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RESEARCH ARTICLE

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Performance of Bamboo Fibre on Modifying Mechanical Properties of Concrete

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Abstract:

Introduction: Towards Go-green's concept, the use of natural fibres in the construction industry has received substantial attention from many engineering fields. Literature shows that the waste has been used as a replacement or addition material in the concrete mixture for producing lightweight concrete and improving the mechanical properties of the concrete. This innovation is one of the alternative solutions in converting waste into valuable, sustainable materials and consequently reducing the abundance of the waste that may permit environmental pollution.

Aims: This study aims to investigate the mechanical properties of concrete with the addition of bamboo fibre (BF) from species type *Bambusa Vulgaris*, specifically focusing on the compressive and tensile strength of concrete. The chosen bamboo fibre is adopted because it is largely found in Peninsular Malaysia and has a high tensile strength, as suggested by previous researchers.

Methods: To achieve this, three percentages of the BF, *i.e.*, 0.5%, 1%, and 1.25%, were added to concrete grade M20. The plain concrete *i.e.*, 0% BF, was prepared as a control sample. The performance of BF on modifying the mechanical properties of concrete for both fresh (*i.e.*, slump test) and hardened (*i.e.*, compression and split tensile tests) states were examined after 7 to 28 days of the curing process.

Results: The findings indicate the effectiveness of BF in improving the mechanical properties of the concrete grade M20. It is noted that the concrete samples with the addition of 0.5% BF is considered as the optimum percentage because it able to increase the compressive and tensile strength of concrete grade M20.

Conclusion: This study provides significant information on the ability of BF as a concrete strength enhancer which subsequently converts the abundance of unwanted agriculture by converting the waste to new green and sustainable concrete material.

Keywords: Bamboo Fibre, Mechanical Properties, Concrete, Strength Enchanter, Fire Resistance, Low Construction Cost.

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1. INTRODUCTION

Concrete is widely used as a main construction material as it provides high compressive strength, good fire resistance, and low construction cost. Concrete is a composite material made from fine and coarse aggregate bonded along with a liquid cement paste that cures the concrete to harden completely. However, concrete has moderately low tensile strength, limited ductility, and low resistance to cracking. Usually, the microcrack of structural components, especially in plain reinforced concrete, will develop even before loading, particularly due to drying, shrinkage or other volume changes [1].

Most commonly, steel reinforcement is used to provide a high tensile strength in concrete structural components, *e.g*., beams, columns, slabs and foundations. This composite structure is widely known as a reinforced concrete structure. The reinforcement is installed as a strengthening material and aids in improving the elasticity of concrete, which subsequently limits the cracking of the concrete or the risk of structural failure. However, there are some disadvantages of steel material whereby this material is vulnerable to corrosion risk, non-renewable and relatively expensive, which causes an increment in the total construction cost.

Recently, many studies investigated the use of natural fibres in enhancing the strength of the concrete either as a replacement or addition material in a concrete mixture [2-5]. Natural fibres are a sustainable materials that can be found easily, renewable and relatively cheaper than synthetic fibre *e.g*., steel, carbon, and glass fibres. In most studies, fibre is added to a cement matrix in an orderly or randomly distributed manner. Concrete strength with the replacement or addition of natural fibre can be improved depending upon the efficiency of the concrete mixture and fibres in transferring the induced stresses. This largely depends on the type, percentage of replacement or additional, geometry, content, and distribution of the fibres in concrete. Besides, the mixing and compaction techniques of concrete, size, and shape of the aggregate also play an important role in improving the mechanical properties of the concrete [1-3].

Numerous studies showed that natural fibres such as pineapple leaf, coconut, kenaf, and bamboo fibre have successfully improved the tensile strength and energy absorption of concrete [2, 6-9]. For instance, studies conducted by Ali *et al*. [9], Fuqua *et al*. [10], Ahmad *et al*. [11] and Aziz *et al*. [12] reported that the natural fibres not only enhanced the tensile strength of concrete but have successfully bridging the crack of the concrete. In addition, numerous researchers proved that bamboo as an alternative to steel as a reinforcement in providing high tensile strength and bond strength [6, 13-22]. Meanwhile, bamboo Fibres (BF) have recorded remarkable achievements as reinforcing materials in various applications, such as concrete [23-28], mortars [29-30], asphalt [31, 32], and recycled plastic composites [33-35]. Most of the studies reported similar agreement that the addition of BF has significantly improved the mechanical properties (*i.e*., tensile, compressive, and flexural strength) and cracking resistance of the hybrid composites. The literature concludes that the maximum strength of bamboo-reinforced composites can be achieved after 28 days of curing with varying optimum addition percentages of BF, which range from 0.5% to 1.5% by weight of cement [23-28,30-35].

Surprisingly, Marcus Maier *et al*. [29] observed an insignificant adverse effect on the addition of BF when utilized in a mortar mixture. They highlighted that the reinforced mortar specimens experienced slight losses of compressive strength. However, they stressed that the addition of BF was able to improve crack-bridging effects and control crack propagation.

