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MECHANICAL STRENGTH OF TREATED PHILIPPINE BAMBOO MORTAR INFILL JOINT CONNECTION FOR CONSTRUCTION

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Abstract

Bamboo is commonly used for building construction. This plant is widespread and abundant in the Philippines, where some areas of the country use bamboo for construction, such as the structural parts of buildings. A crucial issue in bamboo construction is the connection system, where the connection failure develops at a low level of loading associated with bamboo splitting. This study addresses the problems in a joint between bamboo connections and determines the structural strength and durability of the Philippine bamboo mortar infill joint connection. The experimental research was conducted by carefully choosing bamboo species such as *Bambusa Blumeana Schultes*, *Dendrocalamus Merrillianus Elmer*, *Bambusa Vulgaris Schrad,* and *Dendrocalamus Asper Schulte.* These were treated by soaking in seawater and mango polyphenol extract, mortar in filling, bolt, and bamboo slats, and slaving and subjecting the samples to compression and bending tests. The results show that the mechanical strength of bamboo mortar infill joint connections increases, whereas bolted–mortar infill connections are more durable when treated with bamboo compared with untreated bamboo, and significant correlations of the bamboo mechanical strength with the properties of mortar infill, bamboo slats, bolts, treatments, curing age, and bamboo mechanical properties. Furthermore, these bamboo joint mortar infill connections resolved the failures among environmentally friendly, economical, and structurally sound connections.

Keywords: Bamboo, Bamboo Mortar Infill, Bamboo Connections, Bamboo Joint, Bamboo Materials, Bamboo Joint Connections, Philippine Bamboo

INTRODUCTION

Bamboo is usually used for building constructions, and this plant is prevalent and abundant in the Philippines. Some areas in the country and the world utilize bamboo to construct construction parts of the building like trusses, joists, walls, beams, and columns. Bamboo possesses excellent mechanical properties compared with other commonly used construction materials. The connection system is crucial in bamboo construction (Hong C. t al., (2020). Review of connections for engineered bamboo structures. The connection failure develops at a low level of loading associated with bamboo splitting. Traditional connections involve friction-tight lashings such as ropes, rattans, and cords of dried grasses and pin-and-socket connections such as dowels and pegs. However, more recent advances have involved integration with steel hardware and concrete. In addition, nails, bolts, screws, and a wide variety of cement have been used for coupling join bamboo sections structurally connections, but expensive joints such as those used in fishing poles, which are mechanical fastenings that have failed because of the tendency of the bamboo to split from the bulkhead to the bulkhead. Several studies have been conducted on the construction of joints for structural durability and reliability. This is true

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according to the jointing method, Steel-bamboo composite joint, simplified mechanical model, and method to calculate the rotation of the connection.

The sleeve-bolt and groove-plate connections (Wang et al., 2020). The connections between bamboo parts include sleeve-bolt-cement and sleeve-modified gypsum (Yu et al., 2015). As stated by (Moreira et al., 2022) Connection, combining bamboo cable members such as overall joints and steel components (Ghavani & Moreira, 1996) joint, using aluminum or steel plates and pin joints in double-pin-ended joints. Aluminum Plate pin-end Joint, Mentioned (Disen & Clouston, 2013). According to (Seixas et al., 2022), A simple bamboo pin joint is commonly used in many types of structures, especially in plane and space structures and nonlinear pressure distributions at the contact area of a steel pin in a circular bamboo hole (Moran et al., 2017). The Mechanical joints are inefficient, and their construction is a tedious task, which increases labor costs and prevents their widespread use in housing projects. In addition, the connection comprises screw bars, plates, fish-mouth cuts, and injection with mortar (Moran & Garcia, 2019); (Villegas et al., 2019). A simple new joint to connect bamboo slats is favorable. Bamboo jointing is the most challenging part of bamboo building construction; most bamboo structural failures occur at the joints (Moran et al., 2017). However, several studies still required additional studies to find relatively perfect solutions. An early study by (Rizzuto et al., 2010) sectional building structures and couplings and connections, therefore, mainly to sectional construction kits utilizing sections of natural bamboo as elements. The extensive use of bamboo for structural frame purposes in making various devices, building structures, etc., has been minimal because of the impracticability of coupling bamboo sections together to form strong (Liese et al., 2015).

