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Original article

Strength properties of bamboo and steel reinforced concrete containing manufactured sand and mineral admixtures

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ABSTRACT

In a quest to ensure sustainability of the future generation, various research attempts are focusing on the use of alternative materials for construction. In this study, bamboo strips were used as reinforcement in a concrete that was made with supplementary cementitious materials and partial replacement of river sand with manufactured sand (m-sand). Cement was partially replaced by 25% of combination of admixtures such as fly ash and Ground Granulated Blast Furnace Slag (GGBS). In alignment with standard requirements, concrete samples such as cubes, cylinders and beams were produced and tested at stipulated periods. Micro scale analysis was performed on the bamboo using SEM and FTIR, and its tensile strength was also determined. The results of the micro scale and tensile strength tests revealed that bamboo is a strong and ductile material. The study showed that a combination of fly ash, GGBS and m-sand used as alternative materials in concrete improves the compressive and split tensile strengths. Under flexural loading, performance of bamboo reinforced concrete (BRC) made with alternative materials (fly ash, GGBS, and m-sand) was significantly low compared to BRC containing conventional materials. In addition, BRC made with conventional materials developed more flexural strength than the SRC, with a variation representing 6.5% strength gain.
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1. Introduction

Cost of concrete production is currently on the increase due to the recent recession in world economy. Conventional construction materials are becoming expensive. Therefore, numerous alternative materials are being proposed for concrete production. Interestingly, recent investigations (Ahmaruzzaman, 2010; Emmanuel and Oluwaseun, 2016; Mustafa et al., 2011) have suggested various alternatives such as fly ash, *Cordia millenii* ash, and rice husk as admixtures (Van et al., 2014) or partial replacement for cement. In all cases, the alternative materials have proved suitable in blended cement for improving the strength characteristics of concrete. Also, both fine and coarse natural aggregates have been substituted with materials such as ceramic tiles (Alves et al., 2014; Awoyera et al., 2016), and steel slag (Abu-Eishah et al., 2012; Awoyera et al., 2015a). From these studies both ceramic and steel slag aggregates have been identified as a good alternative material for making concrete.

Steel reinforced concrete (SRC) is mostly used for construction of load bearing structures. However, factors such as high cost and non-renewability of steel are a major concern for users (Agarwal et al., 2014). Therefore, consideration is given to a low-cost and sustainable material like bamboo, which apparently possesses some physical features of steel. Bamboo is a natural perennial grass-like composite, and is one of the fastest growing woody plants in the world (Awoyera et al., 2015b). It belongs to the grass family *Bambusoideae*, which consists of cellulose fibre embedded in a lignin matrix. It is widely used as scaffolds and wall proportioning, because of its high strength to weight ratio. Many promising studies have been conducted which showcased diverse application of bamboo for construction. In a study on parallel strand bamboo (PSB) adhesively bonded under high pressure, Huang et al. (2015), discovered that PSB was a high strength and transversely isotropic biocomposite. Also, an overview of the use of bamboo fibre was made by Abdul Khalil et al. (2012), and it was concluded that natural fibres such as bamboo can be used as biocomposites

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and integrated into sustainable, eco-friendly and well-designed industrial products which can minimise or replace the dominance of petroleum based products in future. Method of extraction and preparation of bamboo fibre-reinforced composites was proposed by Zakikhani et al. (2014). According to them, mechanical extraction methods are more eco-friendly than chemical methods, and steam explosion and chemical methods significantly affect the microstructure of bamboo fibres. Hebel et al. (2014) developed composites using bamboo fibre which could yield maximum tensile capacity of 180 MPa and also evaluate the process parameters, such as temperature, pressure and press/hold time.

In recent development, bamboo is being processed to typical reinforcement bar sizes which may be used instead of conventional steel bars. Adewuyi et al. (2015), comparatively evaluated the flexural performance and deformation characteristics of concrete elements reinforced with bamboo, rattan and twisted steel rebars. It was concluded that the bamboo bars are suitable rebars for non-load bearing and lightweight reinforced concrete flexural structures. Another study (Ikponmwosa and Fapohunda, 2017) studied the behaviour of foamed aerated concrete beams reinforced with bamboo. The deflection of beams decreased with increase in the area of bamboo splints, also failure load decreased with increase in area of bamboo at the tension area. Other studies (Ghavami, 2005; Terai and Minami, 2011) also evaluated the behaviour of BRC. Hence, it was suggested that, bamboo has the potential to be used as substitute for steel as reinforcement in structural members. So far, in the available literatures, there are little or no sufficient data on BRC composite made with admixture such as fly ash and GGBS. Therefore, in the present study, bamboo was used as reinforcing material for beam specimens containing: 25% of combination of admixtures such as fly ash and GGBS as partial replacement for cement, and manufactured sand as fine aggregate. The properties investigated in the samples include: compressive and split tensile strengths, flexural strength and load–deflection characteristics, crack development pattern and propagation. Moreover, micro scale analysis of bamboo was also performed.

