Construction and Building Materials 191 (2018) 554–563

Contents lists available at ScienceDirect

Construction and Building Materials

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

Effectiveness of the surface modified jute fibre as fibre reinforcement in controlling the physical and mechanical properties of concrete paver blocks

Sarada Prasad Kundu [a,c], Sumit Chakraborty [a,b,*], Subrata Chakraborty [b]

[a] Materials Science Centre, Indian Institute of Technology, Kharagpur 721302, India
[b] Department of Civil Engineering, Indian Institute of Engineering Science and Technology Shibpur, Howrah 711103, India
[c] Rural Concreting Company Ghatal Pvt. Ltd., Ghatal 721232, India

HIGHLIGHTS

- Effect of jute as fibre reinforcement in improving the performances of paver blocks.
- Selective modification of fibre in enhancing the performances of paver blocks.
- Enhancement of fibre matrix compatibility modifying with polymer and tannin.
- Design of a model for explaining the overall improvements of paver blocks.
- A new concept for improving the life of the paver and reducing maintenance cost.

ARTICLE INFO

Article history:
Received 3 August 2017
Received in revised form 4 October 2018
Accepted 5 October 2018

Keywords:
Concrete paver blocks
Jute fibre reinforcement
Fibre modification
Mechanical property
Fibre-matrix interaction

ABSTRACT

Concrete reinforced with natural fibres is considered to be an effective scheme nowadays to fulfill the global demand for sustainable infrastructures development. The present article investigates the salient features of concrete paver blocks fabricated using mild alkali, dilute polymer emulsion, and tannin modified natural jute fibre as fibre reinforcement. Initially, the chopped jute fibres (3–5 mm) were modified using sodium hydroxide, dilute carboxylated styrene butadiene, and tannin, followed by fabricating and characterizing the concrete paver blocks. Analyzing the physico-mechanical properties, it is demonstrated that the paver blocks containing 1 wt% modified jute fibre (with respect to weight of cement) show 30%, 49% and 166% higher compressive strength, flexural strength, and flexural toughness, respectively, as compared to that of the reference blocks. Finally, based on the Fourier transform infrared spectroscopy, X-ray diffraction, thermogravimetric analysis, and microstructure analysis, the compatibility of reinforcing fibre with matrix phases was established. The use of modified chopped jute fibre as fibre reinforcement is found to be very effective to improve the mechanical properties and the long-lasting-life of paver blocks that may lead to minimizing the maintenance cost as well.

1. Introduction

In the arena of diversified applications, concrete is used in producing pre-cast paver blocks widely. Extensive uses of these concrete foundations were so far seen for ornamentation of roads and parking lots at the industrial and domestic places [1]. The demand for concrete paver blocks is reported to be very high in developing countries for hastily growing their infrastructural facilities [1]. In this scenario, the shelf-life of concrete paver blocks is an important parameter that needs to consider prior to use of paver blocks at the application site. The shelf-life of these block-structures depends on the empirical design of paver blocks, organization of surface laying courses, sub-base, and sub-grade of the foot traffic and/vehicles traffic [1–3]. In fact, continuous stress exposure of paver blocks to the sub-base brings brittle failure of concrete structure [4]. The brittle failure of paver blocks may cause considerable financial involvement for its maintenance. Thus, for troubleshooting, production costs of paver blocks were tried to be minimized modifying the aggregates and using the waste materials like waste marble [1]. Usually, the use of waste marbles decreases the mechanical strength of blocks marginally but increases the freeze-thaw durability and abrasive wear resistance with the increase in marble content [3]. It is reported that 1 m^3

* Corresponding author.
E-mail address: sumit9@hanyang.ac.kr (S. Chakraborty).

https://doi.org/10.1016/j.conbuildmat.2018.10.045
0950-0618/© 2018 Elsevier Ltd. All rights reserved.