The advantages of the use of BF are extended in the research conducted by Tonmoy Kumar Brahmachary and Md. Rokonuzzaman [36] and Siswanto, *et al*. [37], whereby the BF is added in weak soil, improve the mechanical properties of the concrete. They concluded that the soil mechanical properties increase proportionally to the increment in length and diameter of BF. It was also found that increasing the percentage of BF increases the CBR value of reinforced soil, and this increment is significant at fibre dosage of 1.2%.

To highlight the inherent benefit of natural fibres, in this present study, the mechanical properties of concrete with the addition of BF were investigated. Three percentages of the BF, *i.e*., 0.5%, 1%, and 1.25% [25-27] were added in concrete grade M20. The results are reported for both fresh (*i.e*., slump test) and hardened (*i.e*., compression and split tensile load tests) states of concrete. The mechanical properties of the concrete with and without the addition of BF were tested after 7 to 28 days of the curing process. The outcome of this study may provide essential information on the utilization of BF as a new sustainable construction material in the industry. Consequently, the finding also offers an alternative solution to convert the abundance of bamboo to wealth.

2. MATERIALS AND METHOD

The material and experimental setup in this study is divided into subheadings *i.e*., preparation of bamboo fibre, preparation of concrete mix design for M20, preparation of compression load test, and preparation for the tensile load test. Each subheading provides a detailed and concise description of the types of materials used and experimental works conducted in this study.

2.1. Preparation of Bamboo Fibre

Bamboo waste used in this study is from the species of *Bambusa Vulgaris* because it is largely found in Peninsular Malaysia and has a high tensile strength, as suggested by previous researchers [5, 13, 21-23]. The fibres (coarse and short) were extracted from the untreated (*i.e*., no preservation treatment during post-harvest) bamboo culms waste using the manual handling method, *i.e*., using a hammer (Fig. **1**). The fiber was left dried under sunlight for 24 hours to remove any substances before cut into ± 10 mm length (*l*) with diameter (*d*) in range of 0.25 mm and aspect ratio (*l/d*) of 40 [18,19,21-27] the untreated BF, *i.e*., 0.5%, 1%, and 1.25% was added in concrete mixture grade M20 based on weight calculation method as recommended by Kavitha S. and T. Felix Kala [25-27].

(a) (b) (c)

Fig. (1). Preparation of Bamboo Fibres (**a**) Bamboo culm; (**b**) Bamboo fibres extracted manually using hand-hammer; (**c**) Bamboo fibres left dry for a few days.

2.2. Preparation of Samples for Concrete Mixture M20

A concrete grade M20 was designed in accordance with standard BS 5328: Part 2: 1997 [38]. Table **1** shows the standard mix ST5 chosen in this study for the calculation of the concrete design mix of cube and cylinder samples. In the standard, the concrete mix design is presented as the total weight of cement, fine and coarse aggregate for 1 m^3 volume of sample. The cube sample with the dimension of 0.15×0.15×0.15 m^3 was prepared for the compression test, meanwhile, the cylinder sample with a dimension of π×0.075×0.3 m^3 was used for the tensile split test. The Ordinary Portland Cement (OPC), with the maximum size of fine and coarse aggregate limited to 5 mm and 20 mm, respectively, was used in compliance with the Malaysian Standard (MS) MS 522: Part 1:2003 [39].

Table **2** shows the concrete mix percentage for the cube and cylinder samples used in the laboratory test, which contains the weights of water, BF, coarse aggregate, and fine aggregate. The concrete samples were made using three BF addition percentages, *i.e*., 0.5%, 1.0%, and 1.25%, in accordance with other studies conducted by [3, 6-9]. For validation reasons, samples with 0% BFW were generated as a reference or control sample.

A total of 36 samples (Fig. **2**) were tested in two concrete states, *i.e*., fresh and hardened concrete. The slump test was measured in the fresh concrete state to determine the workability of the mixture. Further, in the hardened concrete state, the compression and tensile split tests were conducted to determine the mechanical properties of the concrete. The results of each laboratory test were recorded based on the average of three samples prepared with the addition of BF, as summarised in Table **3**.

2.3. Preparation of Laboratory Testing

The effect of BF on concrete was investigated by performing the mechanical properties of the concrete in fresh and hardened states. The slump test was conducted according to BS EN 12390 Part 2 [40] to determine the workability of the concrete mixture of fresh concrete samples. In contrast, following the BS EN 12390 Part 3 [41] and Part 6 [42], two laboratory tests were conducted, *i.e*., compressive test and split tensile test for the hardened state of concrete. Fig. (**3**) shows the compression machine used to conduct testing on the samples of hardened concrete (Table **3**).

Table 1. The concrete mix proportion according to BS 5328 - part 2:1997 [38].

Standard Mix	Characteristic Compressive Strength at 28 Days (N/mm^2)	Constituents (Cement and Total Aggregate) (kg)	Maximum Size of Aggregate			
			40 mm		20 mm	
			Workability			
			Medium	High	Medium	High
ST1	7.5	Cement	180	200	210	230
		Aggregate	2010	1950	1940	1880
ST2	10	Cement	210	230	240	260
		Aggregate	1980	1920	1920	1860
ST3	15	Cement	240	260	270	300
		Aggregate	1950	1900	1890	1820

(Table 1) contd.....