2. Materials and methods

In this study, materials that were utilised includes: cement, fly ash, GGBS, river sand, m-sand, granite, potable water, steel reinforcement and bamboo. Ordinary Portland cement conforming to BS 12 (1996) requirement was used. The aggregates were dried and sieved through sieve 2.36 mm and treated in accordance with BS 882 (1992). Table 1 shows the physical properties of the aggregates. The river sand and m-sand were well graded. A particle size distribution curve for the fine aggregates is presented in Fig. 1. The bamboo was *Bambusa Valgaris* family, normally, it is locally available in Tirupur. The tensile strength of the bamboo strips used was 93.4 Mpa. Preliminary treatment of the bamboo entails subjecting them to soaking under temperature of 27 °C for 48 h, and afterwards they were sun-dried for almost 30 days, thus allowing it to attain adequate dryness. Generally, certain precautions taken prior to using the bamboo was to ensure that the bamboo shows no traces of decay, fungus growth or pores and any deterioration or blemishes. Thereafter, stripping of the bamboo was done at the sawmill, they were sawn into 10 × 10 × 480 mm sizes. Before casting beam samples, bamboo strips were greased thoroughly-in an attempt to enhance adequate bonding with the concrete matrix and also to prevent moisture from soaking into it.

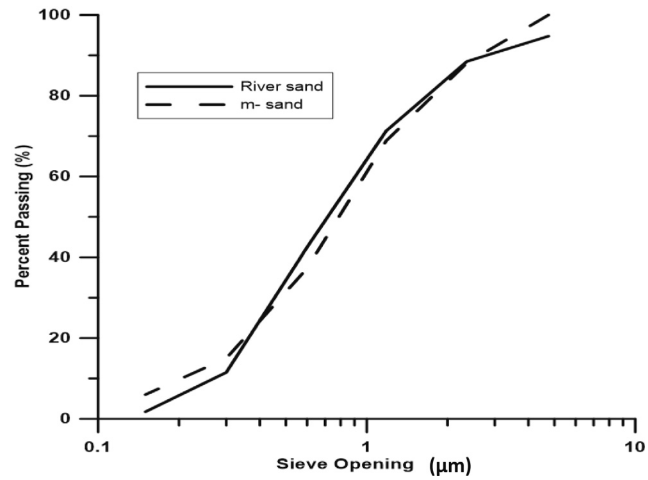

Fig. 1. Particle size distribution for fine aggregates used.

Table 1
Physical properties of aggregates used.

S/N	Aggregates	Specific gravity	Water absorption (%)	Fineness modulus
1	River sand	2.6	6.5	2.89
2	m-Sand	2.84	5.6	2.84
3	Granite	6.5	2.5	–

2.1. Mix design and sample preparation

Three main categories of mix were considered-based on aggregate combinations, they are: mix 1 (Mc) which contains the conventional materials-cement, sand and granite; mix 2 contains cement as binder, m-sand and river sand as the fine aggregate, and granite; lastly mix 3 contains 75% cement and 12.5% each of fly ash and GGBS as binder, m-sand as fine aggregate, and granite. Hence, summary of the mix design is presented in Table 2. Therefore, a total of 27 cubes of 150 mm dimensions and 27 cylinders of 150 mm diameter by 300 mm height were cast and tested in triplicate.

However, for beams, under each category, four set each of beams were produced; and with two samples reinforced with 10 mm steel bars and other two reinforced with bamboo strips. The bamboo strips were fastened firmly together with stirups using binding wire. In all, 36 beams of 100 × 100 × 500 mm were produced and cured by immersion in water for maximum 28 day period. Further, an already established mix ratio of 1:2:4 of cement, sand and granite was adopted. A 20 mm cover spacing was maintained in all the samples. Water to cement ratio of 0.50 was adopted, in alignment with previous study (Ikponmwosa and Fapohunda, 2017).