According to (Ghavani & Moreira,1996), In the assembly of space structures, the most challenging part is the joining of elements (Martinsen et al., 2015). The use of aluminum or steel plates and pin joints in bamboo, considering the safe distance between the holes and the end of the bamboo pole (Hong et al., 2019). A bamboo diaphragm under the pinhole reduces the risk of splitting failure, and Reinforcing bamboo under a steel pinhole improves its split failure Moreira, L. E., & Ghavami, K. (2012). Bamboo joints at the hole can be improved by reducing the stress concentration factors by applying reinforcing elements such as natural fiber strap composites close to the hole (Correal f., 2020). As stated by (Fu et al.,2012), sleeve-bolt and groove-plate connections are two effective forms of bamboo joints under tension and compression loads, and the brittle failure mode of shearing-split typically governs the strength of these two connections (Fu et al., 2012). The joint with the sleeve-cement connection was found to behave more ductile under tension and possesses higher strength under compression than those with the sleeve-bolt and groove-plate connections (Zhou et al., 2022). The sleeve-cement connection ensures an effective transition of the axial load in the bamboo joint (Paraskeva et al., 2019). The shearing split governs the failure mode of the joints with the sleeve-bolt connection and the groove-plate connection (Ghavami et al.,1996). The performances of these two bamboo joints are somewhat brittle under axial load (Liu et al., 2020). The failure mode of the sleeve cement is a relative slip between the bamboo and cement mortar, and this joint has good ductility (Ban et al., 2020). Under tension loading, the

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deformation capacity of the sleeve cement is more than twice that of the other types of bamboo joints (Wang et al., 2019). Under compression loading, the load capacity of the sleeve cement is more than three times that of the other two types of bamboo joints (Huang, T., & Zhou, 2022).

As stated by (Cao et al., 2023), Major forms of bamboo joints mainly rely on the bolts and shear strength of bamboo, and the brittle failure mode of shearing-split usually governs the strength of the connection (Tinkler-Davies et al., 2022). The bamboo joints behave ductile under tension and possess high strength under compression but leave much to be optimized in its design (Vallée et al., 2017). A new configuration of the sleeve-gypsum bamboo joint was designed by replacing cement with gypsum and improving the surface treatment of the inner walls of the bamboo tube (Zhou et al., 2022); (Fu et al.,2013). The connection to improve the joint region's stiffness and overall performance of the steel plates welded to the core of the connection (Yu-shun et al., 2013), the number of bolts has little effect on the shear deformation at the core and the ultimate load capacity of the joints (Feng et al.,2022). However, changes in the stiffener and weld size of the steel tube have apparent influences on the rotational stiffness and anti-seismic parameters (Chen et al., 2019). Assembled structures safely have double-pinned-ended joints, particularly for connection designs (Disen & Clouston, 2013). As stated, (Awaludin & Andriani, 2014), bamboo construction is a connection system where the failure of the connection develops at a low level of loading associated with bamboo splitting; single-bolted bamboo joints in four joints are loaded in the perpendicular loading direction (Sonar & Siddhaye, 2009)., and the rest are loaded in the parallel loading direction or overlap connections (Villegas et al., 2015). The joint connects two GA slats using two small, curved steel plates, a bolt, and a nut, which are used to apply high compressive deformation in the radial direction (Ma et al., 2016). A simple new joint to connect GA slats was developed by applying a high compressive strain along the thickness of the slats or the radial direction using a bolt, nut, and two small, curved steel plates (Gottron et al., 2014). The mechanical tests of the proposed joint showed failures by shearing on the planes parallel to the fibers (Moran & García, 2019). Joints recommended using bolts, curved cuts, and mortar injection to increase the transverse strength (Garcia et al., 2017). The rings apply external pressure to the culm and create a compressive circumferential stress distribution, which counteracts the creation of longitudinal splits (Su et al., 2023). Moreover, even after the initial fissures, the ring avoids separating the parts, which generates ductile failure modes (Garcia et al., 2015). The types of connections can partially restrict the rotation of the supports, despite being essential for modeling and structural design (Andrade Pardo et al., 2016). Influence of each component on connection behavior under different configurations (Pedro et al., 2015). The joint strength and ductility of the proposed connection were higher than those reported in another study for a connection composed of screw bars, plates, fish-mouth cuts, and mortar injection (Widyowijatnoko & Harries,2020); (Moran et al., 2015). Mechanical joints are inefficient, and their construction is a tedious task, which increases labor costs and prevents their widespread use in housing projects (Moran et al., 2017), Metal connectors for GA elements increase the efficiency of the joints and reduce construction time (Lao, 2021).

