Sustainable Building Material: Recycled Jute Fiber Composite Mortar for Thermal and Structural Retrofitting

Arnas Majumder[1](✉), Flavio Stochino[2], Andrea Frattolillo[2], Monica Valdes[2], Fernando Fraternali[1], and Enzo Martinelli[1]

[1] Department of Civil Engineering, University of Salerno, Via Giovanni Paolo II n. 132, 84084 Fisciano, SA, Italy
amajumder@unisa.it

[2] Department of Civil Environmental Engineering and Architecture, University of Cagliari, Via Marengo 2, 09123 Cagliari, CA, Italy

Abstract. The construction sector requires a major part of the produced energy (around 36% globally) and emits the highest amount of greenhouse gases (around 39% globally). Therefore, it has an important impact on global warming and climate change. For centuries the irrational use of natural resources of non-renewable raw materials in the construction and building sector have damaged the eco-system and also hindered the sustainable development.

This experimental research work contributes to the United Nations (UN) sustainable development goals by adapting the use of natural fiber (which is recyclable, bio-degradable) to create new sustainable composite building materials.

In this work recycled-jute fibers have been used to replace the plastic insulation material used to improve the thermal resistance of construction mortar. These jute fibers were collected during jute net fabrication process as production scrapes and testify to the possibility of using a natural material for an extended life cycle.

The mechanical and thermal performance of jute fiber reinforced mortar have been tested in order to evaluate the effectiveness of this material for integrated retrofitting of existing masonry buildings. About 34.11% (with respect to the mortar mass) of the plastic insulation materials (already present in the original manufactured mortar product) have been replaced with 6.33% (with respect to the mortar mass) recycled jute-net fibers.

Due to the presence of jute fibers (residual from net fabrication) in composite samples, approximately around 7.13%, improvement in the thermal insulation capacity has been obtained with respect to the non-reinforced mortar samples. Moreover, an increment in strain energy of the same composite mortar about 632.26% has been assessed.

Keywords: Sustainability · Sustainable materials · Natural fiber composite · Recycled fiber · Recycled jute fiber · Recycled jute net fiber composite · Recycled building materials

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1 Introduction

Mankind has historically used the locally available natural resources (clay, fibers etc.) as construction and building materials and, in the past centuries (only from the end of the XIX° century) the man-made building materials (inorganic fibers, steel and concrete etc.) have dominated this sector. The rapid change in the global climate conditions, poses enormous challenge to the existence of the animal and its surrounding ecosystem.

Among all greenhouse gases (Methene 16%, Nitrogen 6% and F-gases 2% [1]), CO_2 is primarily (76% [1]) responsible for rising the global near-surface air temperature [2]. Notably, the Construction and Building (C&B) sector is singularly responsible for releasing 39% (globally) and 36% (in EU) of the produced CO_2 [3]. According to [4], the electricity generated by burning of fossil fuels accounts for 40% (+) of the energy related CO_2 emissions, whereas the C&B sector consumes 36% (globally) and 40% (in EU) of the total energy [3]. On the other hand, a building, in its whole life cycle generates a huge combination of recyclable and non-recyclable wastes. This value can be quantified as in [5], approximately 160 tons and plus wastes per European Union (EU) citizen are produced during total lifetime. The EU encourage all those countries come under its influence, to recycle majority of the building Construction and Demolition (C&D) (around 70%). According to the directive EU 2008/98/EC [6], limiting them to dispose hundred percentage of the demolition wastes. A major part of the C&D wastes is dumped as land filling and responsible for damaging the environment and ecosystem, conversely sometime these wastes are also very harmful to the human health [7].

Therefore, with increasing consciousness to minimize the global warming, by limiting the greenhouse gases emission and to reduce the carbon footprint (with use of green, natural, recyclable, and sustainable raw materials) have forced scientists and engineers to search for newer and innovative sustainable building materials.

On the other hand, various goals and constrains (like [8–10]) implemented by UN, EU and various governments, have also encouraged the researchers to explore the natural fiber composite materials [11–14].

Locally produced typical natural fibers are widely available [15] in all continents. These fibers are cheap, bio-degradable and recyclable [16].

Majority around 80–85% (India and Bangladesh) of the total jute production come from the Gangetic delta [17]. The jute fiber has many advantages [18, 19]) and uses [20–27]), due to its adequate availability and good mechanical and thermal properties [19].

