CHEMICAL ENGINEERING TRANSACTIONS

VOL. 61, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Petar S Varbanov, Rongxin Su, Hon Loong Lam, Xia Liu, Jiří J Klemeš

ISBN 978-88-95608-51-8; **ISSN** 2283-9216

DOI: 10.3303/CET1761311

Microstructure and Mechanical Properties of Green Concrete Composites Containing Coir Fibre

Ezekiel B. Ogunbode[a,*], Ernest I. Egba[b], Olusegun A. Olaiju[c], Abbas S. Elnafaty[d], Sarkile A. Kawuwa[e]

[a]Department of Building, Federal University of Technology. Minna. Niger State. Nigeria.
[b]Department of Technology and Vocational Education, Ebonyi State University, Abakaliki. Ebonyi State. Nigeria.
[c]Department of Mathematics and Statistics, Federal Polytechnic Ilaro. Ogun State. Nigeria.
[d]Department of Architecture, Faculty of Built Environment. Universiti Teknologi Malaysia, Johor Bahru, Malaysia.
[f]Department of Architecture, Abubakar Tafawa Balewa University, Bauchi, Nigeria.
ezekiel@futminna.edu.ng

Green concrete ensuing from different bio fibre exploration for a cleaner environment is one of the pressing issues for concrete engineers and scientists in the 21st century. Usage of bio fibres in green concrete production has drawn appreciable interest due to its friendliness and reduction of carbon dioxide emission to the environment, improvement of air quality and low-cost compared to synthetic and steel fibres. The concrete properties are being enhanced with the inclusion of the bio fibres. In this paper, the physical, microstructural and mechanical properties of the green concrete composite, which contains coir fibre as a reinforcing agent were studied. Properties studied include slump and VeBe time of fresh concrete as well as quasi-static strength, impact resistance and microstructure of hardened concrete. Six volume fractions of 0 to 3 % were used with Ordinary Portland Cement. It was observed that the inclusion of coir fibre in the concrete decreases the slump factor and increases the VeBe time of the fresh Coir bio fibrous concrete composite. The influences of coir fibre on the microstructure and mechanical behaviour of the concrete was observed to be more significant at a volume fraction of 1 %. The findings of the study demonstrated that there is a promising future for the use of coir fibres as a fibrous material in the production of sustainable green and durable concrete both technically and environmentally.

1. Introduction

The efficient management of the production and utilization of bio fibre for a cleaner and sustainable environment is receiving more attention by government, concrete engineers, material scientists (Mohd et al., 2014) and researchers in the construction industry (Stevulova et al., 2013). This is because of its renewability, low environmental impact, high specific strength, low cost and low density beneficial values compared to synthetic fibres (Ochi, 2008). The use of bio fibre in construction sprout up in a bid to lessen the reliance of sourcing construction materials from petroleum based products due to their environmental consequence. A pressing need to explore environmentally friendly, sustainable and renewable resource materials to replace materials sourced from global warming contributors such as mineral resources or fossil (petrochemical) is highly required to attain safer and cleaner environment (Stevulova et al., 2016). The transition towards a bio-based economy and sustainable developments as a consequence of the Kyoto protocols on greenhouse gas reduction and CO_2 neutral production, offers high perspectives for natural fibre markets. The revival and increasing interest of bio fibre in the construction industry is due to its potential in replacing synthetic fibre and metallic fibre in fibrous concrete composite production at low cost with enhanced properties (Cigasova et al., 2013). The inclusion of bio fibre in concrete has been one of the fundamental ways of enhancing the low tensile strength and large brittleness negative properties of concrete as well as contributes to reduction of greenhouse gases and CO_2 in the atmosphere (Pickering et al., 2016).
The behaviour of structures exposed to static or and dynamic loadings is mostly associated to stress distribution, cracking, bending, creep and surface micro cracking mostly in Jetty structures, bridge structures, concrete silos,