2.2. Experimental investigations

The properties investigated in the samples include: compressive strength, split-tensile strength, flexural strength and load–deflection characteristics-determined using a universal testing machine at a consistent loading rate of 120 kN/min. In addition,

Table 2
Summary of mix design.

S/N	Mix	Binder (kg)			Fine aggregate (kg)		Coarse aggregate (kg)
		Cement	Fly ash	GGBS	River sand	m-Sand	Granite
1	Mc	20	0	0	40	0	80
2	M1	20	0	0	20	20	80
3	M2	15	2.5	2.5	0	40	80

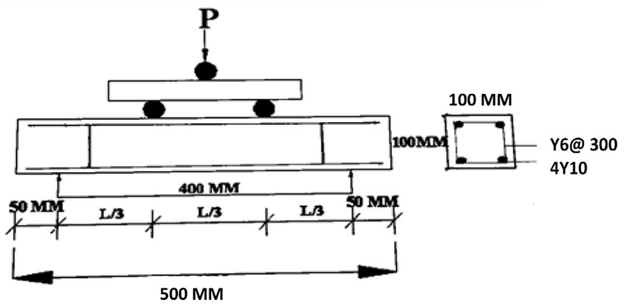

Fig. 2. Schematic loading arrangement for third-point flexural testing (Oluwaseun, 2016).

properties such as crack development and failure pattern were assessed. Moreover, micro scale analysis of bamboo was performed using scanning electron microscope (SEM) and Fourier Transform Infra-red Spectroscopy (FTIR). Micro scale tests were conducted on dry bamboo powder obtained by scratching the bamboo with knife. The cured concrete samples were tested at 7, 14 and 28 days. Fig. 2 shows a schematic loading arrangement for third-point flexural testing adopted. Beam sample was positioned with simply supported ends, with required spacing intervals. Load set up was fixed on the top of the beam, with a load indicator, which denotes the load attained.

3. Results and discussion

3.1. Microstructural analysis of bamboo

FTIR conducted on the bamboo powder samples were evaluated using the diamond crystal attenuated total reflection method (ATR); which is very suitable for powder samples only. This method uses zinc selenide (ZnSe) or germanium (Ge) prism in ATR accessory. Figs. 3 and 4 show the absorptions and transmittance of bamboo dust respectively. As can be seen, bamboo dust exhibits absorption and transmittance peak intensity near 1500 cm^{-1}. The implication of this is that bamboo dust has more complex molecules, having many bonds and vibrational spectra (Lv et al., 2016). In essence, bamboo dust is comprised of big molecules, which as evidence yielded many peaks in their IR spectra (Figs. 3 and 4). There exists a strong bond (C=C) aromatic bending between bamboo particles. Thus, increased frequency seen in the bamboo particle was an indication of increased bond strength.

In addition, SEM image of bamboo dust (using model Leica Cambridge S-360), is presented in Fig. 5. All the surfaces were examined after first sputter coating with gold to avoid electrostatic charging and poor image resolution. The observed crystal surfaces are rough (Jegatheesan et al., 2012), and in like manner, the irregular shape of bamboo fibre together with poor adhesion was due to its hydrophilic nature.

3.2. Compressive and split-tensile strength

Results of compressive and split-tensile strengths are presented in Figs. 6(a and b) respectively. Both strength characteristics of the mixes increased with the curing age, this phenomenon is a norm in concrete composites (Abd elaty, 2013). The rapid hydration of cement in the presence of moisture was responsible for this development. C—S—H (calcium silicate hydrate) formation during hydration of concrete or mortar influences its strength development (Ikponmwosa and Fapohunda, 2017). Highest 28-day compressive strength was recorded in the reference mix (Mc), thus having 7.28% strength than the m-sand concrete (M2). The mix 2 slowly gained strength until 14 days when other mixes rapidly developed early strength. Maybe this was because of fly ash or GGBS addition, which probably retarded the hydration in the mix.