The present paper aims at investigating the use of the recycled jute net fibers for the composite mortar preparation. The used net fibers are the residuals/wastes, and these fibers are collected during the jute net manufacturing process. These recycled fibers were utilized to cast composite mortars with the intention to study its mechanical and thermal properties and behavior.

Moreover, these fibers were used to replace original insulation materials (typically expanded perlite/polystyrene granules or plastic balls) already present in the commercial dry-mixed mortar. Therefore, contributing towards the UN's sustainable development goals [28], this experiment proposes recycling of jute net fibers as alternative to the insulating granules.

Section 2 highlights the materials and methods used for the recycled jute net fiber preparation: the sample composition and the mix design can be found in this section, together with the procedure for the samples casting. The mechanical properties and the thermal behavior of both normal and recycled jute net fiber-composite mortars are described in the Sect. 3 and Sect. 4, respectively. Finally, the conclusive remarks are stated in Sect. 5.

2 Materials and Methods

2.1 Materials

Two different compositions, normal mortar and recycled jute fiber composite mortar were fabricated by using a commercial dry-mixed "Thermal Mortar" (TM).

The TM is a lime-based mortar and it has pre-fabricated insulation materials (expanded perlite/polystyrene granules or Plastic balls (PB)), (see Fig. 1). The TM is classified according to EN ISO 13788 [29] and it is certified as R and T / CSII. The jute fibers were recycled from the jute-net fibric fabrication (see Fig. 2).



Fig. 1. Thermal mortar (TM) with plastic insulation materials (PB)



Fig. 2. Recycled jute net fibers



Fig. 3. (a) Thread fiber pieces of various sizes; (b) Presence of knots in some of the recycled jute net fibers

2.2 Methods

Two mixtures, hereafter referred to as (i) Normal TM and (ii) Jute-net fiber composite mortar without plastic balls, were prepared according to UNI EN 1015-2: 2007 [30] (Fig. 4). The normal TM samples are nominated and grouped under M (without fiber), whereas the jute Net Fiber (NF) composite mortar without/No Plastic Balls (nPB) are nominated and grouped under M(nPB)F6.5(NF).

The inherent insulation materials (i.e. PBs) of the original mortar, take up to 1/3 of the total product/mortar mass (Table 1). Before preparing the jute net fiber composite mortar, the PBs have been removed and separated (Fig. 4c and Fig. 4d) from the original mortar (Fig. 4a) using a powder sifting machine.

The recycled jute-net fibers have been introduced to replace PBs, are the jute-net production wastes (Fig. 4b). These recycled fibers were added to perform both as insulation and binding materials. These residual fibers do not have fixed length (see, Fig. 3a), as their size ranges from 5 mm to 50 mm; in some cases, some of them also have knots (see, Fig. 3b).

Table 1 presents the mix design for normal and composite mortar mixtures. After pouring adequate amount of water (see, Table 1), the normal mortar and composite mortar mixture were stirred (Fig. 4f) approximately for 5 min. The consistency and workability of the mixture was determined by means the flow table test according to UNI EN 1015-3: 2007 [31]. For each mixture, two types of samples were cast: Mechanical Samples (MS) and Thermal Samples (TS). The empty molds sized 160 × 40 × 40 mm^3 for MS and 160 × 140 × 40 mm^3 for TS respectively, were initially half-filled initially and 25 strokes for MS and 75 strokes for TS were applied in order to remove the inside trapped air. Then, the molds were completely filled and again the same number of strokes were applied. Then the top of the molds was leveled and the extra materials were removed.

For the sample curing the UNI EN 1015-11: 2019 [32] has been followed. The curing period can be divided into two phases, the first phase is the period from casting day up to the 8th day and the second phase is the natural drying period (from 8th until 28th day).

First initial two days, the samples were left inside the molds and plastic bags, whereas during next five days samples were kept only inside plastic bags.

During the last phase, samples were placed outside the plastic bags in an environment-controlled room, with quasi-constant ambient temperature and relative humidity of 20 °C (±3) and 65% (±5), respectively.

Table 1. Composition of TM in samples without and with recycled jute-net fiber.