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The connection system determines the strength of the bamboo truss structures (Madsar, 2017). The bolt-tightening force on the truss structure significantly affected the strength of the bamboo truss structure (Madsar et al., 2019). Variations in bolt tightening force on connection system of bamboo truss structure with a wooden clamp (Masdar et al., 2017). Three connection design properties (dowel embedment strength, slip modulus, and screw withdrawal capacity) for one species of bamboo (*Guadua angustifolia Kunth*) using experimental methods adopted from timber engineering (Trujillo & Malkowska, 2018), some researchers have identified problems in jointing between bamboo connections (Sreadha & Pany, 2020). Connections in bamboo constructions are regarded as the weakest parts and have hindered the optimal utilization of excellent bamboo engineering properties (Janssen, 2000); (Yang et al., 2021). The goal of this study is to determine the Structural strength of Bamboo mortar infill joint connection (Pradhan et al., 2020) to compare the structural strength of the bamboo mortar infill joints of untreated and treated bamboo (Chen et al., 2022), and to determine the (Cabanas,2018). Significant correlations between the bamboo structural strength and the properties of mortar infill, bamboo slats, bolts, and bamboo mechanical properties.

MATERIALS AND METHODS

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 (Ruales, 2023), precisely the (a) ***Dendrocalamus Asper Schultes (***Febrianto,2012)***, (b)Bambusa Blumeana Schultes*** (Colis,1996), ***(c) Bambusa Vulgaris Schrad*** (Wahab et al.,2009) ***and (d) Dendrocalamus Merrillianos Elmer*** (Revel,2022).

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

The selected Philippine bamboo species were cut with 300mm to 600 mm lengths with one or two nodes. Each bamboo species had three samples for each treatment and was stocked, as shown below.

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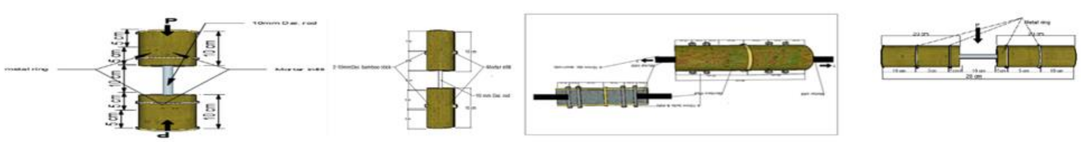
(e) Harvested Matured bamboo (f) Cut with one -node (g) Cut with two-nodes

After cutting the bamboo according to a specified length, the Bamboo treatments were undertaken as follows: (**h) Untreated -Kiln Drying** (Tang,2013), **naturally soaked, (i) Treated with seawater** (Amatosa et al.,2019)**, and (j)Treated with seawater plus Mango Polyphenol** (Amatosa,et al.,2021). The treatment was soaked natural days, 14 days, 28 days, and 56 days.

(h) (i) (j)

Setting up the Bamboo schematic diagrams for bolted connections (Hong et al.,2020), (k) metal ring as connectors fasteners for the set-up of compression (Garcia et al., 2017), (l) Bamboo thongs as connectors for compression (McClure, 1953). (m) bolted connections for tensile strength (Awaludin & Andriani,2014)., and (n) Metal rings as fasteners for mutual connections for the Flexural test (Khoo et al., 2013).



(k) (l) (m) (n)

It was followed by the 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 **(m), (n), (o), (p)** at average room temperature for curing.

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(m) (n) (o) (p)

After assembling, curing of concrete infill followed of the Infill the Bamboo culms with concrete cured for 7, 14, 28, and 56 days according to ASTM standards. The bamboo concrete infill was cured at room temperature figures q to s.

(q) (r) (s)

Then, after curing the Concrete in fill inside the bamboo Culm each sample was tested for its flexural, Tensile, and Compressive strength using Universal Testing Machine. The results were tabulated and analyzed carefully. Laboratory tests were performed according to ASTM standards.

(t) (u) (v) (w)

RESULTS AND DISCUSSIONS

The mechanical strength of untreated and treated bamboo has been tested, as well as the mechanical strength in terms of flexure and bending, tension and compression of bamboo infill joint connections using different connectors and fasteners such as bolts sleeves, Bamboo thong sleeves, and metal ring sleeves. Table 1 reveals that Bamboo culm without concrete infill among the species ***Dendrocalamus Asper Schultes*** had the highest flexural strength of 274 MPa treated with seawater plus mango Polyphenol for 56 days, while *Bambusa Blumeana Schultes* has the highest flexural strength of 268 MPa when treated with seawater for 56 days, *Bambusa Vulgaris Schrader* has the highest flexural strength of 190 MPa when subjected to kiln drying for 56 days. The *Bambusa Vulgaris Schrader* increased flexural strength when treated for several days and a very minimal increase for *Dendrocalamus asper Schultes.* This implies that among the

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species, *Dendrocalamus Asper Schultes* has the highest flexural strength when untreated because of its cell wall, and treatment with seawater and a 10 percent solution of mango polyphenol extract affects the bending stress of bamboo culms subjected to a concentrated load at midspan.