For split–tensile strength, highest 28-day tensile strength was obtained in mix 2 (M2), which has an equal combination of river sand and m-sand as fine aggregate. The effects of blended cement with fly ash and GGBS contribute to blocking micro-pores in the aggregates within concrete matrix. Normally, during splitting tensile test, the major pores of the aggregate particles are usually broken along the surface of failure (Xudong et al., 2012). Thus, it could be inferred that these kinds of admixtures are good in concrete when high tensile strength is desired alongside compressive strength. Further, statistical regression models- using the best-fit

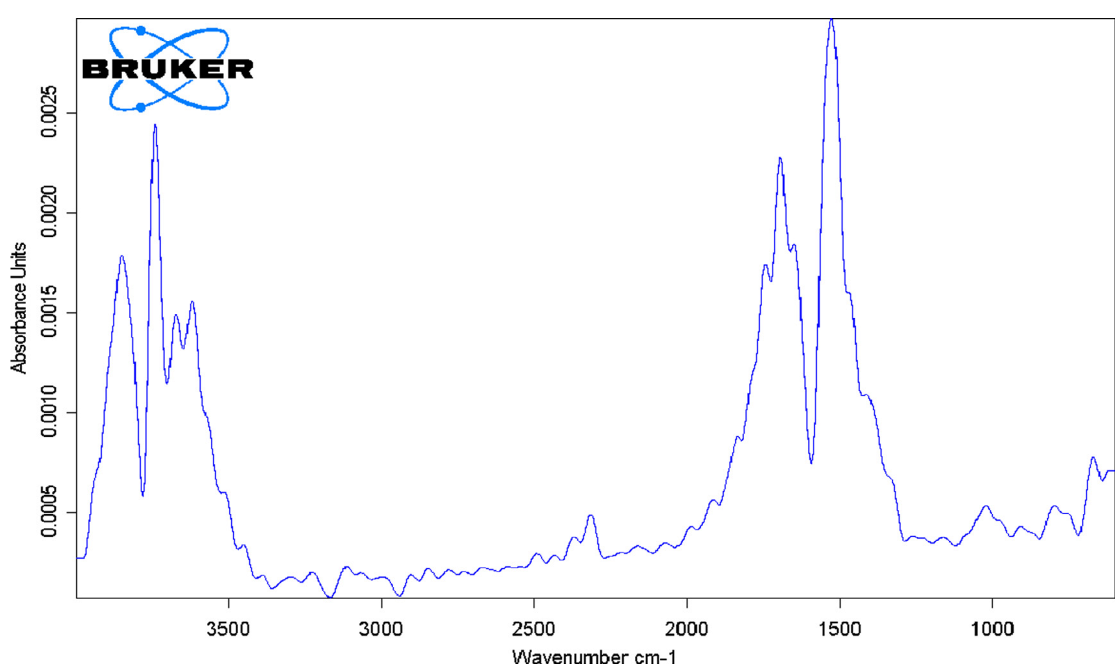

Fig. 3. Absorptions of bamboo dust.

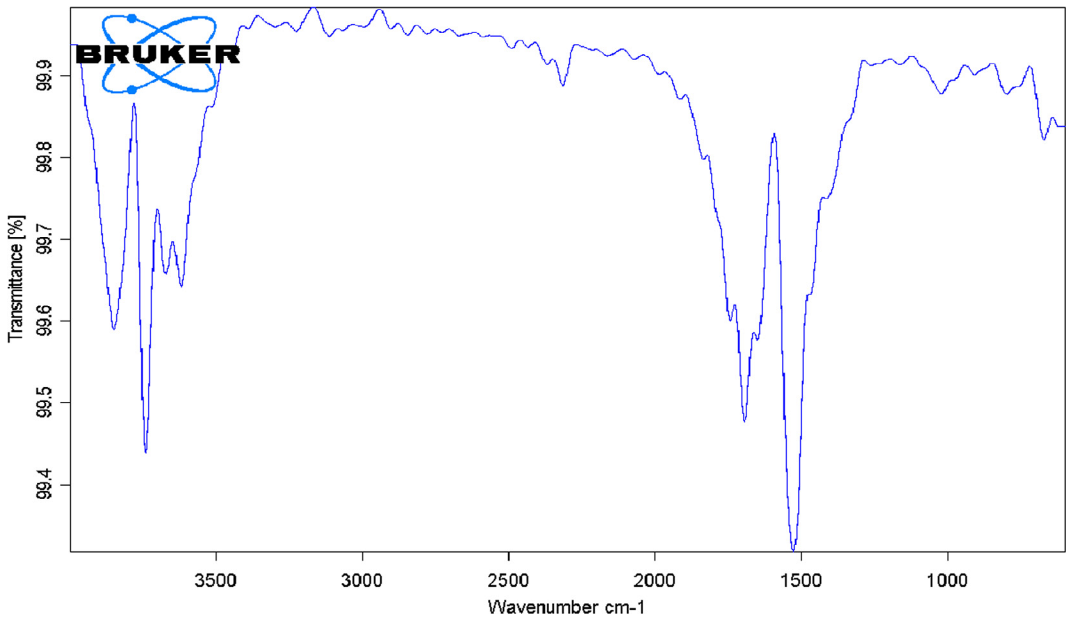

Fig. 4. Transmittance of bamboo dust.

