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MECHANICAL STRENGTH OF REINFORCED – BAMBOO CULM WITH CONCRETE INFILL FOR BUILDING CONSTRUCTION

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Abstract

Bamboo is still considered a material for poor people in rural areas. Still, it also has the potential to be fully developed engineering material reinforced structural beams with concrete infill to increase the structural strength of the structures, which is natural aesthetic, and more durable compared to bamboo alone as structural parts of buildings. This study aims to determine the flexural and compressive strength of bamboo with concrete infill as a structural beam subjected to a concentrated load at the midspan and structural column subjected to axially loaded compression. The materials used were whole bamboo culms, specifically ***Dendrocalamus Asper Schultes, Dendrocalamus Merrillianos Elmer, Bambusa Vulgaris Schrad, and Bambusa Blumeana Schultes*** cut into 300 mm and 600 mm lengths and treated with seawater and seawater with mango polyphenol extract infilled with concrete. The concrete was cured for 7, 14, 28, and 56 days. The results showed that the whole bamboo culm treated with seawater and treated with seawater plus a 10 percent solution of mango polyphenol extract remarkably increased its mechanical strength. The concrete infill to the whole bamboo culm as the beam is effective, increasing mechanical strength when treated with mango. The curing age of concrete and treatment of bamboo culm with seawater and mango polyphenol extract affects the mechanical strength of reinforced bamboo concrete subjected to a concentrated load at midspan and axially loaded. Reinforced bamboo concrete infill-based construction materials can reduce pressure on resources and the environment. These materials have environmental and mechanical advantages over conventional construction materials.

Keywords: Bamboo Culm, Bamboo Concrete Infill, Concrete Infill, Flexural Strength, Compressive Strength, Mechanical Strength, Reinforced–Bamboo Culm

INTRODUCTION

Bamboo is a renewable and versatile resource characterized by high strength and low weight and can be easily operated using simple tools. From early times, Bamboo has been used as a construction material. The main obstacle to applying bamboo as a reinforcement is insufficient information about its interaction with concrete, strength, and durability [1]. **Bamboo** is a building material determinant factor of the success and failure of buildings with bamboo that can be competitive with materials more commonly used. Bamboo has a long history with humankind and is one of the oldest building materials used for construction [2]**.** The Various structural components [3] have been developed using bamboo concrete composites ***(Bamcrete)*** and demonstrated in building houses. Bamboo is used for construction purposes. Bamboo possesses excellent mechanical properties compared with other commonly used construction materials.

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The application outlook and advantages [4] of bamboo structures are discussed according to the design and construction practices of modern bamboo structure demonstration buildings **[5]. T**he structural integrity [6] of sensitive materials used for construction and the structural integrity assessment of bamboo for construction purposes considered that different materials perform differently under particular loading and environmental conditions [6].

Bamboo is a sustainable material [7] with a high potential for structural [8], including failure strain and stress. Structural and engineered bamboo [9] products are comparatively low energy-intensive materials with sufficient structural properties for modern construction. The design and construction of bamboo buildings are suitable for construction applications, the development of bamboo-based products **[10],** and the types of structures typically designed and built with bamboo **[11].** Design considerations include bamboo testing, structural design standards, and building codes **[12].**

The strength of bamboo [13] as a concrete reinforcement is much lower than that of steel reinforcement; Due to excellent properties like high strength-to-weight ratio, high tensile strength, free-cutting, and processing. Bamboo [14] has been widely used as a renewable structural material for building permanent and temporary structures in the past decade. However, the compressive-bearing capacity of bamboo [15] is relatively low, which limits its applications only to structures under light loads [**6]. The** load-bearing capacity of bamboo by filling concrete or cement mortar in bamboo cavities [17]. Bamboo-reinforced concrete [18] simply supported beams were tested for failure under third-point loading [19]**,** and six other beams were subjected to long-term loading [20]. In addition [21], column buckling is considered one of the critical modes of failure in bamboo, often leading to its overall collapse [22]. The axial buckling behavior of bamboo columns failed in the axial buckling behavior of bamboo columns owing to the culm holes [23].