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

Curing Age (days)	(Dendrocalamus Merrillianos Elmer			(Bambusa Vulgaris Schrader)			(Bambusa Blumeana Schultes)			Dendrocalamus Asper Schultes		
	Untreated DME	DME Treated w/ Seawater	DME Treated with seawater + Mango Polyphenol Extract	Untreated BVS	BVS Treated w/ Seawater	BVS Treated with seawater + Mango Polyphenol Extract	Untreated BBS	BBS Treated w/ Seawater	BBS Treated with seawater + Mango Polyphenol Extract	Untreated DAS	DASTreated w/ Seawater	DAS Treated with seawater + Mango Polyphenol
7 days	168	240	257	180	226	220	150	232	222	189	237	245
14 days	170	247	260	185	247	242	160	232	229	189	241	249
28 days	175	250	262	188	252	246	163	265	266	189	247	269
56 days	178	260	272	190	254	260	165	268	270	189	255	274

Table 2 shows the result of the flexural test of the bamboo joints using bamboo thong connections. The Dendrocalamus asper Schultes has the highest flexural strength of 13.78 MPa when treated with seawater plus mango polyphenol for 56 days. On the other hand, Bambusa Vulgaris Schrader has the lowest flexural strength either treated or untreated for several days, as the Bambusa Blumeana Schultes showed remarkable growth in flexural strength except for Dendrocalamus Merrillianos Elmer that have the lowest flexural strength. The treatment with seawater plus mango polyphenol affects the flexural stress of bamboo joints subjected to flexural loading at the midspan.

Table 2: Flexural stress of the joint mortar infill connection using bamboo thong fastener

Curing Age (days)	Dendrocalamus Merrillianos Elmer			Bambusa Vulgaris Schrader			Bambusa Blumeana Schultes			Dendrocalamus Asper Schultes		
	Untreated DME	DME Treated w/ Seawater	DME Treated seawater + Mango Polyphenol	Untreated BVS	BVS Treated w/ Seawater	BVS Treated with seawater + Mango Polyphenol	Untreated BBS	BBS Treated w/ Seawater	BBS Treated with seawater + Mango Polyphenol	Untreated DAS	DAS Treated w/ Seawater	DAS Treated with seawater + Mango Polyphenol
7	6.89	8.27	8.96	6.89	6.89	6.89	6.89	6.89	7.58	6.89	6.89	8.27
14	8.27	8.96	9.37	8.27	8.61	8.27	9.65	8.96	9.65	8.27	9.3	13.09
28	8.96	9.65	9.65	8.96	9.65	9.65	9.82	9.99	10.34	9.65	9.65	13.44
56	9.65	9.99	10.34	9.3	9.92	10.16	9.99	10.23	10.68	10.34	10.34	13.78

Table 3 shows the result of the flexural test of the bamboo joints using sleeve bolted connections, and Dendrocalamus Merrillianos Elmer has the highest flexural strength when untreated as well when treated with seawater and seawater pus mango polyphenol. On the other hand, the Dendrocalamus Merrillianos Elmer and Dendrocalamus Asper Schultes have put high strength in bending with 11.37 MPa and 11.02 MPa when treated with sweater plus mango polyphenol for 56 days, as of the *Bambusa Vulgaris Schrader* that has lowest flexural strength when sleeves with bolts. The *Dendrocalamus Merrillianos Elmer* has the highest flexural strength because of its thick cell wall, and treatment with seawater plus mango polyphenol affects the flexural stress of bamboo joints subjected to flexural loadings are midspan. This implies that bamboo infill joint connections fastened with sleeve bolts' flexural strength depends on the curing and

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treatment period and the treatment processes used. The flexural strength of each bamboo species depends on the treatment processes and the period of curing and treatments, wherein the bamboo treated with seawater plus mango polyphenol has the highest strength gained for 56-day treatments periods.

Table 3: Flexural stress of the joint mortar infill connection using sleeve bolt fasteners

Curing Age (days)	Dendrocalamus Merrillianos Elmer			Bambusa Vulgaris Schrader			Bambusa Blumeana Schultes			Dendrocalamus Asper Schultes		
	Untreated DME	DME Treated w/ Seawater	DME Treated with seawater + Mango Polyphenol	Untreated BVS	BVS Treated w/ Seawater	BVS Treated with seawater + Mango Polyphenol	Untreated BBS	BBS Treated w/ Seawater	BBS Treated with seawater + Mango Polyphenol	Untreated DAS	DAS Treated w/ Seawater	DAS Treated with seawater + Mango Polyphenol
7	6.89	6.89	6.89	6.89	6.89	6.89	6.89	6.89	7.58	6.89	6.89	6.89
14	8.27	8.27	8.96	8.27	8.27	9.65	8.27	8.96	9.65	8.27	8.27	9.65
28	8.96	9.65	10.34	8.27	8.96	9.99	8.27	9.3	9.65	8.96	8.96	10.34
56	9.65	**11.02**	**11.37**	8.27	9.65	10.34	8.96	**9.44**	10.47	8.96	9.65	11.02