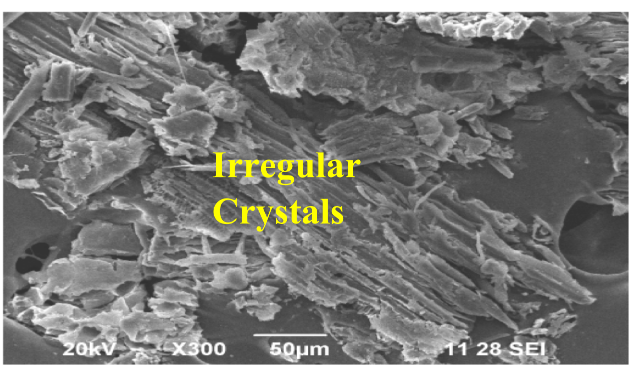

Fig. 5. SEM images of bamboo dust.

curve for both compressive and split-tensile strengths were determined (shown in Table 3) for all the mixes considered. Because concrete behaves in a nonlinear (Oluwaseun, 2016; Zhao et al., 2004) (showing a brittle like failure in compression), therefore the models generated were polynomial-which can best describe the true behaviour of concrete (Ahmad et al., 2014). The r-squared values for the mathematical expressions are significant.

3.3. Flexural strength, failure pattern and load–deflection pattern

The flexural strength gained by the samples (Mc, M1 and M2) over 28-day period are presented in Figs. 7(a–c), and their corresponding load–deflection behaviour at 28-day are shown in Figs. 8(a–c) respectively. For reference concrete (Fig. 8a), bamboo reinforced sample slightly gained more flexural strength (excess

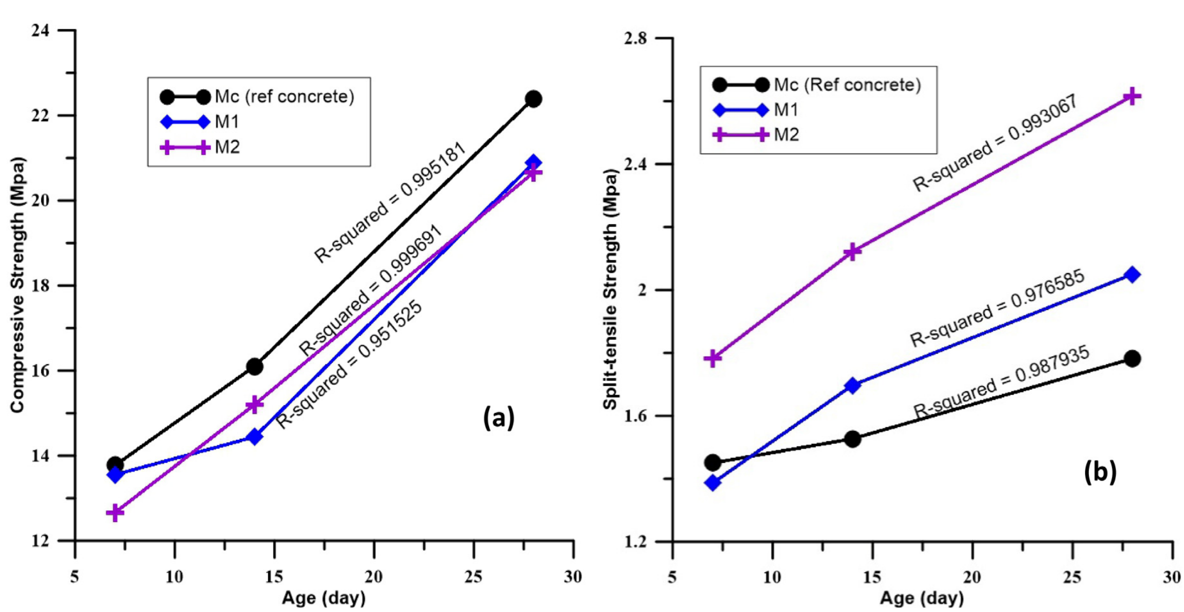

Fig. 6. Strength development with days (a) compression (b) Split-tensile.

Table 3
Regression statistics for the strength properties of the mixes.