Standard Mix	Characteristic Compressive Strength at 28 Days (N/mm^2)	Constituents (Cement and Total Aggregate) (kg)	Maximum Size of Aggregate			
			40 mm		20 mm	
			Workability			
			Medium	High	Medium	High
ST4	20	Cement	280	300	300	330
		Aggregate	1920	1860	1860	1800
ST5	25	Cement	320	340	340	370
		Aggregate	1890	1830	1830	1770
Workability – Slump (mm)			50 - 100	80 - 170	25 - 75	65 - 135

Table 2. Concrete mix proportion for one sample.

Component	ST5	Cube	Cylinder
	1m^3	0.15×0.15×0.15 m^3	π×0.075×0.3 m^3
Cement (kg)	383	1.302	2.03
Coarse Aggregate (kg)	1256	4.270	6.657
Fine Aggregate (kg)	560	1.904	2.97
Water (kg)	192	0.653	1.018
Bamboo Fibre (BF)			
0.5%	-	0.0374 kg	0.0583 kg
1%	-	0.0748 kg	0.1166 kg
1.25%	-	0.0935 kg	0.1457 kg

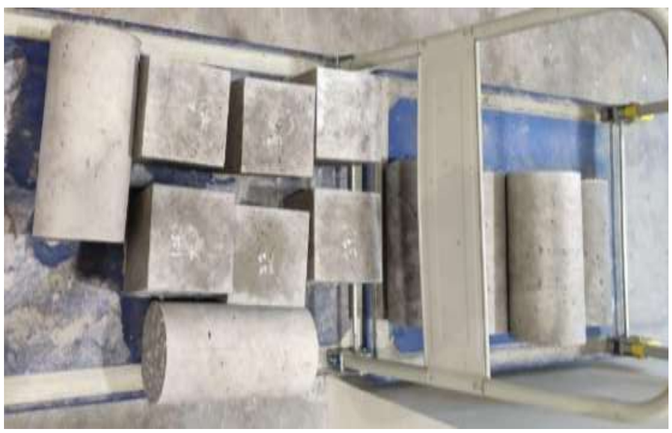

Fig. (2). Cube and cylinder concrete samples.

Table 3. Total concrete samples for each laboratory testing.

Sample		Compression Test Cube: 0.15×0.15×0.15 m^3		Split-Tensile Test Cylinder: π×0.075 ×0.3 m^3
		Curing Days		
		7	28	28
% of Bamboo Fibre (BF)	0% (Control)	3	3	3
	0.5%	3	3	3
	1.0%	3	3	3
	1.25%	3	3	3
Total		12	12	12

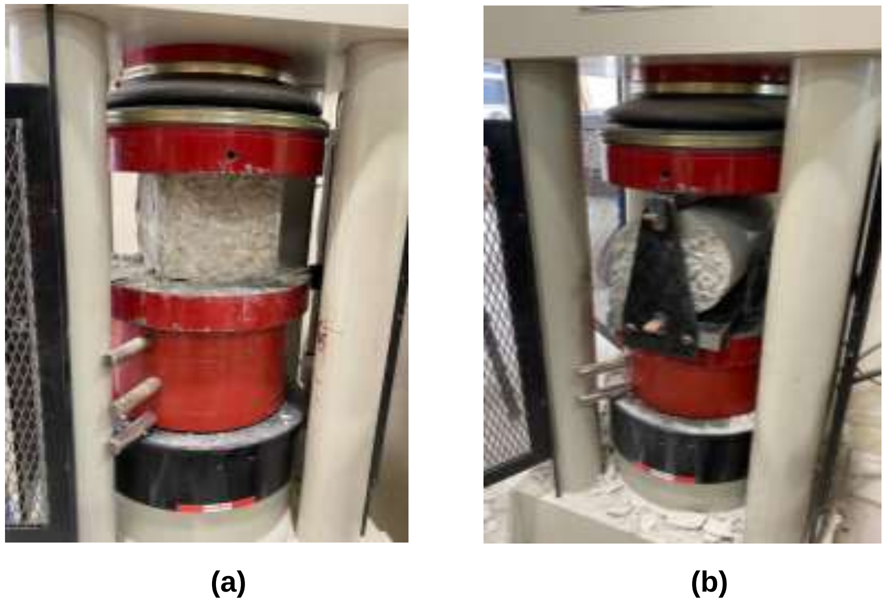

Fig. (3). Experimental setup for (a) compression test; (b) split tensile test.