Table 4 shows the result of the flexural test of the bamboo joints using metal ring connectors. The *Dendrocalamus Asper Schultes* had the highest flexural strength of 10.68 MPa, followed by the Dendrocalamus Merrillianos Elmer when treated with seawater plus mango polyphenol. On the other hand, the Bambusa Vulgaris Schrader has the lowest flexural strength because of its thin culm wall. The results also show that the treatment process and period of curing and treatment affect the flexural strength of the mortar infill joint connections using a metal ring.

Table 4: The flexural stress of the joint mortar infill connection using metal ring fasteners

Curing Age (days)	Dendrocalamus Merrillianos Elmer			Bambusa Vulgaris Schrader			Bambusa Blumeana			Asper Schultes		
	Untreated DME	DME Treated w/ Seawater	DME Treated with seawater + Mango Polyphenol	Untreated BVS	BVS Treated w/ Seawater	BVS Treated with seawater + Mango Polyphenol	Untreated BBS	BBS Treated w/ Seawater	BBS Treated with seawater + Mango Polyphenol	Untreated DAS	DAS Treated w/ Seawater	DAS Treated with seawater + Mango Polyphenol
7	6.89	6.89	6.89	6.89	6.89	6.89	6.89	6.89	7.58	6.89	**6.89**	**6.89**
14	8.27	8.27	8.96	8.27	8.27	8.27	8.27	8.75	8.96	8.27	**8.27**	**8.27**
28	8.96	9.3	9.65	8.61	8.96	9.65	8.96	8.96	9.65	8.96	**9.65**	**9.65**
56	9.65	9.99	10.34	9.23	9.3	9.99	9.65	9.44	9.99	9.65	**10.34**	**10.68**

Table 5 shows the result of the compressive test of the bamboo joints using the bamboo thong connection's compressive strength on the untreated part with 9.65 MPa for all connections when treated for 56 days. On the other hand, the *Dendrocalamus Asper Schultes* has the top compressive strength when cured and treated with seawater plus mango Polyphenol. This implies that seawater plus mango Polyphenol is a good bamboo treatment. The curing period and treatment period show the best when more extended periods. The highest compressive strength is caused by its thick cell wall, and treatment with seawater affects the compressive stress of bamboo joints subjected to compression loadings.

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Table 5: The compressive stress of the joint mortar infill connection using bamboo thongs as connectors

Curing Age (days)	Dendrocalamus Merrillianos Elmer			Bambusa Vulgaris Schrader			Bambusa Blumeana Schultes			Dendrocalamus Asper Schultes		
	Untreated DME	DME Treated Seawater	DME Treated seawater + Mango Polyphenol	Untreated BVS	BVS Treated Seawater	BVS Treated sweater + Mango Polyphenol	Untreated BBS	BBS Treated Seawater	BBS Treated seawater + Mango Polyphenol	Untreated DAS	DAS Treated Seawater	DAS Treated seawater + Mango Polyphenol
7	6.89	8.27	8.96	6.89	6.89	6.89	6.89	6.89	7.58	6.89	6.89	**8.27**
14	8.27	9.65	9.65	8.27	7.58	8.27	7.58	8.96	8.27	8.27	11.02	**13.09**
28	9.65	9.65	9.65	9.65	8.96	8.96	8.27	8.96	8.96	9.65	12.4	**13.09**
56	9.65	9.65	10.34	9.65	9.65	9.65	9.65	9.65	9.65	9.65	13.09	**13.78**

Table 6 reveals that when the bamboo infill joint connection was fastened by bolt sleeve, the *Dendrocalamus asper Schultes* garnered the highest compressive strength of 9.89 MPa (7 days) treated with seawater plus mango polyphenol. The other three species are *Dendrocalamus Merrillianos Elmer, Bambusa Blumeana Schultes, and Dendrocalamus Asper Schultes*. On the other hand, when Bambusa Vulgaris Schrader, when treated and cured for 56 days with seawater plus mango polyphenol, has the highest compressive strength of 11.34 MPA. At the same time, the Dendrocalamus compressive strength of 9.65 (14 days) and 10.40 MPa (28 days) when treated with seawater plus mango polyphenol. The results imply that seawater plus mango polyphenol is beneficial for bamboo preservations.