Mix type	Compressive strength (Mpa)	Split-tensile strength (Mpa)	Remark
Mc	$Fc = 11.98 + 0.22X + 0.0056X^2$ R-squared = 0.995	$Yc = 1.41 + 0.0038X + 0.00034X^2$ R-squared = 0.987935	Good
M1	$F1 = 14.21–0.21X + 0.016X^2$ R-squared = 0.951	$Y1 = 0.98 + 0.064X - 0.00091X^2$ R-squared = 0.976585	Good
M2	$F2 = 10.25 + 0.34X + 0.0013X^2$ R-squared = 0.99	$Y2 = 1.38 + 0.062X - 0.00063X^2$ R-squared = 0.993	Good

Note: X = curing age.

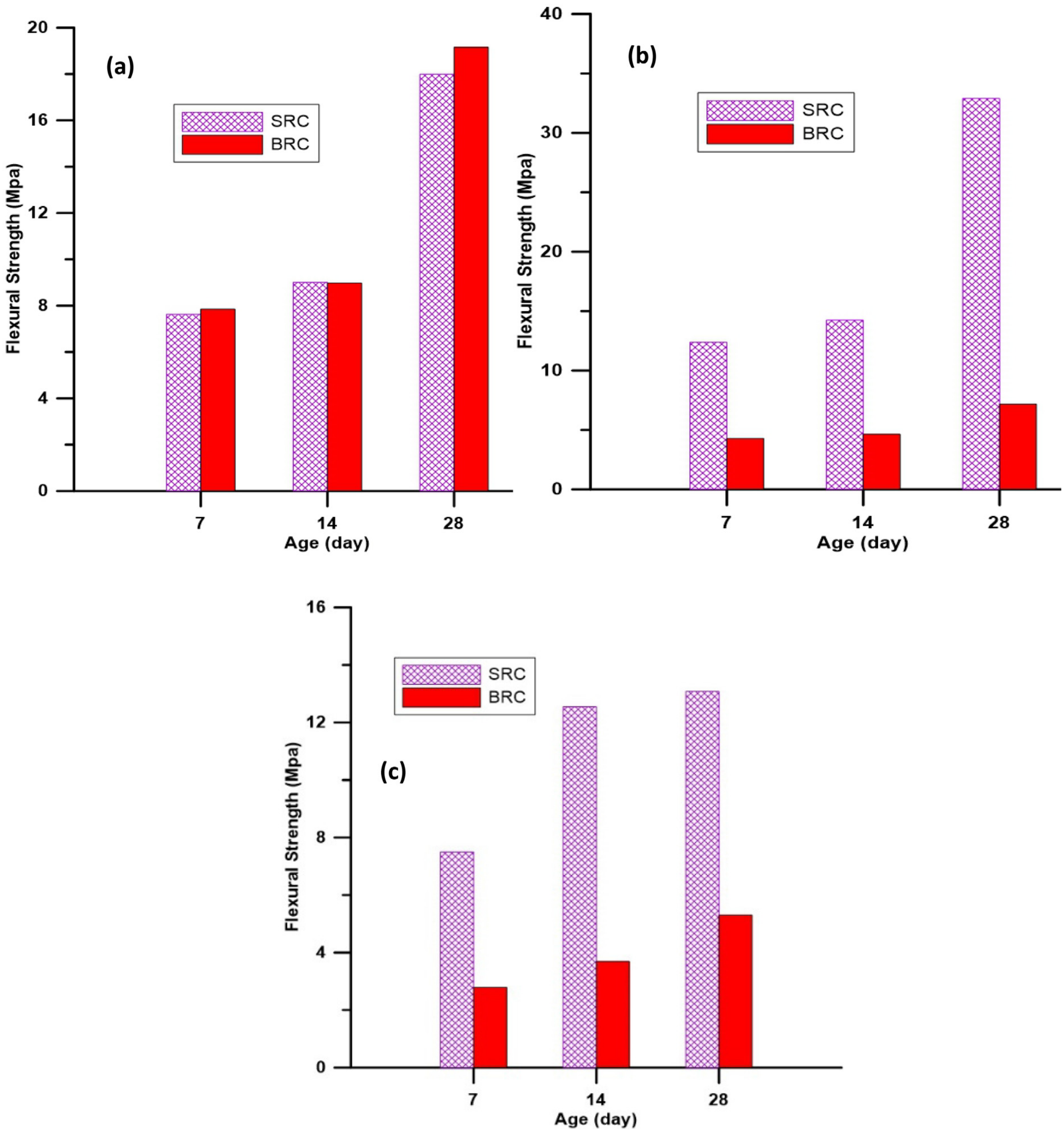

Fig. 7. Flexural strength development over 28 days (a) Reference (Mc) (b) Mix 1 (M1) (c) Mix 2 (M2).