The various structural components [24] using bamboo concrete composites ***(Bamcrete)*** and demonstrated them in building houses [25] and experimentally verified structural arch forms using bamboo as a structural element [26]**.** The mechanical behavior of bamboo-reinforced concrete members [27]; [28] the difference in the structural properties of steel-reinforced concrete and bamboo-reinforced concrete [29]. And the mechanical properties of bamboo-reinforced concrete members are studied **[30].** Modern bamboo structures [31] have excellent structural properties, confirming that the capacity of these bamboo composites is comparable in strength with similar reinforced concrete [32]. And modern engineered bamboo structures make it possible to replace RC wherever required [33]. Bamboo materials are often characterized using standard tension coupon tests [34], and non-uniform bending stresses are introduced across the breadth of the cross-section during testing [35]. An experimental study [36] on the axial load behavior of material-filled structural bamboo was conducted to investigate the effects of infilled materials [37]. The effective circumferential moduli under compression [38] are similar to those obtained under tension. Consistent behavior was observed between the tension

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and compression tests [39]. All functions could simulate the elastic distribution through the wall thickness of bamboo [40].

The reinforcement and bamboo elements [41] could form an integrated composite cross-section. The failure modes, ultimate load, and cross-sectional stiffness of the bamboo culm beams were significantly correlated with the diameter of the treatment of the bamboo bundle [42] and applying bamboo-based structural composite materials in practical engineering [43]. The un-reinforced beams [44] to evaluate their bending properties indicated that the reinforcement and bamboo elements could form an integrated composite cross-section [45]. This research aims to determine the Mechanical strength of bamboo culm untreated, treated with seawater, and treated with seawater plus mango Polyphenol, to determine the mechanical strength of the bamboo culms reinforced with concrete infill and bamboo culm without concrete infill, to determine the significant correlations between the mechanical strength of the bamboo culm with concrete infill and no concrete infill and it is the culm diameter and thickness, bamboo treatment periods/durations and concrete curing durations; **t**o determine the significant difference between the mechanical strengths 0f bamboo culms of different species when Untreated, treated with sea seawater**,** treated with seawater plus mango polyphenol of no concrete infill and Infill with concrete.

METHODOLOGY

The specific methods and procedures are enumerated as follows.

Step 1. Choosing the three-year-old matured bamboo was selected carefully, and harvested bamboo Species *were used* as a material. In this study, Philippines Bamboo species were utilized preferably where the abundance of these four species can, be found specifically the **(a)** ***Dendrocalamus Asper Schultes, (b)Bambusa Blumeana Schultes, (c) Bambusa Vulgaris Schrad and (d) Dendrocalamus Merrillianos Elmer.***

(a) (b) (c) (d)

Step 2. The selected Philippine bamboo species were cut with 600 mm length with one or two nodes. Each bamboo species had three samples for each treatment and was stocked as shown below.

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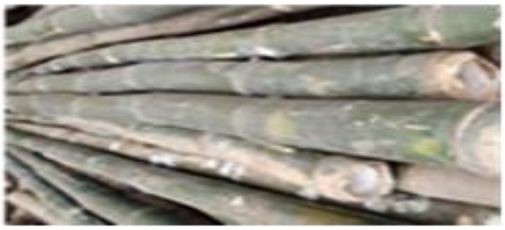  

(e) Harvested Matured bamboo. (f) Cut with one -node. (g) Cut with two-nodes

Step 3. After cutting the bamboo according to a specified length. The Bamboo treatments were undertaken as follows: (**h) Untreated (Kiln Drying), naturally natural soaked, (i) treated with seawater, and (j) Treated with seawater plus Mango Polyphenol**. The treatment was naturally soaking for 7 days, 14 days, 28 days and 56 days.

  

(h) Kiln Drying (i) Treated with Seawater (j) Treated with seawater +Mango Polyphenol

Step 4. Preparations of concrete infill materials (Cement, sand, and gravel) Type 1 cement is used, and sand and gravel properties were controlled based on ASTM Standards. The bamboo nodal tubes were carefully removed, and the Concrete Infill materials were carefully filled in the bamboo Culms. The bamboo culm concrete infill was stocked **(k), (l), (m)** at normal room temperature for curing.