Table 6: The compressive stress of the joint mortar infill connection using bolts sleeve fastener

Curing Age (day)	Dendrocalamus Merrillianos Elmer			Bambusa Vulgaris Schrader			Bambusa Blumeana Schultes			Dendrocalamus Asper Schultes		
	Untreated DME	DME Treated Seawater	DME Treated seawater + Mango Polyphenol	Untreated BVS	BVS Treated Seawater	BVS-treated seawater + Mango Polyphenol	Untreated BBS	BBS Treated Seawater	BBS Treated seawater + Mango Polyphenol	Untreated DAS	DAS Treated Seawater	DAS Treated seawater + Mango Polyphenol
7	6.89	7.9	8.9	6.89	6.9	7.8	6.89	6.89	7.58	7.89	8.89	**9.89**
14	8.27	8.97	**9.65**	8.27	8.27	8.27	8.27	7.96	**9.65**	8.7	8.27	**9.65**
28	8.96	8.98	10.34	8.27	9.65	9.65	8.27	8.65	10.34	9.5	10.34	**10.4**
56	9.65	10.65	11.02	8.27	10.34	**11.34**	8.27	9.34	10.84	10.3	10.34	11.3

Table 7 show the result of the compressive test of the bamboo joints connections using Metal ring as fasteners, wherein the *Dendrocalamus Merrillianos Elmer* has the highest compressive strength of 7.89 MPa, 8.70 MPa, 8.96 MPa, and 9.65 MPa respectively when untreated and cured for 7, 14, 28 and 56 days respectively. When the seawater was used for treatment, *Dendrocalamus Asper Schultes* has the highest compressive strength of 8.89 MPa when treated and cured for seven days and 9.27 MPa when treated and cured for 14 days, while the *Dendrocalamus Merrillianos Elmer* has highest compressive strengths of 9.75 MPa (28 days curing and treatment) and 10.13 MPa (56 days curing and treatment).On the other hand, the *Dendrocalamus Asper Schultes*, when Treated with seawater plus Mango Polyphenol, compressive strength of 9.89 MPa (7 days), 10.27 MPa (14 days), 11.65 MPa (28 Days), and 12.68 MPa (56 days). The *Bambusa Vulgaris Schrader* and *Bambusa Blumeana Schultes* have low tensile strength compared to other species. The compressive strength of the *Dendrocalamus Merrillianos Elmer* and *Dendrocalamus Asper Schultes* has the highest compressive cause of its thick cell wall,

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and treatment with seawater plus mango polyphenol affects the tensile stress of bamboo joint connections fastened by metal ring subjected to compression load at both ends.

Table 7: The compressive stress of the joint mortar infill connection using a Metal Ring fastener

Curing Age (day)	Dendrocalamus Merrillianos Elmer			Bambusa Vulgaris Schrader			Bambusa Blumeana Schultes			Dendrocalamus Asper Schultes		
	Untreated DME	DME Treated Seawater	DME Treated seawater + Mango Polyphenol	Untreated BVS	BVS Treated Seawater	BVS-treated seawater + Mango Polyphenol	Untreated BBS	BBS Treated Seawater	BBS Treated seawater + Mango Polyphenol	Untreated DAS	DAS Treated Seawater	DAS Treated seawater + Mango Polyphenol
7	**7.89**	6.9	8.9	6.8	6.89	6.89	6.89	6.89	7.58	7.59	**8.89**	**9.89**
14	**8.7**	8.96	9.65	7.27	8.27	8.27	8.27	8.27	8.27	8.27	**9.27**	**10.27**
28	**8.96**	**9.75**	9.85	7.96	9.3	9.65	8.65	8.96	8.96	8.65	9.65	**11.65**
56	**9.65**	**10.13**	10.47	8.65	9.65	9.99	8.96	9.3	9.58	8.85	9.99	**12.68**

Table 8 shows the tensile test of the bamboo infill joints connections using bolts fasteners when untreated it shows that *Dendrocalamus Merrillianos Elmer* had the highest tensile strength of 8.96 MPa and 8.99 MPa kiln dried for seven days and 14 days, and *Dendrocalamus Asper Schultes* tensile strength when untreated for 28 days and 56 days increased and surpassed other species with a tensile strength of 9.90 MPa and 10.65 MPa respectively. The Bambusa Blumeana Schultes joints infill connections fastened with metal rings when treated with Seawater show remarkable results of 11.26 MPa (7 days curing), 11.39 MPa (14 days Curing), 11.71 MPa (28 days) and 12.06 MPA (56 days). The *Dendrocalamus Asper Schultes* shows the highest tensile strengths when treated with seawater plus Mango Polyphenol having a tensile strength of 12.02 MPA (7 days curing), 12.71 MPa (14 days curing),13.06 MPa (28 days curing) and 13.09 MPa (56 days curing). The seawater and seawater plus treatment was an effective treatment for bamboo that has the highest tensile stress when joints were subjected to tensile load at both ends, among others curing period remarkably shows of incremental increase of the tensile stress to all bamboo species disregard of the treatment process; this shows the more prolonged the curing period, the higher tensile strength.