For the compression test, according to S. Mali *et al*. [43], Y. Xiao *et al*. [44], and P. Rossi *et al*. [45], the 7 to 28 days of curing samples were tested for a maximum load rate of 15 NM/m^2/min (*i.e*., 150 kg/cm^2/min) until the samples fail or break using compression machine depicted in Fig. (3). The test was performed to estimate the ultimate compressive strength of samples under the applied compression load. The compressive strength (f_c) is determined according to BS EN 12390-3:2002 [41] as shown in Eq. (1). Two parameters are required for the calculation of f_c, *i.e*., the maximum load after the sample break, F (N), and the surface area of the contacted sample, A_c (mm^2).

$$f_c = \frac{F}{A_c} \quad (1)$$

Conversely, the tensile split strength (f_{ct}) was determined based on the shear failure of the samples at the age of 28 days of curing. According to the BS EN 12390-6:2000 [42], the f_{ct} is calculated using the Eq. (2);

$$f_{ct} = \frac{2F}{\pi L d} \quad (2)$$

where

F = maximum applied load on the sample, N

L = length of the contact line on the sample, mm

d = diameter of the sample, mm

3. RESULTS AND DISCUSSION

This section summarizes the results and discussion of the overall experimental works, which are divided into two subheadings, *i.e*., fresh state concrete test and hardened state concrete test. The results obtained from slump, compression and slip tensile tests for a total of 36 samples are presented herein.

3.1. Fresh State Concrete

3.1.1. Slump Test

Based on the observation, the slump test results reduced from 60 mm to 30 mm due to an increment in the percentage of BFW in the mixtures of concrete (Fig. 4). It is noted that 1.25% addition of fibres provides the smallest slump of 30 mm due to the low capability of the fibres to mix well with other materials in the concrete. The slump test result showed a good agreement with BS 5328 - Part 2:1997 [40], as described in Table 1 above. The standard recommends that for standard concrete mix type ST5 with maximum coarse aggregates of 20 mm, the fresh concrete mixture may experience two types of slump workability, *i.e*., medium and high workability for the slump. The medium workability results when the slump drops in the range of 25 mm to 75 mm, while when the slump is between 65 mm to 135 mm, the concrete mix is considered to have high workability. Thus, the result denoted that the concrete mixture is classified under true slump type with medium workability.

3.2. Hardened State Concrete

3.2.1. Compressive Strength (f_c)

The compressive strength of the concrete samples with the addition of different percentages of BFW was obtained by performing the compression test. Fig. (5) shows the average compressive strength (f_c) of concrete samples with four different percentages of BFW tested after 7- and 28-days of the curing process. As can be seen, the f_c after 7 days of curing is slightly lower than the result obtained after 28 days [2-4, 6, 7, 9]. The difference in percentage of the f_c is between 5% to 10%. The highest of the f_c (*i.e.*, 10% increment) was recorded for the concrete samples with the addition of 0.5% BF in the mixture. However, the trend started to decrease with more addition of BF for both 7- and 28-day concrete samples.

However, the f_c of the 28 day samples increased slightly to it designed concrete grade M20 of each concrete sample. The lowest strength was recorded for concrete with 1.25% BF, *i.e.*, 14.02 N/mm^2, while the highest strength of 25 N/mm^2 was obtained when 0.5% BF was added to concrete samples. It is found that the optimum addition percentage of BF is 0.5%, whereby the increment of strength between the samples with and without the addition of BF is approximately 7.33% and 8.33% for 7- and 28-day concrete samples, respectively.

It is interesting to remark that the addition of BF in concrete was able to increase the f_c within 28 days of the curing process. As reported by previously mentioned researchers [2-4, 6, 7, 9, 18], the increment of strength might be due to the ability of the fibres to improve the bonding in the mixture and absorb the energy release from the applied load while subsequently retarding or reducing the risk of cracking.

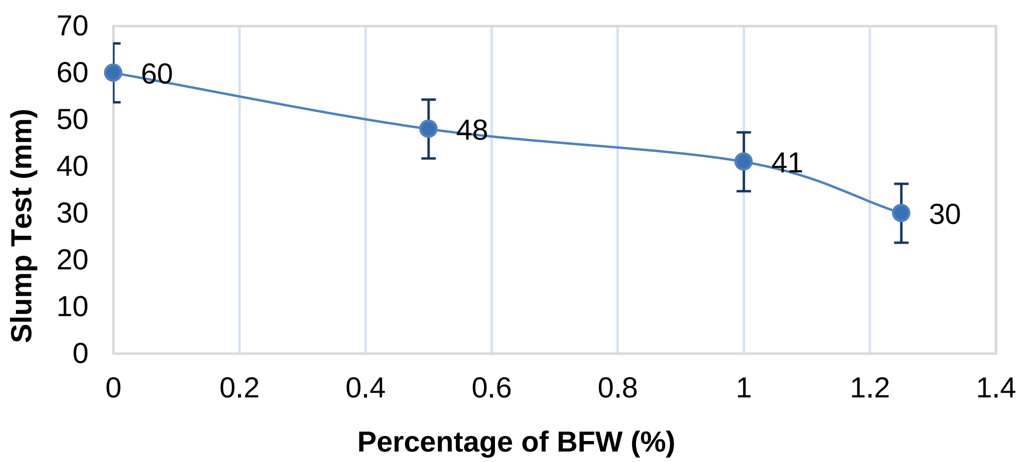

Fig. (4). Slump test of concrete mixture with addition of bamboo fibre waste.