  

(k) (l) (m)

Step 5. Curing of concrete infill. The bamboo concrete infill was cured at room temperature **(k to m)**. Infill the Bamboo culms with concrete cured for 7, 14, 28, 56 and days according to ASTM standards.

Step 6. Testing of the Samples: After curing the Concrete in fill inside the bamboo Culm each sample was tested for its flexural strength using Universal Testing Machine subjected to concentrated loading at midspan and axial compression test. Laboratory tests were performed according to ASTM standards. The results were tabulated and analyzed carefully.

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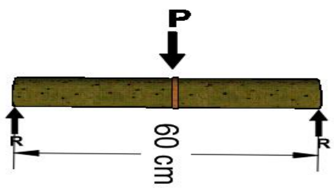
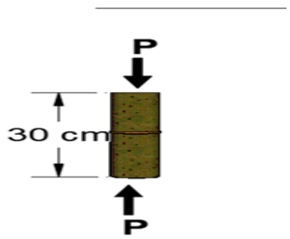



(n) Flexural test Set-up **(o) Actual flexural Testing** **(p) Actual Flexural Failures**




(q) Compression set up **(r) Actual Compression test** **(s) actual compression failures**

RESULTS AND DISCUSSION

The selected bamboo species were selected subjected to no treatment, treated with seawater, and treated with seawater plus a 10 percent solution of mango polyphenol extract of seven days, 14 days, 28 days, and 56 days respectively, filled with concrete infill having a water cement ratio of 0.50 and cured for seven days, 14 days, 28 days and 56 days tested using universal testing machine subjected to a concentrated load at mid-span and axial compressive test the results were presented below.

Table 1: Flexural Strength of Whole bamboo column without Concrete infill

Curing Age (days)	Bamboo Culm without Infill - Flexural Strength (MPa)											
	Dendrocalamus Merrillianos Elmer			Bambusa Vulgaris Schrader			Bambusa Blumeana Schultes			Dendrocalamus Asper Schultes		
	DME-Untreated (Kiln Drying)	DME - Seawater Treatment	DME-Seawater + Mango Polyphenol Treatment	BVS-Untreated	BVS-Seawater treatment	BVS-Seawater +Mango Polyphenol Treatment	BBS-Untreated	BBS-Seawater Treatment	BBS-Seawater +Mango Polyphenol Treatment	DAS-Untreated	DAS-Seawater Treatment	DAS-Seawater +Mango Polyphenol Treatment
7	8.61	8.96	9.99	8.27	8.61	9.65	6.89	8.61	9.65	8.96	9.65	10.34
14	8.96	9.65	10.75	8.61	9.3	10.34	8.27	9.23	10.34	8.96	10.34	11.02
28	9.65	10.34	11.51	8.96	9.99	11.02	8.96	9.85	10.82	9.65	11.02	11.71
56	9.65	11.02	12.06	9.65	10.68	11.71	9.65	10.47	11.58	10.34	11.37	12.4

The table and graph reveal that Bamboo culm without concrete infill among the specie *Dendrocalamus asper Schultes* had the highest flexural strength of 10.34 MPa for untreated and 11.37 MPa for treated with seawater for 56 days and 12.40 MPA for treated with seawater plus 10 percent Mango Polyphenol for 56 days. An increase in Flexural strength of an average of 10 percent every treatment period is remarkable, and a rise of 10 percent for each treatment is also significant. *Dendrocalamus Merrillianos Elmer* also

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shows a high flexural strength of 12.06 MPa when treated with seawater plus 10 percent mango polyphenol [46]. *Bambusa Blumeana Schultes* shows remarkably increased flexural strength after treatment with seawater and a 10 percent solution of mango polyphenol extract as well as *Bambusa Bulgaris Schrader* This implies that among the species, *Dendrocalamus Asper Schultes* has the highest flexural strength followed by *Dendrocalamus Merrillianos Elmer* when treated because of its cell wall and treatment with seawater plus mango polyphenol affects the bending stress of bamboo culm subjected to a concentrated load at midspan [47].