of 6.5%) than the SRC. The implication of this was that there exist a perfect gripping between the concrete matrix and the bamboo strip. Thus, the resistance of concrete further complemented the appreciable tensile strength of bamboo strip. The corresponding load–deflection curve for this sample also corroborated the behaviour (Fig. 8a). In a parallel study, Agarwal et al. (2014) concluded that bamboo could be used as replacement for steel reinforcement in concrete member. Failure mode of typical Mc beam is shown in Fig. 9a, which highlighted a progressive crack pattern in the samples and it was a form of diagonal tension failure. The beams

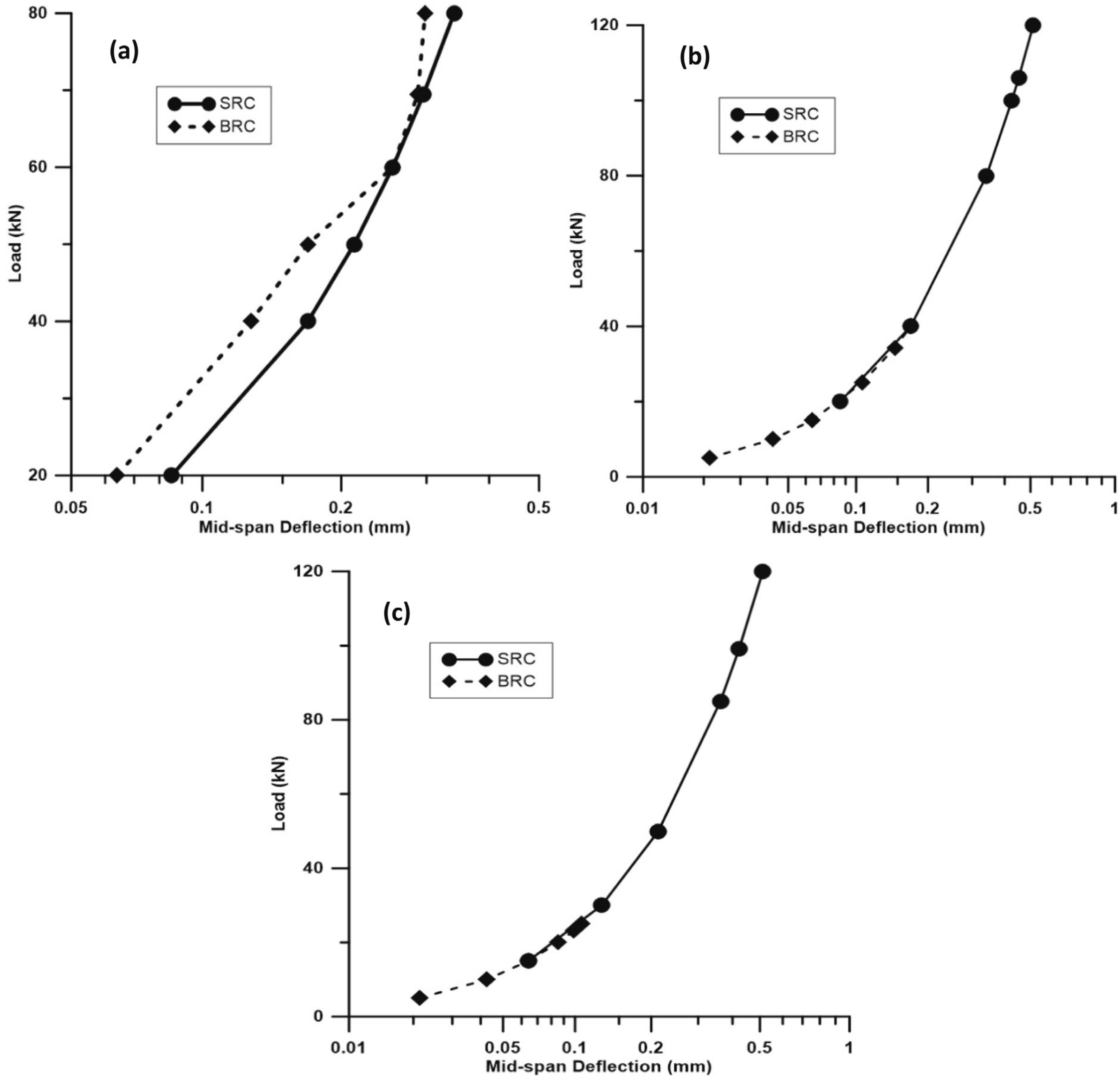

Fig. 8. Load-deflection behaviour after 28 days curing (a) Reference (Mc) (b) Mix 1 (M1) (c) Mix 2 (M2).

