of rural societies. Aforementioned report proposed that manufacturing process of such products should be relatively easy and suitable for production in the rural areas.

This present research aims to explore the potential of using locally available natural short discrete fiber yarns together with polyester matrix to produce sustainable natural yarn reinforced polymer (NYRP) composite bars. Such bars provide affordable and reliable source for sustainable construction applications at rural regions where such natural yarns are available. Specifically, flax plant was chosen as it provides good source of sustainable development (e.g. source for oil and animal food) on general. In addition, flax has low cultivation expanses and it can be cultivated in different soil types and environmental conditions as well as various water salinity levels. On the other hand, the investigated yarns where made of the less expansive short discrete flax and jute secondary fibers, instead of continues long fibers which are usually used for textile industry. Therefore, the main objectives of this study are summarized in the following points:

1. Investigate the main properties of yarns made of locally available flax and jute short natural fibers.
2. Asses the efficiency of simple manufacturing processes, suitable for rural areas, for producing reliable polyester bars reinforced with the studied natural yarns (NYRP).
3. Explore the main properties of the produced bars.
4. Investigate the flexural performance of concrete slabs, reinforced with the produced NYRP bars.

2. Experimental work

The experimental work consists of the following consecutive procedures:

a- Testing and selecting the yarn types.
b- Producing and testing NYRP bars.
c- Testing concrete slabs reinforced with NYRP bars.

2.1. Testing natural yarns

The purpose of this experimental phase is to determine the main physical and mechanical properties of the investigated jute and flax yarns to select the strongest types for further application during the rest of the experimental work. Table 1 shows different types and numbers for the yarns initially explored in the experimental program. The yarn Number (Nm), the number of twists, moisture content and microscopic examination were measured as the main physical properties for each yarn. These tests were implemented according to ASTM D1907 [9], ASTM D1422 [10], AATCC20-20A [11] and ASTM D276 [12] respectively. Maximum carrying load, tenacity and elongation were measured as the main tensile properties for each yarn type according to ASTM-D 2256 [13]. Due to the difficulty of measuring the yarn diameter, precisely, tenacity is used to measure the strength of a yarn. Tenacity is calculated by dividing the breaking force of the yarn by its linear density.

2.2. Production of polyester bars reinforced with natural yarns

Yarns, had the highest tenacity values, were selected to be used for the rest of the experimental work of each fiber type. Accordingly, flax yarn specimen K2 and jute yarn specimen J2 were used for producing the proposed NYRP bars. During this experimental work, more than simple and common manufacturing processes were investigated for producing the natural yarn reinforced rebars. This exploratory study was performed to provide simple and reliable manufacturing technique to produce suitable NYRP bars. Based on this investigation, infusion technique was chosen for producing the NYRP bars to provide well distributed impregnated yarns, among the other explored techniques, as shown in Fig. 1 [2,3].

The proposed infusion technique was implemented by applying polyester resin under pressure to impregnate the natural yarn laid in aluminum mold. The mold consists of 2-part each part was engraved with the required rebar diameter as shown in (Fig. 2.a). The mold was machined to have two different rebar diameters (i.e. 12 and 16 mm). Thin rubber plats were placed between the two parts of the mold to prevent the leakage as shown in (Fig. 2.b). Infusion orifice holes were placed in the middle of each mold as shown in (Fig. 2.a and .b). An air-pressurized container – connected to air compressor – was designed to enforce resin through the mold orifice as shown in (Fig. 2.c). The air pressure was sustained to infuse the polyester inside the aluminum mold till the resin appeared at the ends of the mold as shown in (Fig. 2.d). NYRP bars were released from the molds after 24 hrs of polyester curing at room temperature and these bars were not used before 7 days of curing completion at 25 °C. However, the curing time can be adjusted using different amount of reaction accelerator.

2.3. Testing the NYRP composite bars

2.3.1. Physical properties testing

The average weight of the meter length (i.e. representing density), microscopic examination, water absorption and the fiber weight fraction were evaluated for all NYRP bar specimens.

2.3.2. Mechanical properties testing

Tensile load, tensile strength, tensile modulus of elasticity and pullout strength from concrete were determined, according to ASTM D 7205M [14], as the main mechanical properties of the NYRP composite bars. Tensile strength was also measured for NYRP