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Bonding Strength of Bamboo Reinforcement in Concrete – A Systematic Literature Review (SLR)

(Kekuatan Ikatan Tetulang Buluh Dalam Konkrit – Kajian Literatur Sistematik)

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ABSTRACT

Towards sustainable environmental goals, the utilization of agricultural waste as concrete material in the low-cost construction industry has received special interest from many researchers. It is the best approach in converting waste into valuable sustainable products which consequently reduces abundant of the waste and avoid environmental pollution. Literature proved that bamboo has high tensile strength and the mechanical properties of bamboo are almost similar to steel reinforcement, besides the advantage of its lightweight and cost-effective. In this study, a Systematic Literature Review (SLR) is conducted to review the behaviour of the bonding strength of bamboo reinforcement in concrete. The SLR is proposed based on the widely adopted review protocol named 'Reporting standards for Systematic Evidence Syntheses' (ROSES). The proposed SLR procedure is critically discussed, starting from the formulation of the research question until the process of data abstraction and analysis. Particular emphasis is given on the different types of behaviour of bonding strength developed in bamboo reinforced concrete based on results of the pull-out test. Different types and behaviour of bamboo bonding reinforcement are studied and discussed. The study highlights the mechanical properties of bamboo as an alternative reinforcement in concrete and types of bamboo reinforced structural components. This reviews also compared the methodology adopted for surface treatment and preparation of bamboo reinforcement.

Keywords: Agriculture waste; bonding; bamboo reinforcement; concrete; pull-out test

ABSTRAK

Dalam menuju ke arah matlamat kelestarian alam sekitar, penggunaan sisa pertanian sebagai bahan konkrit dalam industri pembinaan kos rendah telah menarik minat khusus dari banyak penyelidik. Ini adalah pendekatan terbaik dalam menukar sisa menjadi produk lestari yang berharga yang seterusnya mengurangkan perlambakan sisa pertanian dan mengelakkan pencemaran alam sekitar. Literatur membuktikan bahawa buluh mempunyai kekuatan tegangan tinggi dan sifat mekanik buluh hampir sama dengan tetulang keluli, selain kelebihannya yang ringan dan menjimatkan. Dalam kajian ini, Kajian Literatur Sistematik (SLR) dilakukan untuk mengkaji tingkah laku kekuatan ikatan tetulang buluh dalam konkrit. SLR diusulkan berdasarkan protokol tinjauan yang diadopsi secara meluas bernama 'Standar pelaporan untuk Sistematik Bukti Sintesis' (ROSES). Prosedur SLR yang dicadangkan telah dibincangkan secara kritis, bermula dari rumusan persoalan kajian hingga proses pengambilan dan analisis data. Penekanan khusus diberikan pada pelbagai jenis tingkah laku kekuatan ikatan yang dikembangkan dalam konkrit bertetulang buluh berdasarkan hasil ujian tarik keluar tetulang. Pelbagai jenis dan tingkah laku pengukuhan ikatan buluh dikaji dan dibincangkan. Kajian ini memberi tumpuan kepada sifat mekanik buluh sebagai tetulang alternatif dalam konkrit dan jenis komponen struktur bertetulang buluh. Ulasan ini juga membandingkan metodologi yang digunakan untuk rawatan permukaan dan penyediaan tetulang buluh.

Kata kunci: Sisa pertanian; ikatan; pengukuhan buluh; konkrit; ujian tarik keluar

INTRODUCTION

construction industry has increased in an urban city, whereby concrete materials is widely used in the building construction because of its ability to sustain the imposed load with low construction cost. Although concrete has high compressive strength and good heat resistance, however, it has low tensile stress resistance.

However, towards sustainable environmental goals, a lot of innovation has been done to produce green concrete by adding or replacing some amount of concrete material with natural agricultural waste (hereafter known as agro-waste). These new innovations have received special interest from many industrial and research engineering parties. The utilization of agro-wastes in the construction industry become one of the best approaches in converting the wastes into valuable sustainable products, which consequently solve abundant of agro-waste and avoid environmental pollution. Numerous researches have been conducted to investigate the behaviour and effectiveness of utilizing the agro-waste as a construction material for concrete production (Amit et al. 2015).