Please cite this article as: Ogunbode E.B., Egba E.I., Olaiju O.A., Elnafaty A.S., Kawuwa S.A., 2017, Microstructure and mechanical properties of green concrete composites containing coir fibre, Chemical Engineering Transactions, 61, 1879-1884 DOI:10.3303/CET1761311

concrete dams, concrete tower, plants, and sometimes in other applications. A great deal of attempt has been made and various practices have been used to manage the stress effect on the low tensile and large brittleness negative properties of concrete as well as to evaluate the ductility performance of concrete structures. Guo et al. (2014) stated that to enhance concrete low tensile and large brittleness, fibrous materials can be added into the concrete mixture. The purpose of such addition is to enhance its toughness, tensile and flexural strengths, resistance against impact loads and other mechanical properties. The availability and common waste product features of bio fibre gives it an advantage over other fibres. The addition of bio fibre materials has been recommended by Ogunbode et al. (2016) for the possible static properties and Ali et al. (2012) for dynamic properties of concrete enhancement. However, there lies a need to investigate the impact resistant performance of bio fibrous concrete made with coir fibre under dynamic loading. Coir fibre is a type of bio fibre. There is still a dearth of information in literature on the impact response behaviour of coir bio fibrous concrete composite. It is required to understand the impact resistant performance of coir bio fibrous concrete under dynamic loading. Of concern is the impact resistance behaviour of coir bio fibrous concrete exposed to tensile loading. Therefore, this paper presents the analysis of the mechanical and microstructure properties of coir bio fibrous concrete composite.

2. Materials and experimental study

2.1 Materials

Type I Ordinary Portland cement (OPC) that complies with the recommendations of ASTM C 150-07 was used. The coir fibre shown in Figure 1(a) that was collected from local sources in Malaysia was used. It was subsequently treated using 6 % sodium hydroxide concentration and soaked for 5 h before washing thoroughly in clean distilled water to remove all remnant of alkali on the fibre surface. The treated fibres were uncurled by hand and combed with a steel comb before cutting to the required two different lengths of 20 mm and 40 mm. The average diameter of the coir fibre used in this experiment is 0.25 mm. The coir fibre general properties and the micrograph of the fibre morphology is displayed in Table 1 and Figure 1(b). A saturated surface dry fine aggregate obtained from the river, passing through a 4.75 mm sieve, with 1.3 % water absorption, specific gravity of 2.68 and fineness modulus of 2.42 was used. While a crushed granite of maximum size of 10 mm with a specific gravity of 2.83 and water absorption of 1.5 % was used as the coarse aggregate in this study. Both mixing and curing was done with supplied tap water. In order to improve the workability and obtain fibrous concrete mixture of good strength, 1.0 % by weight of cement of RHEOBUILD 1100 brand of polymer-based superplasticizer was applied to the concrete mix.

Table 1: Properties of coir fibre

Item	Value	Unit
Length	20 and 40	mm
Diameter	0.25	mm
Density	1,120	kg/m^3
Tensile Strength	178	MPa
Tensile modulus	22.6	GPa
Reaction with water	Hydrophilic	-

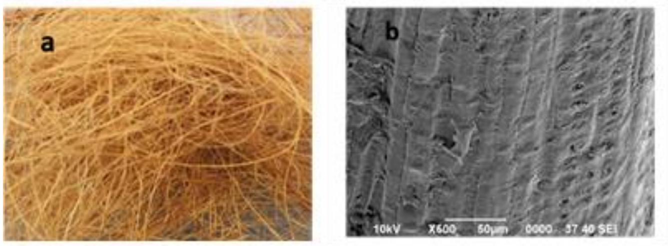


Figure 1: (a) Coir fibre (b) Micrograph of the coir fibre

2.2 Mix design

The concrete composite tested in this experiment were made from seven mixes in two series of 20 mm and 40 mm fibre length (L_f). The water cement (w/c) ratio of 0.51 was kept constant in all mixture. Each series contained coir fibre volume fraction (V_f) varying from 0 % to 3 % at an interval of 0.5 %. The mix design details are illustrated in Table 2.