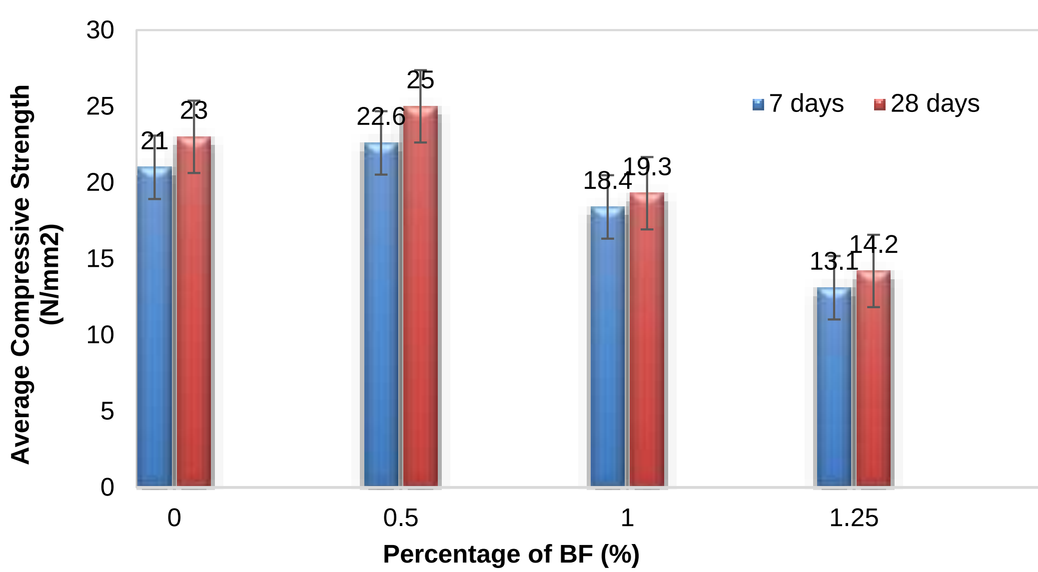

Fig. (5). Average compressive strength of concrete M20 samples.

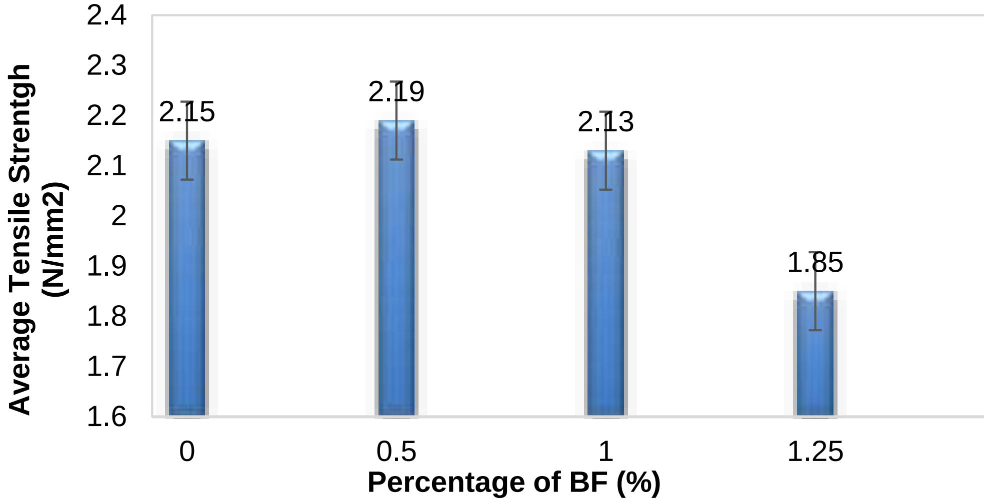

Fig. (6). Average tensile split strength of concrete samples.

Table 4. Comparison on mechanical properties of concrete at 28 days curing.

Strength	BF Content %	Present Study, 2024 Concrete M20	S. Kavitha and T. Felix Kala [25] Concrete M30
Average Maximum Compressive strength (N/mm^2)	0	23	32.8
	0.5	25	33.7
	1	19.3	41
	1.25	14.2	38.9
Average Maximum Split tensile strength (N/mm^2)	0	2.15	2.68
	0.5	2.19	3.1
	1	2.13	4.8
	1.25	1.85	4.3

3.2.2. Split Tensile Strength (f_{ct})

The split tensile test after 28 days of the curing process was carried out to determine the capability of samples to resist the applied tensile load. Fig. (**6**) demonstrates the result of the average tensile split strength (f_{ct}) of the specimens. The tensile strength of the sample without the addition of BF is 2.15 N/mm^2 was used as the reference value. It is noted that there is a slight increment of f_{ct} when the concrete is added with 0.5% BF *i.e.*, 2.19 N/mm^2. A similar trend of strength decrement was experienced when more BF was added in concrete [24-37]. The lowest was 1.85 N/mm^2 for samples with the addition of 1.25% BF. It is noted that the f_{ct} in the present study produced relatively lower strength compared to previous literature [2-4, 6, 7, 9].