Table 8: Tensile strength of bamboo joints with mortar infill connections using bolt fasteners

Curing Age (day)	Dendrocalamus Merrillianos Elmer			Bambusa Vulgaris Schrader			Bambusa Blumeana Schultes			Dendrocalamus Asper Schultes		
	Untreated DME	DME Treated Seawater	DME Treated seawater + Mango Polyphenol	Untreated BVS	BVS Treated Seawater	BVS Treated Seawater + with Mango Polyphenol	Untreated BBS	BBS Treated Seawater	BBS Treated seawater + Mango Polyphenol	Untreated DAS	DAS Treated Seawater	DAS seawater + with Mango Polyphenol
7	**8.96**	10.34	10.96	8.9	9.27	9.96	8.27	**11.26**	11.65	8.7	11.2	**12.02**
14	**8.99**	11.02	11.96	8.91	9.97	10.65	8.9	**11.39**	11.99	8.96	11.37	**12.71**
28	9.65	11.37	12.65	9.05	10.65	11.34	8.96	**11.71**	12.34	**9.9**	11.61	**13.06**
56	10.34	11.71	12.99	10.14	11.34	12.37	9.65	**12.06**	12.51	**10.65**	12.06	**13.09**

Table 9 shows the result of the tensile test of the bamboo joints using metal ring connections for untreated bamboo. It shows that Dendrocalamus Merrillianos Elmer has the highest tensile strength of 10.80 MPa when untreated for seven days of curing and for 56 days with a tensile strength of 12.24 MPa. On the other hand, the Dendrocalamus Merrillianos Elmer tensile strength for 7 and 14 days treated with seawater plus mango polyphenol shows remarkable tensile strength. The same bamboo specie had the highest tensile strength of 12.51 MPa when treated with seawater for 56 days, and Dendrocalamus Asper Schultes, when treated with seawater plus mango polyphenol, put

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the top strength in tensile of 12.85 MPa and 13.06 MPa when treated and cured for 28 days and 56 days respectively. Bambusa Vulgaris Schrader and Bambusa Vulgaris Schrader have low tensile strength, while the two other species has the highest tensile strength because of their thick cell wall. The treatment process and period of curing with seawater plus mango Polyphenol affect the tensile stress of bamboo joint infill connections fastened with metal rings subjected to tensile load at both ends.

Table 9: Tensile strength of bamboo joints connections with mortar infill using metal ring fasteners

Curing Age (day)	Dendrocalamus Merrillianos Elmer			Bambusa Vulgaris Schrader			Bambusa Blumeana Schultes			Dendrocalamus Asper Schultes		
	Untreated DME	DME Treated w/ Seawater	DME Treated with seawater + Mango Polyphenol	Untreated BVS	BVS Treated w/ Seawater	BVS Treated with seawater + Mango Polyphenol	Untreated BBS	BBS Treated w/ Seawater	BBS Treated with seawater + Mango Polyphenol	Untreated DAS	DAS Treated w/ Seawater	DAS Treated with seawater + Mango Polyphenol
7	**10.8**	10.88	**11.22**	8.84	8.88	8.98	9.5	9.59	9.62	10.52	10.72	11.2
14	10.88	11.22	**11.56**	8.84	9.18	9.52	9.52	9.86	10.2	10.52	10.84	10.54
28	10.88	11.39	12.04	8.84	9.52	9.86	9.52	10.2	11.2	10.52	11.2	**12.85**
56	**12.24**	**12.51**	12.85	9.52	10.03	10.54	10.2	10.25	11.54	11.2	11.56	**13.06**

Table 10 reveals that Bamboo joints using bamboo thongs connection with mortar infill that *Dendrocalamus Merrillianos Elmer* and *Dendrocalamus Asper Schultes* had the highest tensile strength of 13.53 MPa when treated for 56 days with seawater plus mango Polyphenol. The *Dendrocalamus Asper Schultes* shows a remarkable tensile strength of 11.51 MPa and 12.51, respectively, when untreated and treated with seawater for 56 days. The *Bambusa Blumeana Schultes* had a very limited increased in tensile strength, *Bambusa Vulgaris Schrader* had the highest tensile strength of 11.84 MPa when treated with Mango Polyphenol for 14 days and the *Dendrocalamus Merrillianos Elmer* had the highest tensile strength of 12.84 MPa when treated with Seawater plus mango polyphenol for 28 days. Among the species, *Dendrocalamus Merrillianos Elmer* and *Dendrocalamus Asper Schultes* have the highest tensile strength when untreated because of their thick cell wall. The treatment of seawater plus mango polyphenol for a more extended period increases the tensile strength; longer curing of bamboo culm concrete infill can increase the tensile strength to hold the bamboo thongs connection as fasteners that results to a higher tensile stress of bamboo joint subjected to shear load at both ends.