Table 2: Compressive strength of whole bamboo culm without concrete infill

Curing Age (days)	Bamboo Culm with Concrete Infill - Compressive Strength (MPa)											
	Dendrocalamus Merrillianos Elmer (DME)			Bambusa Vulgaris Schrader (BVS)			Bambusa Blumeana Schultes (BBS)			Dendrocalamus Asper Schultes (DAS)		
	DME-Untreated (Kiln Drying)	DME - Seawater Treatment	DME-Seawater + Mango Polyphenol Treatment	BVS-Untreated	BVS-Seawater treatment	BVS-Seawater +Mango Polyphenol Treatment	BBS-Untreated	BBS-Seawater Treatment	BBS-Seawater +Mango Polyphenol Treatment	DAS-Untreated	DAS-Seawater Treatment	DAS-Seawater +Mango Polyphenol Treatment
7.00	12.40	13.78	13.78	12.40	12.40	13.78	12.40	13.09	13.78	12.40	13.78	15.16
14.00	12.40	13.78	16.54	13.78	13.78	14.47	13.78	15.16	17.91	13.78	15.16	16.54
28.00	13.78	13.78	17.91	15.16	13.78	16.54	14.47	15.85	19.29	15.16	16.54	19.29
56.00	16.54	17.23	20.67	15.16	13.78	19.29	16.54	17.23	19.98	17.91	19.29	20.67

The table shows the compressive strength results of whole bamboo culm treated for seven days, 14 days, 28 days, and 56 days respectively. The results reveal that *Dendrocalamus Merrillianus Elmer and Dendrocalamus Asper Schultes* increased the compressive strength treated for 56 days, showing that treatment with seawater with Mango Polyphenol has a higher compressive stress of 20.67 MPa. The *Bambusa Vulgaris Schrader and Bambusa Blumeana Schultes* also show a remarkable increase when treated with seawater with mango polyphenol extract with compressive strength of 19.29 MPa [46]. The results show that the compressive strength significantly increased when properly treated at a certain period. The longer the treatment period, the better compressive strength [48]. This shows that the increasing treatment period shows a remarkably significant increase in the compressive strength of the bamboo culm [49]. The type of treatment also affects the increased bamboo culm compressive strength [50]. Among the treatments, seawater plus mango polyphenol helps to increase it significantly [46].

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Table 3: Flexural strength of bamboo culm reinforced with concrete infill

Curing Age (days)	Bamboo Culm with Concrete Infill - Flexural Strength (MPa)											
	Dendrocalamus Merrillianos Elmer (DME)			Bambusa Vulgaris Schrader (BVS)			Bambusa Blumeana Schultes (BBS)			Dendrocalamus Asper Schultes (DAS)		
	DME-Untreated (Kiln Drying)	DME - Seawater Treatment	DME-Seawater + Mango Polyphenol Treatment	BVS-Untreated	BVS-Seawater treatment	BVS-Seawater +Mango Polyphenol Treatment	BBS-Untreated	BBS-Seawater Treatment	BBS-Seawater +Mango Polyphenol Treatment	DAS-Untreated	DAS-Seawater Treatment	DAS-Seawater +Mango Polyphenol Treatment
7	11.12	11.22	12.06	10.14	10.38	11.71	8.99	10.68	11.71	11.12	11.71	12.49
14	13.14	13.32	14.02	11.29	12.17	13.18	11.71	12.68	13.78	12.23	14.74	16.29
28	14.13	13.61	14.08	12.13	13.16	14.07	12.40	13.30	15.98	12.92	15.33	16.58
56	13.19	13.90	15.00	13.29	13.45	14.11	12.92	13.75	16.50	13.44	15.47	16.77

The table shows the increase in flexural strength when subjected to a concentrated load at mid-span. Among the species, infill with concrete Dendrocalamus *Asper Schultes* shows remarkable improvements due to the larger hollow culms filled with concrete cured in 56 days with 16.77 MPa Flexural strength and the *Bambusa Blumeana Schultes* that were treated with 10 percent solution mango polyphenol extract with 16.50 MPa Flexural Strength. Flexural strength shows a significant increase in all species in each treatment. It also shows that the treatment period significantly affects the increase in it flexural strength [51]. The results show an average of 32 percent increase in flexural strength when bamboo culm was reinforced with concrete infill. An average of 4 MPA was added to the bamboo culm flexural strength when concrete was infilled. The results imply that the curing age of the concrete infill contributed to the increased flexural strength of the reinforced bamboo culm with concrete infill [52]. The longer the curing age of concrete and bamboo's culm treatment period, the higher the flexural strength [53].