Sample type	Insulation materials	Percentage of insulation materials with respect to mortar mass	Water used for the mixture
M(without fiber)	Plastic balls (Already present in the manufactured product)	34.11%	30%
M(nPB)F6.5(NF)	Jute net fiber (Added externally replacing PB)	6.33%	58%
Where, nPB = No Plastic Balls; NF = Net Fiber			

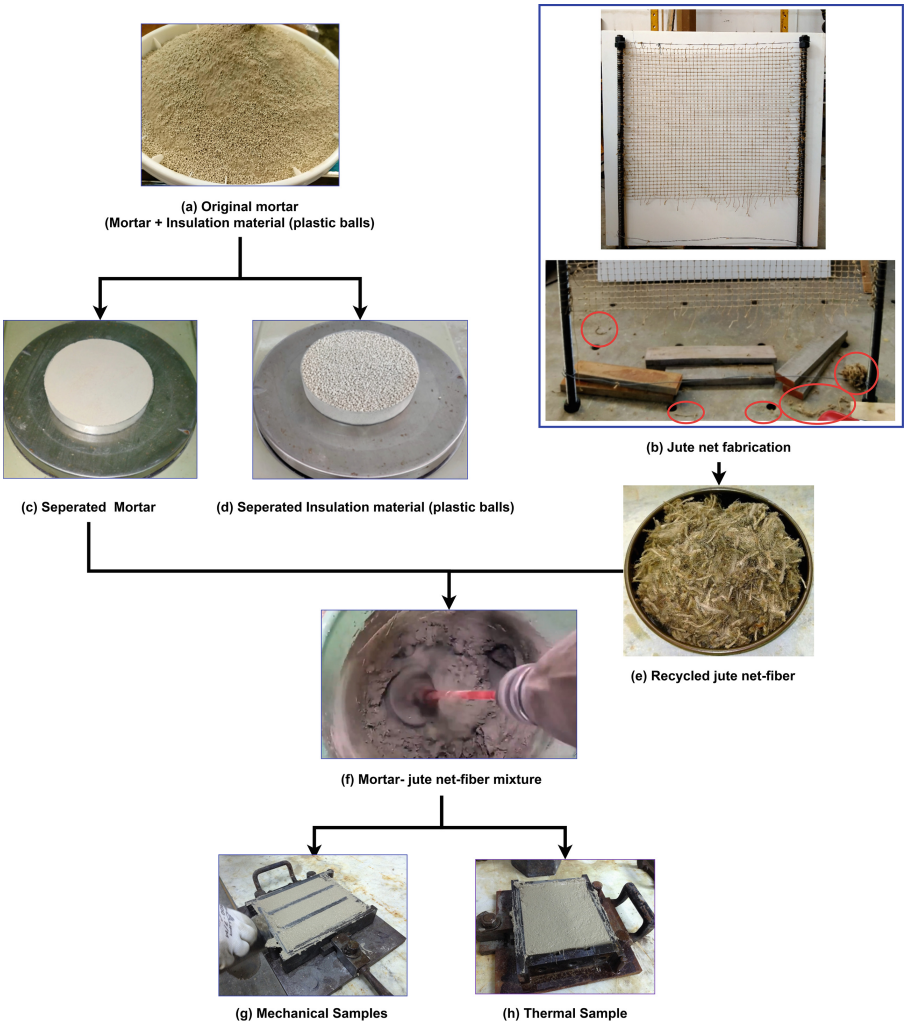


Fig. 4. The recycled jute net fiber composite mortar preparation scheme

3 Experimental Results: Mechanical Properties of the Jute-Net Fiber Composite Mortars

The mechanical behaviour of each prismatic sample ($160 \times 40 \times 40$ mm^3) was determined through flexural (Fig. 5) strength tests. The tests were conducted on the 28th day of casting, and the strain energy (U), the flexural strength (ft) and flexural strain of each sample were determined. Three samples of each category were tested.

A universal displacement-controlled machine: Metrocom-1 has been used to conduct the three point bending flexural test (UNI EN 1015-11:2019 [32]). The loading machine has maximum load capacity of 4.9 kN, with sensibility/scale division of 0.02 kN. The

machine is equipped with a load cell of class 1 (measuring capacity of 5 tons and with nominal sensitivity of 2 mV/V) and a transducer (max. range 50 mm, nominal sensibility output 2 mV/V and linearity - <0.10%F.S) in order to measure the applied central load and displacement, respectively. The load was applied with displacement rate of 1.5 mm/min.



Fig. 5. Flexural strength test

With the removal of PB from original mortar and the addition of jute fibers (recycled from net fabrication), the strain energy improved more than 600% (see, Table 1), when compared with the samples without fiber and with PB. This was due to unequal and longer fibers (some with knots, see Fig. 3b) whose presence helped in binding and gripping mortar materials better than that of PBs; imbodied fibers helped in absorbing and dissipating the applied load, too. During the flexural tests the samples with fibers have shown ductile behavior.