Table 10: Tensile strength of bamboo joints with mortar infill using bamboo thong connections

Curing Age (days)	Dendrocalamus Merrillianos Elmer			Bambusa Vulgaris Schrader			Bambusa Blumeana Schultes			Dendrocalamus Asper Schultes		
	Untreated DME	DME Treated w/ Seawater	DME Treated with seawater + Mango Polyphenol	Untreated BVS	BVS Treated w/ Seawater	BVS Treated with seawater + Mango Polyphenol	Untreated BBS	BBS Treated w/ Seawater	BBS Treated with seawater + Mango Polyphenol	Untreated DAS	DAS Treated w/ Seawater	DAS Treated with sea water + Mango Polyphenol
7	9.52	9.52	10.84	8.16	9.16	9.84	8.52	10.52	11.18	**9.52**	10.52	10.2
14	10.2	10.54	11.8	10.2	11.16	**11.84**	9.52	10.86	11.35	10.52	10.86	11.2
28	10.54	10.68	**12.84**	10.2	11.84	12.52	10.2	11.2	11.86	11.2	12.2	12.56
56	10.88	11.88	**13.53**	10.8	11.8	13.2	10.54	11.56	12.2	**11.54**	**12.51**	**13.53**

CONCLUSIONS

Bamboo construction Structural systems' principal technical difficulties involved with this application will be carefully investigated and analyzed to address jointing systems that are more durable and structurally sound. Additionally, several tentative structural jointing

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styles will be developed to explore the applications of this bamboo composite structure. The joining process of bamboo to address the existing solutions on bamboo structural joint connections. To overcome this problem, a new bamboo connection uses three fasteners: sleeve bolts, a bamboo thong, and a ring clip to hold the bamboo mortar infill, which can accommodate various culm sizes for Joint Infill connections. The mechanical strength of untreated and treated bamboo has been tested, as well as the mechanical strength in terms of flexure and bending, tension and compression of bamboo infill joint connections using different connectors and fasteners such as bolts sleeves, Bamboo thong sleeves, and metal ring sleeves. Among the fasteners, the sleeve bolted connections show the best infill joint connections compared to bamboo thongs and metal rings as fasteners.

The Dendrocalamus Asper Schultes has the highest flexural strength when untreated and treated with seawater plus mango polyphenol because of its cell wall, and treatment with seawater plus 10 percent solution of mango polyphenol extract and the Bambusa Vulgaris Schrader has the lowest flexural strength when untreated. The Dendrocalamus Merrillianos Elmer and Dendrocalamus Asper Schultes joint infill connection fastened by sleeve bolts, metal rings, and bamboo things have high strength in tensile when treated with sweater plus mango polyphenol for 56 days subject to flexural loadings are midspan. The Dendrocalamus Asper Schultes bamboo joints infill connections fastened with sleeve bolts, bamboo thongs, and metal rings have the highest compressive strength when cured and treated with seawater plus mango Polyphenol for 56 days. The Bambusa Vulgaris Schrader and Bambusa Blumeana Schultes have low mechanical strength compared to other species. The compressive strength of the Dendrocalamus Merrillianos Elmer and Dendrocalamus Asper Schultes has the highest compressive strength because of their thick cell wall, and treatment with seawater plus mango polyphenol affects the tensile stress of bamboo joint connections. The seawater plus mango polyphenol treatment was an effective treatment for bamboo that has the highest mechanical stress when joints were subjected to tensile, bending, and compression test, among others curing period remarkably shows of incremental increase of the mechanical stress to all bamboo species disregarding of the treatment process. This shows that the longer the curing period, the higher the tensile strength, thus the treatment of seawater plus mango polyphenol for a more extended period increases the mechanical strength; longer curing of bamboo culm concrete infill can increase the mechanical strength to hold the infill joint fasteners. The results imply that seawater plus mango polyphenol is beneficial for bamboo preservation.

RECOMMENDATIONS

Bamboo construction Connecting Joints utilization of excellent bamboo engineering properties. Bamboo joint mortar infill connections will resolve failures among bamboo joint connections. Thus, bamboo infill joint connections fastened with sleeve bolts, bamboo thongs, and metal rings were environmentally friendly, economical, and structurally sound connections to develop a marketable product of bamboo jointing methods. Designers and engineers should use various other connection details to create bamboo structure

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standard connections available in the market at a low cost using economically, environmentally, and socially acceptable by the consumers.

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