Table 2: Mix design of coir bio fibrous concrete

Mix ID	Cement (kg/m^3)	Water (kg/m^3)	Fine agg. (kg/m^3)	Coarse agg. (kg/m^3)	V_f (%)	V_f (kg/m^3)	L_f (mm)	Slump (mm)	VeBe (Sec)
A	461	240	739	898	0	0	0	190	3.3
B1	461	240	739	898	0.5	5.6	20	120	5.8
B2	461	240	739	898	1.0	11.2	20	80	10.6
B3	461	240	739	898	1.5	16.8	20	65	16.4
B4	461	240	739	898	2.0	22.4	20	50	24.5
B5	461	240	739	898	2.5	28.0	20	30	39.0
B6	461	240	739	898	3.0	33.6	20	15	52.2
C1	461	240	739	898	0.5	5.6	40	105	8.3
C2	461	240	739	898	1.0	11.2	40	75	14.7
C3	461	240	739	898	1.5	16.8	40	60	19.1
C4	461	240	739	898	2.0	22.4	40	45	26.2
C5	461	240	739	898	2.5	28.0	40	20	44.1
C6	461	240	739	898	3.0	33.6	40	10	58.6

agg. = aggregate

2.3 Specimen preparation and test methods

Grade 30 concrete was prepared and used for the test. The fresh state properties were investigated by using the slump and VeBe tests in consonance to the requirement of BS EN 12350-2:2009 and BS EN 12350-3:2009 respectively. All the mix concrete types were tested for compression (BS EN 12390, 2009), tension (ASTM C496 / C496, 2011) and flexure (ASTM C293 / C293M, 2016) using a 100 mm cube specimens, 100 Ø x 200 mm cylinder specimen and 100 mm x 100 mm x 500 mm prism specimen.

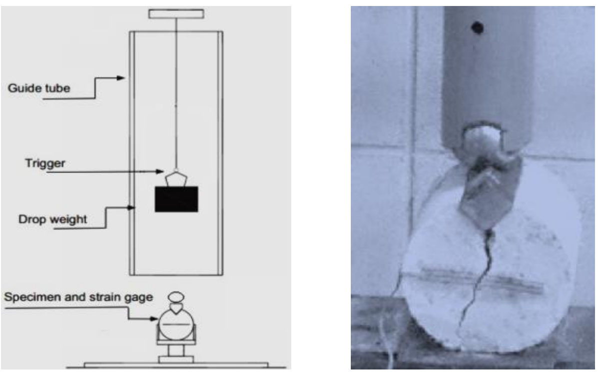
The Impact resistance under tensile loading test on concrete was performed based on the works of (Xua et al., 2012) with some modification on the setup. This was done to determine the potential energy of the coir fibrous concrete. The experimental set up is illustrated in Figure 2(a). The cylindrical specimen was placed on the testing machine plate as shown in Figure 2(b). The formulae for calculating impact energy at initial crack (I_{pe-dwi}) and impact energy at ultimate crack (I_{pe-dwu}) are shown in Eq(1) and Eq(2).

$$I_{pe-dwi} = n_1 mgh \quad (1)$$

$$I_{pe-dwu} = n_2 mgh \quad (2)$$

Where the first subscript pe symbolises potential energy, which is the type of energy absorbed during the test and the second subscript dwi and dwu signifies the drop weight test type at initial crack and at ultimate failure, respectively. n_1 and n_2 are the number of blows at initial and ultimate crack level, m is the mass of drop hammer (1.3 kg), g is acceleration due to gravity (9.81 m/s^2) and h is the releasing height of drop hammer (1,000 mm).

The morphology of the fibrous concrete specimens was examined at room temperature using the SEM.



(a) (b)

Figure 2: Operational procedure for impact resistance of coir bio fibrous concrete under tensile loading: (a) Drop weight impact test set up (b) Drop weight splitting setup

3. Result and discussion

3.1 Analysis of workability

The results from the slump and VeBe time tests of concrete mixtures are presented in Table 2. It was observed that increasing the coir fibre volume fraction led to decrease in the values of slump of the tested concrete. The plain concrete which serve as the control mix exhibited the highest slump value of 190 mm. The mixture comprising of 40 mm coir fibre at 3 % fibre content, recorded the least slump value of 10 mm. Furthermore, it was seen that the VeBe time increased linearly as the coir fibre volume fraction ratio increased. This is to note that the inclusion of longer length of 40 mm coir fibre against the 20 mm reduced the slump values of concrete mixes. An increment in fibre volume fraction ratio also had a similar effect on the slump of the fibrous concrete as illustrated in Table 2. Uday and Jitha (2017) opined that the usage of bio fibre in concrete mixture makes it to be stiffer with a lower workability due to the fibres hydrophilic property. The experimental results on the fresh concrete are also similar to those described by (Ali et al., 2012).