Furthermore, validation with previous literature is conducted by comparing the mechanical properties of concrete with various percentages of bamboo fibre addition, as demonstrated in Table **4**. According to the table, it is found that both studies observed a significant increment in compressive and tensile strengths of the concrete with the addition of BF. However, the optimum addition percentage observed from both studies differs, *i.e.*, the present study reports a strength increase of 0.5% BF, whereas the previous literature observed the optimum increment of strength after 1% BF is added in concrete. This variance may be due to the different concrete grades used by both researchers. Conversely, it may be hypothesised that the fibre functions as a bridge material, impeding the propagation of cracks in the hardened mixture and thereby enhancing its strength.

CONCLUSION

In this study, the performance of BF in modifying the compressive and tensile properties of concrete was investigated. Three percentages of the BF, *i.e.*, 0.5%, 1%, and 1.25% were added in concrete grade M20. The results were examined under two hardened states of concrete, *i.e.*, compression and tensile split tests. The results denoted that the addition of BF in concrete has slightly improved the mechanical properties of the concrete. The optimum addition percentage of BF is recorded at the addition of 0.5% BF at 28 days of curing.

According to the results, theaddition of BF has successfully increased the compressive strength of the samples by approximately 7.33% and 8.33% for 7- and 28-days of M20 concrete samples, respectively. An insignificant increment of tensile strength of concrete was recorded for tensile strength of the concrete. Nevertheless, a similar trend of strength decrement was experienced when 0.5 - 1% of BF is added in concrete [2-4,6,7,9,25-27]. The research found that similar agreement with previous literature [24-37] is observed when the strength of concrete drops at 1.25% fiber content due to poor bonding between the cement matrix and aggregate. This study presents significant information on the ability of BF as a concrete strength enhancer which subsequently converts the abundance of natural waste by converting the waste to application of production of noble green and sustainable concrete material.

HIGHLIGHTS

• Bamboo Fibre (BF) increased the compressive strength of the concrete grade M20.

• Bamboo Fibre (BF) increased the tensile strength of the concrete grade M20.

• Bamboo Fibre (BF) provides the ability to be used as a strength enhancer in concrete mixtures.

LIST OF ABBREVIATIONS

BFW	=	Bamboo Fibre Waste
BS	=	British Standard
MS	=	Malaysian Standard
EN	=	European Standard
OPC	=	Ordinary Portland Cement

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIAL

The data used to support the findings of this study are included in the article.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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REFERENCES

[1] M. Brindha, K.S. Khan, S.S.S. Narayanan, A.M.S. Kumar, and V. Vivek, "Properties of concrete reinforced with bamboo fibre", *Int. J. Innov. Res. Sci. Eng. Technol.,* vol. 03, no. 5, pp. 3809-3812. [http://dx.doi.org/10.15680/IJIRSET.2017.0603149B]

[2] N.A. Misnon, S.K. Che Osmi, N. Chouw, and S. Shahidan, "Influence of coir random fibre length on concrete: Mechanical properties", *Malays. Constr. Res. J.,* vol. 22, no. 2, pp. 47-58.

[3] S.K. Che Osmi, M.A. Zaınuddın, N.A. Misnon, S. Sojipto, and H. Husen, "Effect of pineapple leaf fibre as additional material in concrete mixture", *Lect. Notes Civ. Eng.,* vol. 215, pp. 525-537. [http://dx.doi.org/10.1007/978-981-16-7924-7_34]

[4] N.A. Misnon, S. Shahidan, F.H. Khairuddin, N.L. Rahim, C.S.K. Osmi, and H. Husen, "Effect of Coconut Fibre on Coconut Shell Concrete", *Advances in Civil Engineering Materials,* Springer, pp. 239-247. [http://dx.doi.org/10.1007/978-981-33-6560-5_25]

[5] C.S.K. Osmi, S. Hzlan, M.N. Nor, H. Husen, S. Sojipto, and N.A. Misnon, "Mechanical properties of bamboo coated with surface treatment under static loading", *World Sustainable Construction Conference Series,* pp. 020011-1-020011-13. 15–16 October 2021, Kuantan, Pahang, Malaysia

[6] A. Yusra, I.Y. Salena, I.G. Raka, and E. Saputra, "The influence of bamboo fibers as additive on the mechanical properties of high strength concrete", *J. Phys. Conf. Ser.,* no. 1, p. 2020. [http://dx.doi.org/10.1088/1742-6596/1625/1/012013]

[7] P.P. Sai, K. Murali, G.S. Kumar, and K.V. Teja, "Study on properties of natural fibre reinforced concrete made with coconut shells and coir fibre", *Int. J. Civ. Eng. Technol,* vol. 9, no. 1, pp. 416-422.

[8] K.H. Mo, S.P. Yap, U.J. Alengaram, M.Z. Jumaat, and C.H. Bu, "Impact resistance of hybrid fibre-reinforced oil palm shell concrete", *Constr. Build. Mater.,* vol. 50, pp. 499-507. [http://dx.doi.org/10.1016/j.conbuildmat.2013.10.016]

[9] M. Ali, A. Liu, H. Sou, and N. Chouw, "Mechanical and dynamic properties of coconut fibre reinforced concrete", *Constr. Build. Mater.,* vol. 30, pp. 814-825. [http://dx.doi.org/10.1016/j.conbuildmat.2011.12.068]

[10] M.A. Fuqua, S. Huo, and C.A. Ulven, "Natural fiber reinforced composites", *Polym. Rev.,* vol. 52, no. 3, pp. 259-320. [http://dx.doi.org/10.1080/15583724.2012.705409]

[11] Z. Ahmad, H.M. Saman, and P.M. Tahir, "Oil palm trunk fiber as a bio-waste resource for concrete reinforcement", *Int. J. Mech. Mater. Eng,* vol. 5, no. 2, pp. 199-207.