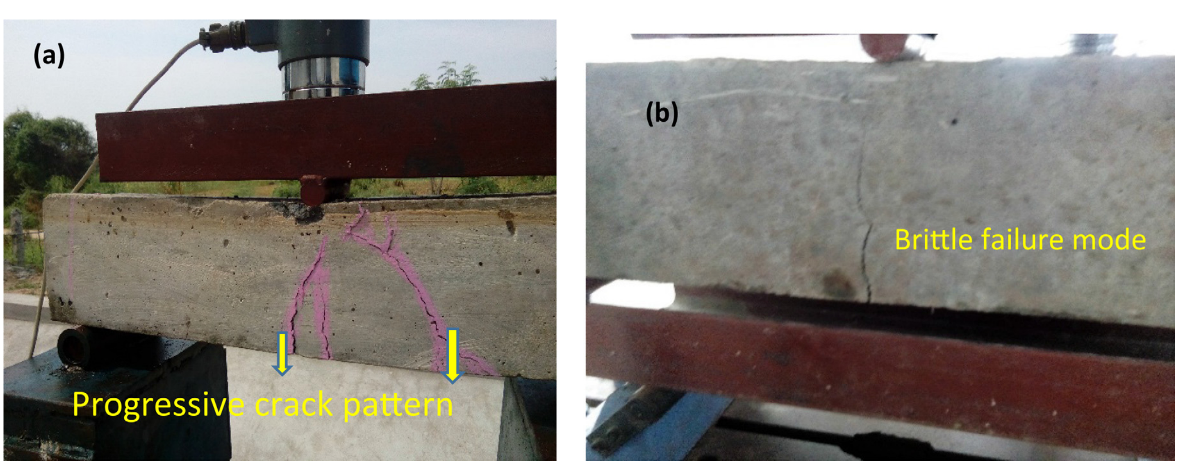

Fig. 9. Typical crack pattern failure mode (a) Mc beam (b) BRC beam.

appeared to have failed at their middle-third; that is, they experienced pure bending condition under loading.

Conversely, in other mixes (M1 and M2), there was a poor performance by BRC relative to the SRC beams. As shown in Figs. 7b, c, 8b,c SRC gained over 50% flexural strength than BRC at all the curing ages. This poor result was not a function of the ductility of bamboo, however, it can be suggested that there was poor bonding between bamboo and the concrete matrix. A brittle-like mode of failure (Fig. 9b) was observed in the M1 and M2 BRC. In addition, M1 and M2 SRC developed high flexural load resistance (as shown in Fig. 9a and b respectively). As can be seen in Fig. 7c, the best performance under flexural loading was recorded with M1 (SRC). This appreciable behaviour highlighted the valuable influence of fly ash, GGBS and m-sand. Hence, it can be recommended for construction of structural elements requiring high bending resistance.

4. Conclusion

This study focused on the strength properties of bamboo and steel reinforced concrete containing manufactured sand and mineral admixtures. The following conclusions were drawn from the investigation:

1. From the morphological (FTIR and SEM) characteristics of bamboo dust examined, it was deduced that bamboo is a ductile reinforcing material having some appreciable tensile strength, which makes it suitable as a substitute for steel. Due to its strongly bonded particles, bamboo can be an excellent material for members subjected to compression and bending.
2. Partial replacement of cement with fly ash and GGBS in concrete containing wholly m-sand as fine aggregate yielded a promising compressive strength. Although, their values are low relative to the reference concrete, but it can form a good material for some structural applications. Yet the materials are better than the reference concrete in terms of split tensile strength.
3. Under flexural loading, performance of BRC made with alternative materials (fly ash, GGBS, and m-sand) was significantly low compared to BRC with reference materials. Perhaps a poor bonding of bamboo with concrete with alternative material can be a factor, because bamboo on its own has good strength and ductility. In addition, BRC made with reference materials yielded more flexural strength than the SRC, thus representing 6.5% strength gain.

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