3.2 Quasi-static strength test

Table 3 presents the cube compressive, tensile and flexural strength of concrete specimens measured in the experiment. The results show that the cube compressive strength of the concrete decreased with increasing fibre content; however, this reduction is not significant and the strength values are in the range of structural applications. It was also observed that the fibrous concrete had a decrease in strength by 4 %, 11.10 %, 21.29 %, 27.96 %, 35.82 % and 44.99 % compared to the plain concrete 28 d curing age, with fibre content of 0.5 %, 1 %, 1.5 %, 2 %, 2.5 % and 3 %, respectively. The tensile strengths of concrete specimens containing 40 mm long coir fibres were significantly higher compared to the specimens containing 20 mm long coir fibres. When the splitting occurred and was sustained, the coir fibres bridging the split parts of the specimens acted over the stress transfer from the matrix to the fibres, and gradually supported the full tensile stress. The transferred stress enhanced the tensile strain capacity of the concrete matrix and, thus, improved the tensile strength of the fibrous mixtures over the non-fibrous concrete mixture counterpart. Inclusion of 40 mm long fibre increases splitting tensile strength of mixes at the age of 28 d by 1.19 %, 6.87 %, 3.28 %, and decreases by 1.79 %, 9.85 % and 13.73 % compared to that of fibre less concrete for the coir fibre contents of 0.5 %, 1 %, 1.5 %, 2 %, 2.5 % and 3 %. The result obtained in this study corroborates the research findings by (Ali et al., 2012) and more recently Uday and Jitha, 2017). The flexural strengths of the tested plain and fibrous concrete prism was measured under four point flexural loading system and recorded. The outcome of the experiment show a similar trend as of the tensile strength. It was observed that the flexural strength value riched its optimum at 1% fibre content before its started to decline for both 20 mm and 40 mm fibre length, as presented in Table 3. For instance, 40 mm long coir fibre reinforcement of the plain concrete by 0.5 %, 1 %, 1.5 %, 2 %, 2.5 % and 3 %, led to 2.84 %, 18.78 %, 7.21 %, 4.59 %, 1.31 % and 4.37 % increase in the flexural strength of specimens compared to that of the control mix respectively at the age of 28 d curing. The curing age was also seen to influence the flexural strength of both the plain and fibrous concrete. Conversely, the fibrous concrete specimens, even at small fibre volume fraction were seen to retain post cracking ability to carry loads. Few short and narrow cracks were seen on almost all the coir fibrous concrete specimens tested in flexure. Constraining the growth of cracks in concrete is one of the major objectives of fibrous concrete technology, the concrete low tensile strength is the cause of concrete weakness.

Table 3: Concrete strength test result

Mix id	Compressive strength (MPa)		Splitting tensile strength (MPa)		Flexural strength (MPa)	
	7 d	28 d	7 d	28 d	7 d	28 d
A	29.78	35.23	3.03	3.35	3.97	4.58
B1	26.36	33.04	2.98	3.31	4.02	4.66
B2	25.38	30.34	3.07	3.32	4.19	4.93
B3	24.85	27.38	2.86	3.02	3.38	4.78
B4	22.77	24.87	2.66	2.97	3.03	4.42
B5	18.54	20.32	2.58	2.72	2.75	4.13
B6	16.82	19.19	2.34	2.61	2.47	3.96
C1	30.46	33.82	3.18	3.39	4.13	4.71
C2	28.47	31.32	3.27	3.58	4.41	5.44
C3	26.91	27.73	3.14	3.46	4.26	4.91
C4	23.73	25.38	2.96	3.29	4.05	4.79
C5	20.36	22.61	2.78	3.02	3.76	4.52
C6	17.57	19.38	2.53	2.89	3.44	4.38