Table 4: Compressive strength of reinforced bamboo culm with concrete infill

Curing Age (days)	Bamboo Culm with Concrete Infill - Compressive Strength (MPa)											
	Dendrocalamus Merrillianos Elmer (DME)			Bambusa Vulgaris Schrader (BVS)			Bambusa Blumeana Schultes (BBS)			Dendrocalamus Asper Schultes (DAS)		
	DME-Untreated (Kiln Drying)	DME - Seawater Treatment	DME-Seawater + Mango Polyphenol Treatment	BVS-Untreated	BVS-Seawater treatment	BVS-Seawater +Mango Polyphenol Treatment	BBS-Untreated	BBS-Seawater Treatment	BBS-Seawater +Mango Polyphenol Treatment	DAS-Untreated	DAS-Seawater Treatment	DAS-Seawater +Mango Polyphenol Treatment
7	13.78	16.54	16.54	12.40	13.78	13.78	15.57	15.85	18.60	14.74	16.26	19.29
14	16.40	17.91	17.91	16.12	16.54	17.91	15.16	16.12	19.29	15.71	17.50	20.67
28	18.60	18.60	22.74	17.23	17.91	18.60	17.91	17.64	20.67	18.60	18.33	22.05
56	19.98	22.74	23.74	15.16	21.74	22.43	19.29	19.98	22.67	20.67	22.05	23.73

The table shows that bamboo-reinforced concrete infill had a remarkable increase in compressive strength. It also reveals that treated samples in seawater plus mango polyphenol extract had higher compressive strength. The results show that *Dendrocalamus asper Schultes and Dendrocalamus Merrillianos Elmer* had the highest compressive strength of 23.74 MPa and 23.73 MPa, respectively, when treated with seawater pus mango polyphenol extract for 56 days. The Bambusa Blumeana Schultes had 22.67 MPa compressive strength, while Bambusa *Vulgaris Schrader* had only 22.43 MPa Compressive strength when treatments the same at seawater plus mango

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polyphenol for 56 days [46]. This implies that the concrete infill contributes to the structural integrity and strength of the whole bamboo culm compressive strength. Thus the concrete curing age, bamboo culm treatment period, and types of treatment affect the compressive strength [54]. The longer the treatment period on the bamboo culm and the longer the curing age of the concrete, the higher the compressive strength of an average of 3.22 MPa or 20 percent of the bamboo culm, specifically with concrete infill.

Table 5: Correlations between the bamboo culm diameter and the mechanical strength of the treated and untreated bamboo culm no concrete infill and with concrete infill

Bamboo Culm Wall diameter	Mechanical Strength (MPa)			
No concrete Infill	**Correlation Ratio**	**T- Value**	**T- Values @ 0.05**	**Remarks**
Untreated Bamboo Culms	0.146	0.553	1.76	NS
Treated with seawater	0.361	0.140	1.76	NS
Treated with seawater +Mango Polyphenol	0.180	0.683	1.76	NS
With Concrete Infill	**Correlation Ratio**	**T- Value**	**T- Values @ 0.05**	**Remarks**
Untreated Bamboo Culms	0.040	0.151	1.76	NS
Treated with seawater	0.092	0.345	1.76	NS
Treated with seawater +mango Polyphenol	0.083	0.312	1.76	NS

The table reveals no significant correlation between the Mechanical strength (flexural and compressive strength) of the bamboo culm without or with concrete infill and the bamboo culm wall thickness because its T- values computed did not exceed the t-values of 1.76 at 0.05 level of significance. The different treatment of different bamboo culm diameter has very slight relationships to the mechanical strength of the bamboo culm with or without concrete infill. This implies that the bamboo culm wall diameter has no significant effect on the mechanical strength of the bamboo culm even if it was treated well or untreated and even with concrete infill, thus, the treatment procedure also affects its mechanical strength [55].