concrete for paving blocks requires 34 USD in Turkey. However, the production cost goes down to ~ 30 USD when waste marble (40%) was used as aggregates [3]. Wattanasiriwech et al., [5] also recommended that waste mud from ceramic tile production factory can also be used for manufacturing compressed paving blocks. The waste mud contains both coarse and fine aggregates and it is able to replace traditionally used aggregates in cement pavers. Poon and Chan, (2006) [6] reported that the replacement of conventional aggregates of concrete paver blocks using recycled concrete aggregate and crushed clay brick as coarse and fine aggregates, respectively, the mechanical performances of paver blocks remain similar to that of the conventional concrete paver blocks. They also reported that the blocks prepared using 25 wt% crushed clay brick as fine aggregate can achieve an adequate compressive strength for producing Grade B paving blocks as prescribed by ETWB of Hong Kong in trafficked areas. In contrary, some researchers reported that use of recycled coarse aggregate instead of natural coarse aggregate in fabricating concrete paver blocks increases water absorption and reduces density as well as the strength of paver blocks [7]. However, use of recycled crushed glass may tackle these difficulties since recycled crushed glass particles possess a low water absorption value [7].

Still, these modifications were unable to achieve expected deformation against excessive cyclic stress. The structural responses of pavement can be improved if the surface and laying courses of blocks deform extreme without any major crack formation [4]. In view of this, researchers have opted to use short natural fibre as fibre reinforcement in the concrete paver blocks [4], which will be uniformly distributed and randomly oriented in the concrete matrix [8]. The fibre reinforcement may retard the crack propagation acting as a bridge between micro crack tips during load transfer. Consequently, a satisfactory enhancement of strength and flexibility of concrete composites takes place [9,10]. Numerous investigations were carried out to develop fibre reinforced cement composite using jute [8], heamp [9], sisal [11], coconut [12], baggase [13] etc. Being natural origin, these fibres need further modification to improve their compatibility with the highly alkaline cement matrix and long-term durability [14–16]. Recently, the mild alkali and the combined alkali and polymer modified jute fibres were used to develop green sustainable cement composites [17–21].

It is apparent from the existing literature as discussed in the above that an adequate attempt has been made to improve the performances and properties of concrete using natural fibre reinforcement. However, the effect of surface modified fibre on the properties and performances of concrete paver blocks is yet to be investigated adequately. In the present study, the suitability of natural jute fibre as fibre reinforcement to improve the strength and flexibility of concrete paver blocks is investigated. Additionally, considering the fibre-matrix compatibility, as well as the fibre durability in the highly alkaline cementitious medium, an effective modification of jute fibre and concrete matrix using a suitable polymer and plant-based natural admixture (tannin) is prescribed, followed by studying mechanism to explain the effectiveness of surface modified jute fibre in controlling the performances of paver blocks.

2. Experimental study

The impact of jute fibre modified using a selective aqueous based polymer and a plant-based natural admixture (tannin) on the performance and properties of concrete paver blocks was evaluated through a systematic experimental research program as elaborated below.

2.1. Materials

Jute fibres (*Corchorus olitorius*) of TD4 grade as per standard IS 271 (2003) [22] collected from Gloster Jute Mill, India was used as fibre reinforcement in concrete paver blocks. Analytical grade sodium hydroxide supplied by Merck, India and the carboxylated styrene-butadiene copolymer (SIKA latex, supplied by Sika India Pvt. Ltd.) were used for the surface modification of jute fibre. Portland Pozzolana cement as per standard IS 1489 (Part 1) (2005) [23] supplied by Ambuja Cements Ltd. was used as a primary binder for preparing concrete paver blocks. The oxide composition of cement is presented in Table 1. The plant based natural admixture (tannin) collected from the local market was used to modify the concrete matrices. In this study, the paver blocks were fabricated using coarse aggregates of size 10 mm down up to 4.75 mm and fine aggregates, i.e., river sand, grading zone II of size 300 μm sieve passed. The grading of concrete aggregate as per IS 383 (2002) [24] is shown in Fig. 1a. Additionally, Fig. 1b and c represent both cumulative mass percent finer and individual percentage retain (IPR) plot of the combined aggregate grading for the concrete mixture. Ideally, the IPR plot should be a bell-shaped [25] since the fraction of medium size particles should be abundant in a concrete mix. As shown in Fig. 1c, the gradation curve of the aggregates nearly follows an ideal trend.