3.3 Impact resistance test

Analysis of Table 4 shows that the addition of coir fibres into the concrete mixtures increases the number of blow required for the first crack deformation to occur to about 115 % and 118 % for 20 mm length and 40 mm length fibre, respectively. The inclusion of coir fibre also raised the percentage in the number of crack blows to ultimate failure (n_2-n_1/n_1) value over the tested plain concrete specimens. This signifies that the coir fibre considerably enhanced the ductility of the fibrous concrete. The impact energy for the initial crack and ultimate failure of concrete mixtures containing coir fibres are also presented in Table 4. It can be seen that, as coir fibre was added into the concrete mixtures, a significant rise in the number of blows to attain the first initial crack and the ultimate failure as compared to plain concrete control specimens was found. The concrete mix containing 1 %, 40 mm long coir fibre demonstrated the highest impact energy of 624.90 and 3,392.30 J (kN mm) for first crack and ultimate failure. A similar behaviour was observed in the concrete mix with 1 %, 20 mm long coir fibre. The impact energy was lesser compared to the 1 %, 40 mm long coir fibre concrete mixtures. The impact energy outcome reported by Mohammadhosseini et al. (2017) are somewhat similar, though the test was conducted using synthetic fibre. Synthetic fibre is known to possess similar low modulus characteristic like the bio fibre in which coir fibre belongs.

Table 4: Tensile drop weight impact test result

Mix id	Impact resistance (blows)			Impact Energy (J)		
	First crack (n1) Drop number	Ultimate failure (n2) Drop number	n2-n1	First crack (n1) Absorption Energy	Impact Energy (J) Absorption Energy	[(n2-n1)/(n1)]100
A	14	14	0	178.54	178.54	0.00
B1	20	76	56	255.06	969.23	280.00
B2	43	201	158	548.38	2,563.35	367.45
B3	10	41	31	127.53	522.87	310.00
B4	13	59	46	165.79	752.43	353.85
B5	13	43	30	165.79	548.38	230.77
B6	9	37	28	114.78	471.86	311.11
C1	26	92	66	331.58	1,173.28	253.85
C2	49	266	217	624.90	3,392.30	442.86
C3	12	48	36	153.04	612.14	300.00
C4	14	14	0	204.05	803.44	293.75
C5	20	76	56	165.79	663.16	300.00
C6	43	201	158	140.28	548.38	290.91

3.4 Microstructure test

SEM images were used to reach a deep understanding of the impact resistance and failure mechanisms of fibre-cement matrix. As the desired bonding was formed between the coir fibres and cementing materials, cement hydrated products covered the surface of the fibres as illustrated in Figure 3. Figure 3 reveals the microstructure of fibre surface and hydrated cement matrix after the fracture of concrete specimen. The contact point between C-S-H gels and the fibres increased, which ultimately provided strengthening and crack resistance effect of fibres in the cementitious matrix. The surface of the coir fibre is covered with densely hydrated cement matrix. Similar observations have been made by (Mohammadhosseini et al., 2017).

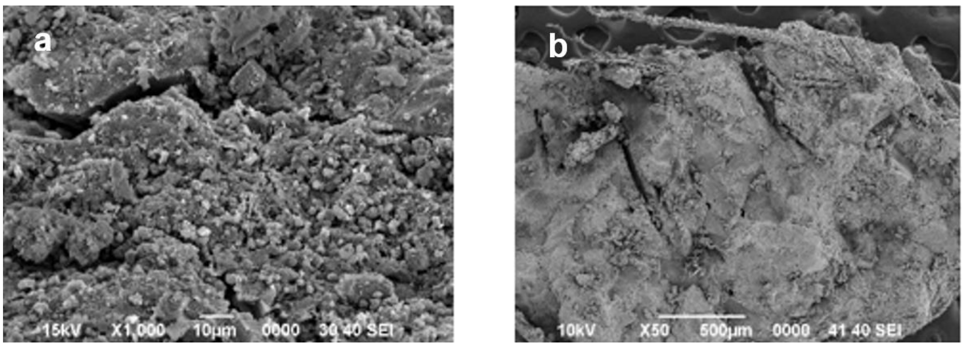


Figure 3: SEM micrographs of the bonding interface between coir fibres and matrix after impact resistance: (a) Plain concrete (b) Coir fibrous concrete