Table 6: Correlations between the bamboo culm thickness and mechanical strength of the untreated and treated bamboo culm with and without concrete infill

Bamboo Culm Wall Thickness	Mechanical Strength (MPa)			
No Concrete Infill	**Correlation Ratio**	**T- Value**	**T- Values @ 0.05**	**Remarks**
Untreated Bamboo Culms	0.005	0.018	1.76	NS
Treated with seawater	0.108	0.407	1.76	NS
Treated with seawater +Mango Polyphenol	0.396	1.713	1.76	NS
with Concrete Infill	**Correlation Ratio**	**T- Value**	**T- Values @ 0.05**	**Remarks**
Untreated Bamboo Culms	0.005	0.019	1.76	NS
Treated with seawater	0.108	0.407	1.76	NS
Treated with seawater +mango Polyphenol	0.273	1.861	1.76	S

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The table reveals that the bamboo culm wall thickness without concrete infill of the untreated, treated with seawater, and treated with seawater plus mango polyphenol has no significant relationship to the mechanical strength because the computed T- values are lower than the t- values of 1.76 at 0.05 level of significance. Thus, there is a slight relationship but insignificant between the mechanical strength and the bamboo culm wall thickness even though it was treated with seawater and concrete infill [56]. However, the bamboo culm treated with seawater plus mango polyphenol [46] has significant relationships with the mechanical strength subjected to flexural and compression tests both with concrete infill because the computer t- values of 1.861 exceeds that t- values of 1.76 at 0.05 level of significance This implies that when properly treated with mango polyphenol and seawater, wall thickness has effects and significant contributions to the mechanical strength of bamboo culm with concrete fill. Therefore, when properly treated with seawater plus polyphenol extract, bamboo culm wall thickness significantly affects its mechanical strength [57].

Table 7: Correlations between the periods of bamboo culm treated with seawater and with seawater plus 10 percent mango polyphenol extract and its mechanical strength when infilled with concrete and without concrete infill

Bamboo Treatment Periods	Mechanical Strength (MPa)			
(No Concrete Infill)	**Correlation Ratio**	**T- Value**	**T- Values @ 0.05**	**Remarks**
Untreated Bamboo Culms	0.213	1.35	1.76	NS
Treated with seawater	0.3621	2.45	1.76	S
Treated with seawater + Mango Polyphenol	0.532	2.81	1.76	S
(With Concrete Infill)	**Correlation Ratio**	**T- Value**	**T- Values @ 0.05**	**Remarks**
Untreated Bamboo Culms	0.213	1.35	1.76	NS
Treated with seawater	0.362	2.45	1.76	S
Treated with seawater + Mango Polyphenol	0.532	2.81	1.76	S

The table reveals a moderate to substantial correlation between the treatment period of bamboo culm, the bamboo species, and the types of bamboo treatment, both with and without concrete infill to the mechanical strength because of its correlation value ranging from 0.213 to 0.532. This also shows that bamboo culm treated with seawater and seawater plus mango polyphenol with or without concrete infill is significantly related to the mechanical strength [46] and the bamboo treatment period. This means that the bamboo’s culm treatment period is significantly effective for the mechanical strength of Bamboo reinforced concrete infill materials [58]. This implies that the longer the treatment period of bamboo culms with seawater and sweater plus polyphenol, the better mechanical strength.