Table 2. Change in mechanical properties with addition of jute fiber and removal of insulation materials: the sample M(nPB)F6.5(NF) Vs. M (without fiber)

Flexural properties	
Stain energy	Flexural stress/strength (σ)
kNmm	MPa
+632.26%	−50.01%
Where, nPB = No Plastic Balls; NF = Net Fiber	

4 Experimental Results: Thermal Charactristics of the Jute-Net Fiber Composite Mortars

Thermal characteristic of each sample (160 × 140 × 40 mm^3) was evaluated by measuring the Thermal Conductivity (TC) value using a heat flow meter (TAURUS TCA300).

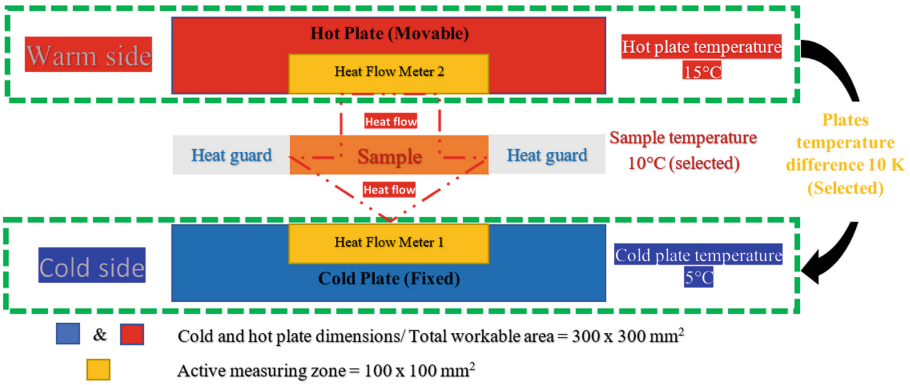


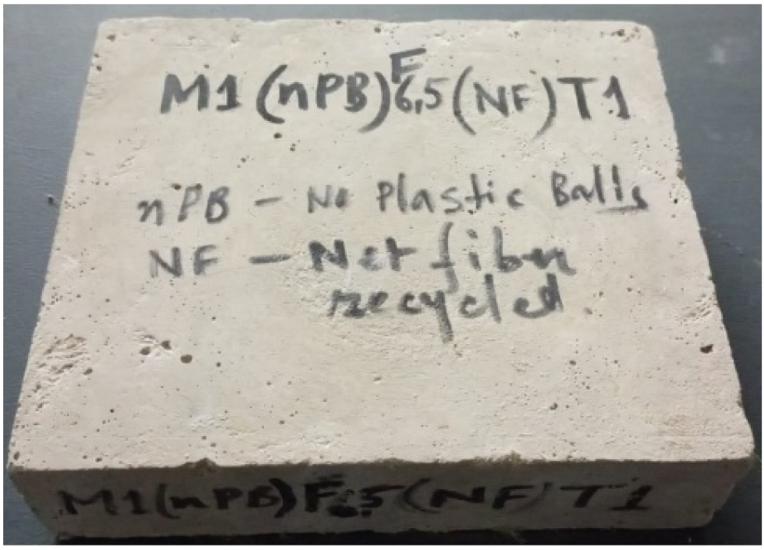
Fig. 6. Schematic diagram of the heat flow meter (TAURUS TCA300).

Normal mortar samples (M) with plastic balls and without fiber, and composite mortar samples (M(nPB)F6.5(NF)) (Fig. 7a) without plastic balls and with recycled jute net fiber were used to conduct measurements following ISO 8301 [33] and DIN EN 1946-3 [34].

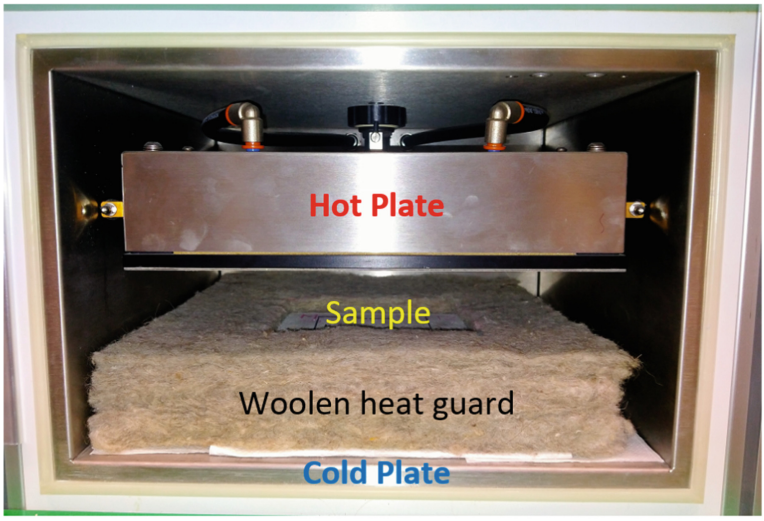
After 28th day of restricted and natural drying (see, Sect. 2.2) each sample was placed in oven for forced drying and this period range from 7 to 14 days. The range of the forced oven drying period was varied, due to the presence of different amount of moisture contained in each sample. According to UNI EN 12667 [35], samples were dried in oven at 50 °C in order to reduce the moisture level, as presence of humidity influence the TC measurement. Existence of no moisture was confirmed, when two successive measurements have same (±0.1 g sample mass) value.