4. Conclusions

The current paper investigated the microstructure and mechanical properties of sustainable green concrete composites containing coir fibres and subjected to static and dynamic loading. Based on the experimental results and observations made, the following conclusions could be deduced; the workability of concrete was largely affected by the inclusion of coir fibres. Increasing fibre length and volume fraction led to a decrease of slump values and increase of VeBe time. The concrete specimens containing coir fibres exhibited better performance in terms of ductility due to the bridging action of the fibres than that of plain concrete. Despite lower improvements in compressive strength, appreciable enhancements were noticed in the tensile and flexural strength values. The addition of coir fibres leads to improved impact resistance and energy absorption capacity of the fibrous concrete. The first crack and ultimate failure impact resistance of concrete with 40 mm length coir fibre increased considerably. The results obtained and the observation made in this study propose that concrete incorporating coir fibres can be used with satisfactory engineering properties in the construction of building road pavements, bridge decks, slabs and other similar applications. However, large-scale application of coir fibre together with its performance behaviour in reinforced concrete members is recommended for future investigation.

Acknowledgments

The authors wish to thank Universiti Teknologi Malaysia for providing the much needed facility for this research. The technical support received from the staff attached to the Structure and Materials laboratory of Universiti Teknologi Malaysia (UTM) is also appreciated and acknowledged.

References

Ali M., Liu A., Sou H., Chouw N., 2012. Mechanical and dynamic properties of coconut fibre reinforced concrete, Construction and Building Materials, 30, 814–825.

ASTM C496 / 496M, 2011. Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens, West Conshohocken, PA, USA.

ASTM C293 / C293M, 2016. Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading), West Conshohocken, PA, USA.

BS EN 12390-3, 2009. Testing hardened concrete. Compressive strength of test specimens, London, UK, ISBN: 978-0-580 -76658-9.

Cigasova, J., Stevulova, N., Sicakova, A., Junak, J., 2013. Some Aspects of Lightweight Composites Durability. Chemical Engineering Transacions, 32, 1615–1620.

Guo Y., Zhang J., Chen G., Xie Z., 2014. Compressive behaviour of concrete structures incorporating recycled concrete aggregates, rubber crumb and reinforced with steel fibre, subjected to elevated temperatures, Journal of Cleaner Production, 72, 193–203.

Mohammadhosseini H., Abdul Awal A.S.M., Mohd Y.J., 2017. The impact resistance and mechanical properties of concrete reinforced with waste polypropylene carpet fibres, Construction and Building Materials, 143, 147–157.

Mohd H.A.B., Arifin A., Nasima J., Hazandy A.H., Khalil A., 2014. Journey of kenaf in Malaysia: A Review, Scientific Research Essays, 9, 458–470.

Ochi S., 2008. Mechanical properties of kenaf fibers and kenaf/PLA composites, Mechanics of Materials, 40 (4-5), 446-452.

Ogunbode E.B., Jamaludin M.Y., Ishak M.Y., Meisam R., Masoud R., Norazura M.A., 2016. Preliminary Investigation of Kenaf Bio Fibrous Concrete Composites., 2nd Int. Conference on Science, Engineering Social Science. UTM, Johor Bahru, Malaysia, 248–249.

Pickering K.L., Aruan Efendy M.G., Le T.M., 2016. A review of recent developments in natural fibre composites and their mechanical performance, Composite Part A: Applied Science and Manufacturing, 83, 98–112.

Stevulova N., Schwarzova I., Hospodarova V., Junak J., 2016. Implementation of Waste Cellulosic Fibres into Building Materials, Chemical Engineering Transactions, 50, 367–372.

Uday V. S., Jitha B.A., 2017. Concrete Reinforced with Coconut Fibres, International Journal of Engineering Science and Computing, 7, 10436–10439.

Xua Z., Hao H., Li H.N., 2012. Dynamic tensile behaviour of fibre reinforced concrete with spiral fibres, Materials and Design, 42, 72–88.