[12] M.A. Aziz, P. Paramasivam, and S.L. Lee, "Prospects for natural fibre reinforced concretes in construction", *Int J Cem Compos Lightweight Concr,* vol. 3, no. 2, pp. 123-132. [http://dx.doi.org/10.1016/0262-5075(81)90006-3]

[13] C.S.K. Osmi, A. Ngadenin, M.N. Nor, H. Husen, M.A. Yahya, and M.N. Daud, "Bonding strength of bamboo reinforcement in concrete – A systematic literature review (SLR)", *J. Eng,* vol. si4, no. 1, pp. 1-11. [http://dx.doi.org/10.17576/jkukm-2021-si4(1)-01]

[14] N. Mohd Daud, M.N. Nor, M.A. Yusof, M.A. Yahya, S.K. Che Osmi, V. Munikanan, and A.A. Musthaffa, "Economic comparison: Bamboocrete multi-purpose panel and typical reinforced concrete panel", *J. kjertran,* vol. si4, no. 1, pp. 43-47. [http://dx.doi.org/10.17576/jkukm-2021-si4(1)-05]

[15] P.R. Mali, and D. Datta, "Experimental evaluation of bamboo reinforced concrete beams", *J. Build. Eng.,* vol. 28, p. 101071. [http://dx.doi.org/10.1016/j.jobe.2019.101071]

[16] R.G.D. Kumar, J.P.B. Prasad, C.B. Ujwal, and A. Professor, "Comparison in characteristics of bamboo and steel reinforcement", *IRJET,* vol. 2019, .

[17] H. Archila, S. Kaminski, D. Trujillo, Z.E. Escamilla, and K.A. Harries, "Bamboo reinforced concrete: A critical review", *Mater. Struct.,* vol. 51, no. 4, p. 102. [http://dx.doi.org/10.1617/s11527-018-1228-6]

[18] S.M. Dewi, M.N. Wijaya, and N.C. Remayanti, "The use of bamboo fiber in reinforced concrete beam to reduce crack", *AIP Conf. Proc.,* vol. 1887, p. 020003. [http://dx.doi.org/10.1063/1.5003486]

[19] K.J. Wong, S. Zahi, K.O. Low, and C.C. Lim, "Fracture characterisation of short bamboo fibre reinforced polyester composites", *Mater. Des.,* vol. 31, no. 9, pp. 4147-4154. [http://dx.doi.org/10.1016/j.matdes.2010.04.029]

[20] J.G. Moroz, S.L. Lissel, and M.D. Hagel, "Performance of bamboo reinforced concrete masonry shear walls", *Constr. Build. Mater.,*

vol. 61, pp. 125-137.
[http://dx.doi.org/10.1016/j.conbuildmat.2014.02.006]

[21] C.S.K. Osmi, M.M.F.I. Fazully, H. Husen, M. Othman, N. Hafizi, M.N. Nor, and S. Sojipto, "Performance of bamboo reinforced interlocking soil-cement block wall under impact loading", *J. Eng. Sci. Tech,* vol. 18, no. 1, pp. 190-204.

[22] B.B. Paulinmary, and D. Tensing, "State of the art report on bamboo reinforcement", *Int. J. Eng. Res. Appl.,* vol. 3, no. 2, pp. 683-686.

[23] E. Kar, and D. Dutta, "Study of strength & deflection of bamboo fiber reinforced concrete member under flexural loading", *IOSR-JMCE,* vol. 1970, pp. 31-35.

[24] R.E. Marrero, H.L. Soto, F.R. Benitez, C. Medina, and O.M. Suarez, "Study of high-strength concrete reinforced with bamboo fibers", *Adv. Mater. TechConnect Br.,* vol. 2, pp. 301-304.

[25] S. Kavitha, and F.T. Kala, "Effectiveness of bamboo fiber as a strength enhancer in concrete", *Int. J. of Earth Sci. Eng.,* vol. 9, no. 3, pp. 192-196.

[26] S. Kavitha, and F.T. Kala, "Effect of bamboo fiber in self compacting concrete partially replacing cement with GGBS and alccofine", *Int. J. Civ. Eng. Technolog.,* vol. 8, no. 3, pp. 158-166.