2.2. Fabrication and characterization of unmodified and modified jute fibres reinforced concrete paver blocks

Four different types of concrete paver blocks, viz., reference (RP) without jute fibre reinforcement, unmodified jute reinforced (UJP), polymer modified jute reinforced (PJP), and combined tannin and polymer modified jute reinforced (TJP) concrete paver blocks were fabricated in this investigation. Table 2 depicts the typical batch formulation of the different types of concrete paver blocks. In this study, a fixed proportion of cement: fine aggregates: coarse aggregates: jute was maintained at 1:3:4:0.01 for all concrete batches. However, the water content (requires for cement hydration) was varied to maintain a particular workability of these four types of concrete. The water (in volume): cement (in weight) ratios were kept 0.15, 0.20, 0.15, and 0.15 for fabricating the RP, UJP, PJP, and TJP, respectively (see Table 2). Note that for the fabrication of PJP and TJP, initially, the required amount of water was mixed with the requisite quantity of polymer emulsion to dilute the emulsion. Thereafter, the dilute polymer emulsion was used to treat jute fibres, followed by mixing with the dry cement-aggregate mixture to obtain a wet jute-concrete mixture.

In fact, for the fabrication of PJP, the unmodified chopped jute fibres (3–8 mm) were treated with 0.5 wt% sodium hydroxide solution maintaining a liquor ratio 1:30 (jute fibres (weight): alkali solution (volume)) for 24 h at ambient condition. The excess liquor (which was not absorbed by jute fibres) was drained out. Prior to modifying the jute fibres using polymer emulsion, 1 ml of polymer emulsion (Sika latex, 41% solid content) was diluted using 800 ml of water. Thereafter, the alkali-modified chopped jute fibres were dispersed in the required quantity of diluted Sika-based polymer emulsion (as mentioned in the above), followed by the gradual addition of the half of the total required cement to produce an alkali and polymer modified jute-cement slurry. Afterward, the total amount of coarse and fine aggregates was mixed with the jute-polymer-cement slurry in a concrete mixer. The mixing was continued for 10 min to disperse the jute fibres in the concrete matrix. The remaining amount of cement was added to the polymer modified jute-concrete mixture, followed by mixing thoroughly for further 5 min to obtain a modified jute dispersed wet concrete mixture with an adequate consistency. Finally, the paver blocks (200 mm (length) × 100 mm (breadth) × 60 mm (depth)) were fabricated using freshly prepared concrete mixture. During casting, the jute concrete mixture was poured into the mould, followed by compaction using a vibrating table and a compression load. A pictographic scheme for the fabrication of modified jute fibre reinforced concrete paver block is depicted in Fig. S1 (See Suplementary Information). In this study, the compressive pressure at a rate of 22 MPa/s was applied for 60 s to mechanically compact the concrete mixture within the mould using a compaction machine. Finally, the fabricated blocks were removed from the moulds and stored for water curing.

The UJP was fabricated following the same concrete mixture preparing process as described for the preparation of PJP. However, this process was conducted using raw jute fibre and fresh water instead of alkali treated jute and polymer emulsion. Therefore, the jute fibre treatment procedure was not followed prior to preparing concrete mixture. Whilst, for the fabrication of TJP, 0.25% of tannin powder (w.r.t. cement weight) was dissolved in the diluted polymer emulsion (Sika latex) prior to modifying the jute fibres using polymer emulsion. Other steps for the fabrication of TJP remained same as described above for the fabrication of PJP. Finally, all the four types of paver blocks were allowed to water cure for 28 days. After specified time of curing, the blocks were surface dried and allowed to test according to IS: 15,658 (2006) [26]. In this study, the result of each concrete batch represents the average of three specimens' test results. In fact, three specimens from each batch of paver blocks were tested to check repeatability of the test result.

Bulk density of concrete paver blocks fabricated using unmodified and modified jute fibres was measured according to ASTM C948 [27]. The compressive strength of rectangular shaped (200 mm (length) × 100 mm (breadth) × 60 mm (depth)) unmodified and modified jute fibre reinforced concrete paver blocks were measured using a 1000 kN hydraulic Universal Testing Machine (AIM: 31402, S. No. 091020, Aimil Ltd., India). The flexural strength of the same were evaluated using a three points bending strength measurement setup of a 10 kN Universal Testing Machine (H10KS, Hounsfield, Salfords, UK) in accordance with a standard procedure described in IS 15,658 (2006) [26]. The flexural toughness (energy absorption capa-