The TC measurements were conducted on the day, when the ambient temperature and relative humidity were found to be 22 ± 2 °C and 60 ±10%, respectively. The samples (160 × 140 × 40 mm^3) need to be placed exactly at the center of the measuring plates (300 × 300 mm^2). The instrument has one hot (moveable) and a cold (fixed) plates, as in Fig. 6 and Fig. 7b. The plates' function can be reversed as desired. The active measuring area (100 × 100 mm^2) is located at the center of each plate which is equipped with one heat flux sensor. The protective zones surround the active zones.

A woolen heat guard/insulating ring has been used (Fig. 7b) to have quasi-uniform monodirectional heat flow and also to minimize the heat losses around the edge of the measuring sample.



(a)



(b)

Fig. 7. (a) Recycled composite sample (160 × 140 × 40 mm^3); (b) Sample placed inside the flow meter, surround with woolen heat guard.

The instrument has the pre-set data sampling time at every 5 s. while the intermediate measuring time and total measuring time were set as 1 min and 300 min, respectively.

The plates temperature difference was chosen to be 10 K. The sample mean temperatures selected as 10 °C, 20 °C and 30 °C, according to UNI EN 12939 [36]. The heat flux $\dot{Q}$ [W/m^2] and the plates temperatures were measured and the Thermal Conductivity λ [W/mK] is calculated by TAURUS TCA according to [21]:

$$\lambda = \dot{Q}\frac{S}{(t_H - t_C)}\left[\frac{W}{mK}\right] \tag{1}$$

where:

$\dot{Q}$ is the heat flux [W/m^2]; S is the sample thickness [m]; t H is the hot plate temperature [°C]; t C is the cold plate temperature [°C].

Table 3. Change in thermal properties with addition of jute fiber and removal of insulation materials: the sample M(nPB)F6.5(NF) Vs. M(without fiber)

Thermal conductivity (λ)		
W/mK		
at 10 °C	at 20 °C	at 30 °C
−7.98%	−8.26%	−7.11%
Where, nPB = No Plastic Balls; NF = Net Fiber		

Table 3 shows the improvement in the TC values at three different temperatures (10 °C, 20 °C and 30 °C) of the composite mortars (without PB and with jute net-fibers) with respect to the normal mortars (with PB and without jute net-fibers). The reduction in TC of 0.017 W/mK at 10 °C, of 0.018 W/mK at 20 °C and of 0.016 W/mK at 30 °C, respectively have been observed when PBs were replaced with the recycled jute-net fibers.

5 Conclusions

The recyclability of the residual jute fiber from net fabrication process and its applicability in the production of new recycled natural fiber composite material have been evaluated in this paper. Moreover, the thermo-structural behaviors of the composite material and its potential use as duel-retrofitting (i.e., structural and thermal) purposes have been studied.

In this process, the insulation materials (expanded perlite/polystyrene granules or plastic balls) already present in the commercial dry-mixed mortar have been replaced with the above-mentioned recycled jute-net fibers. Interestingly, promising results have been obtained with the improvement in strain energy and thermal conductivity. Only three samples of normal mortar (without fiber and with PB) and jute net-fiber composite mortars have mechanical and thermal properties have been compared during this research work. Therefore, further studies need to be conducted to assess the feasibility of using these fibers in construction and building sector.

Different masonry-wall thermo-structural retrofitting composite systems would be developed using jute-composite mortar and jute fiber nets. It would be followed by the in-plane shear tests and thermal performance evaluations.

Future developments are also expected from the recycling of other processing scraps [37, 38] or construction and demolition waste [39] in concrete and mortar for structural retrofitting.

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