[27] S. Kavitha, and F.T. Kala, "Effect of bamboo fibers in fresh and hardened properties of self compacting concrete", *Indian J. Sci. Technol.,* vol. 9, no. 31, .
[http://dx.doi.org/10.17485/ijst/2016/v9i31/95347]

[28] J. Ahmad, Z. Zhou, and A.F. Deifalla, "Structural properties of concrete reinforced with bamboo fibers: A review", *J. Mater. Res. Technol.,* vol. 24, pp. 844-865.
[http://dx.doi.org/10.1016/j.jmrt.2023.03.038]

[29] M. Maier, A. Javadian, N. Saeidi, C. Unluer, H.K. Taylor, and C.P. Ostertag, "Mechanical properties and flexural behavior of sustainable bamboo fiber-reinforced mortar", *Appl. Sci.,* vol. 10, no. 18, p. 6587.
[http://dx.doi.org/10.3390/app10186587]

[30] R.D. Glenn, "Microstructure and mechanical performance of bamboo fiber reinforced mill-scale—fly-ash based geopolymer mortars", *Clean. Chemi. Eng.,* vol. 6, p. 100110.
[http://dx.doi.org/10.1016/j.clce.2023.100110]

[31] T. Xie, W. Ren, Y. Chen, J. Sheng, and L. Wang, "Enhancing the performance of asphalt mastic with natural fiber reinforcement: Basalt and bamboo fibers", *Appl. Sci.,* vol. 13, no. 13, p. 7946.
[http://dx.doi.org/10.3390/app13137946]

[32] C. Xia, C. Wu, K. Liu, and K. Jiang, "Study on the durability of bamboo fiber asphalt mixture", *Materials,* vol. 14, p. 1667.
[http://dx.doi.org/10.3390/ma14071667]

[33] I. Widiastuti, D.H. Pratama, M.L. Hakim, D.S. Wijayanto, and B. Harjanto, "Mechanical and thermal properties of recycled polypropylene bamboo fibre-reinforced composites", *Int. J. of Adv. Appli. Sci.,* vol. 12, no. 3, pp. 205-213.
[http://dx.doi.org/10.11591/ijaas.v12.i3.pp205-213]

[34] Y. Dessalegn, B. Singh, A.W. Vuure, A.A. Rajhi, A.A. Duhduh, N. Hossain, and G.M.S. Ahmed, "Mechanical properties of bambusa oldhamii and yushania-alpina bamboo fibres reinforced polypropylene composites", *Polymers,* vol. 14, no. 13, p. 2733.
[http://dx.doi.org/10.3390/polym14132733] [PMID: 35808778]

[35] P.A.S. Dicky, and I. Widiastuti, "Mechanical properties of bamboo on virgin and recycled high-density polyethylene matrix", *Int. J. Adv. in Appl. Sci.,* vol. 12, no. 3, pp. 205-213.
[http://dx.doi.org/10.11591/ijaas.v12.i3.pp205-213]

[36] T.K. Brahmachary, and M. Rokonuzzaman, "Investigation of random inclusion of bamboo fiber on ordinary soil and its effect CBR value", *Int. J. Geo-Eng.,* vol. 9, no. 1, p. 10.
[http://dx.doi.org/10.1186/s40703-018-0079-x]

[37] J. Siswanto, K. Latifah, B. Supriyadi, A. Rochim, and F. Alzami, "The relation of compressive strength and tensile strength of bamboo fibber for soil stabilization", *J. Phys. Conf. Ser.,* vol. 1808, p. 012009.
[http://dx.doi.org/10.1088/1742-6596/1808/1/012009]

[38] British Standards Institute, "BS 5328: Part 2: 1997 concrete part 2: Methods for specifying concrete mixes", Available from: https://www.scribd.com/document/418697411/209966866-BS-5328-Concrete-Part-2-Methods-for-Specifying-Concrete-Mixes-pdf

[39] Department of Standards Malaysia, "Portland Cement (Ordinary and Rapid-hardening)", *Specification,* no. 3, p. 2003.

[40] British Standards Institute, "BS 1881-102:1983 Testing concrete - Part 2: Method for determination of slump", Available from: https://www.scribd.com/document/488734747/BS-1881-PART-102-1983

[41] British Standard Institute, "BS EN 12390-3:2002 Testing hardened concrete - Part 3: Compressive strength of test specimens", Available from: https://www.scirp.org/reference/ReferencesPapers?ReferenceID=1884343

[42] British Standards Institute, "BS EN 12390-6:2009 Testing hardened concrete - Part 6: Tensile splitting strength of test specimens", Available from: https://standards.iteh.ai/catalog/standards/cen/81ec74fb-9338-4909-a200-6a5042160640/en-12390-6-2009

[43] S. Mali, T. Pachpande, and A. Jogi, "Effect of rate of loading on compressive strength of concrete", *Int. J. Innov. Emerg. Res. Eng,* vol. 2, no. 4, pp. 20-25.

[44] Y. Xiao, J. Shan, Q. Zheng, B. Chen, and Y. Shen, "Experimental studies on concrete filled steel tubes under high strain rate loading", *J. Mater. Civ. Eng.,* vol. 21, no. 10, pp. 569-577.
[http://dx.doi.org/10.1061/(ASCE)0899-1561(2009)21:10(569)]

[45] P. Rossi, J.G.M. Van Mier, F. Toutlemonde, F. Le Maou, and C. Boulay, "Effect of loading rate on the strength of concrete subjected to uniaxial tension", *Mater. Struct.,* vol. 27, no. 5, pp. 260-264.
[http://dx.doi.org/10.1007/BF02473042]