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Vol: 66 Issue 04 | 2023
DOI 10.17605/OSF.IO/RJ876

Table 8: Two-way ANOVA with replications: Comparison of the Compressive strength of bamboo culm with concrete infill when untreated (kiln dried), treated with seawater, and treated with seawater plus mango polyphenol

Source of Variation	SS	df	MS	F	P-Value	F crit
Bamboo species	2236509	1	2236509	30.13	0.000	*4.30
Bamboo Treatments	2453964	10	245396.4	3.31	0.000	*4.29
Concrete infill	857490.9	10	85749.09	1.15	0.369	**2.29
Within	1632800	22	74218.18			
Total	7180764	43				

Reject Null Hypothesis because p < 0.05 (Means are Different)

****Accept Null Hypothesis because p > 0.05 (Means are not Different)***

The table reveals a significant difference between the mechanical strength of each sample or bamboo species because the F- value 0f 30.13 exceeds the F- critical values of 4.30 tested at 0.05 level of confidence. This rejects the null hypothesis. Therefore, there is a significant difference between the bamboo species and its mechanical strength when subjected to flexural and compression tests. Thus, each bamboo species has its unique mechanical strength. This implies that each bamboo species has distinct compressive characteristics [59]. The samples or each bamboo species were subjected to three different treatments [60], the kiln dying (untreated sample), treated with seawater, and treated to seawater plus mango polyphenol, has significantly contributed to the bamboo quality and increased the mechanical strength because of the F value of 3.31 did not exceed the f critical values of 4.29 tested at 0.05 level of significance. Therefore, bamboo treatments are used to affect the mechanical strength of bamboo culm, either reinforced with concrete infill or not. The treatment period of bamboo culm shows that it has significantly different results on the mechanical strength of bamboo culms with or without concrete infill. The table also reveals that the sample interaction is comparable when curing age is considered. The result also shows that concrete curing age has no significant difference in the mechanical strength of bamboo culm with concrete infill [61]. This means the curing age of the samples with concrete shows a significant increase in mechanical strength in all bamboo species subjected to different treatments and treatment periods, and curing periods. This implies that the mechanical strength of each bamboo species was affected by the bamboo treatments, bamboo treatment periods, and when concrete infill was introduced [62].

CONCLUSION

Bamboo is a versatile material that can be reinforced with concrete infill. The whole bamboo culm treated with seawater and mango polyphenol extract showed remarkably increased mechanical strength in both subjected to flexural and compression tests [46]. Among the species, ***Dendrocalamus Asper Schultes*** and ***Dendrocalamus Merrillianos Elmer*** had the highest mechanical strength without or with concrete infill. The concrete infill to the whole bamboo culm is effective, increasing the mechanical

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Vol: 66 Issue 04 | 2023
DOI 10.17605/OSF.IO/RJ876

strength [63]. Among the species, ***Dendrocalamus Asper Schultes*** and Dendrocalamus ***Merrillianos Elmer*** had the highest mechanical strength treated with Mango Polyphenol extract treated in 56 days. The curing age of concrete and treatment of bamboo culm with seawater plus mango polyphenol affects the mechanical strength of reinforced bamboo concrete subjected to concentrated flexural test and compression test [64]. The treated whole bamboo culm gained higher mechanical strength than the untreated one. Also, the Treated reinforced bamboo culm with concrete infill had higher mechanical strength when compared to untreated [65].

Treated Bamboo in seawater plus mango polyphenol extract increases the mechanical strength of any bamboo species [46], wherein the bamboo culm diameter with proper treatment significantly affects the mechanical strength of bamboo culm [66]. Each Bamboo species' mechanical strength was compared, and it was found that each bamboo species had distinct bending compressibility behavior [67]. The Concrete Curing age had no significant relationship to the compressive strength of Bamboo reinforced concrete infill [68]. However, concrete infill significantly affects the increased mechanical strength of bamboo culm concrete infill [69]., thus reinforced bamboo culm concrete infill is good construction material.

RECOMMENDATIONS

Bamboo concrete infill is suitable as a low-cost material for flexural and bending; however, proper treatment at the certain treatment period and curing of concrete infill must be addressed, and proper bamboo culm drying must be performed. Among the bamboo species, Dendrocalamus ***Merrillianos Elmer*** without infill is recommended for beams and joists. ***Dendrocalamus Asper Schultes*** is recommended as flexural materials for beams and joists with concrete infill cured for longer periods. Therefore, Concrete infill is recommended for the column and beam structures. Bamboo treatment is needed to increase the compressibility and bending strength of the bamboo culm. Further studies such as concrete bamboo molecular interactions, seawater and mango polyphenol, and bamboo molecular interlink are recommended for further study.

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