In addressing the advantages of agro-waste, in this study, the behaviour of bamboo reinforcement in concrete is critically discussed by performing the Systematic Literature Review (SLR). Literature proved that bamboo has a high tensile strength which is similar to steel reinforcement. Besides that, the use of bamboo reinforcement promises advantage of its lightweight and is cost-effective. In this study, a Systematic Literature Review (SLR) is conducted based on the widely adopted review protocol named 'Reporting standards for Systematic Evidence Syntheses' (ROSES). The SLR procedure proposed in this study is critically discussed, starting from the formulation of the research question until the process of data abstraction and analysis. Particular emphasis is given on the Behaviour of bonding strength of bamboo reinforced in concrete based on results of the pull-out test. Different types and behaviour of bamboo bonding reinforcement are studied and discussed. The study highlights the application and mechanical properties of bamboo as an alternative reinforcement in concrete. This review also compared the methodology adopted for surface treatment and preparation of bamboo reinforcement. Furthermore, this study provides information on the utilization of bamboo waste as a new construction material and offers a solution to convert abundant of bamboo wastes into valuable products.

RESEARCH METHODOLOGY

REVIEW PROTOCOL - ROSES

ROSES review protocol is used as guidelines in performing systematic literature review (SLR) of the present study. Reporting standards for Systematic Evidence Syntheses, as illustrated in Figure 1 is a review protocol which explicitly designed for SLR. Previous researchers widely use the ROSES (Haddaway et al. 2018; Cook et al. 2013; Edridge et al. 2015; Azril et al. 2020). Based on ROSES, the procedure of conducting SLR includes four significant process which are; (1) formulation the research question, (2) systematic searching strategies, (3) quality appraisal, and (4) data abstraction and analysis. In step (2), systematic searching strategies, three sub-process is required, which consists of identification, screening, and eligibility of collected articles. Throughout the SLR procedure, only the high quality of articles related to the main research question are selected and reviewed.

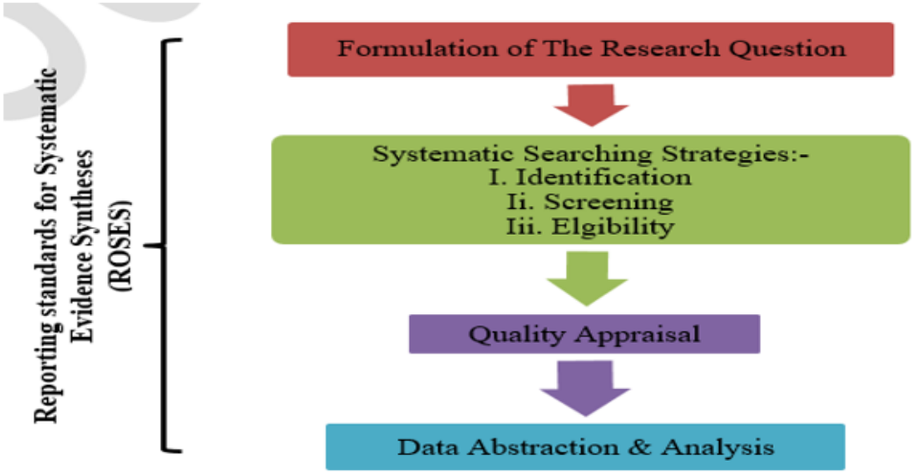

FIGURE 1. ROSES review protocol (modified from Haddaway et al. 2018)

SYSTEMATIC LITERATURE REVIEW (SLR)

As mentioned earlier, the proposed SLR of this study was designed based on the ROSES review protocol. Figure 2 illustrates the SLR procedure for investigating the behaviour of adhesive strength development between bamboo reinforcement and concrete. Four main processes for performing the SLR includes the formulation of the research question, systematic searching strategies, quality appraisal, and data abstraction and analysis. The number of articles (n) was collected and selected in each SLR procedure are presented in Figure 2. The detailed explanation of each procedure is discussed in next sub-heading.

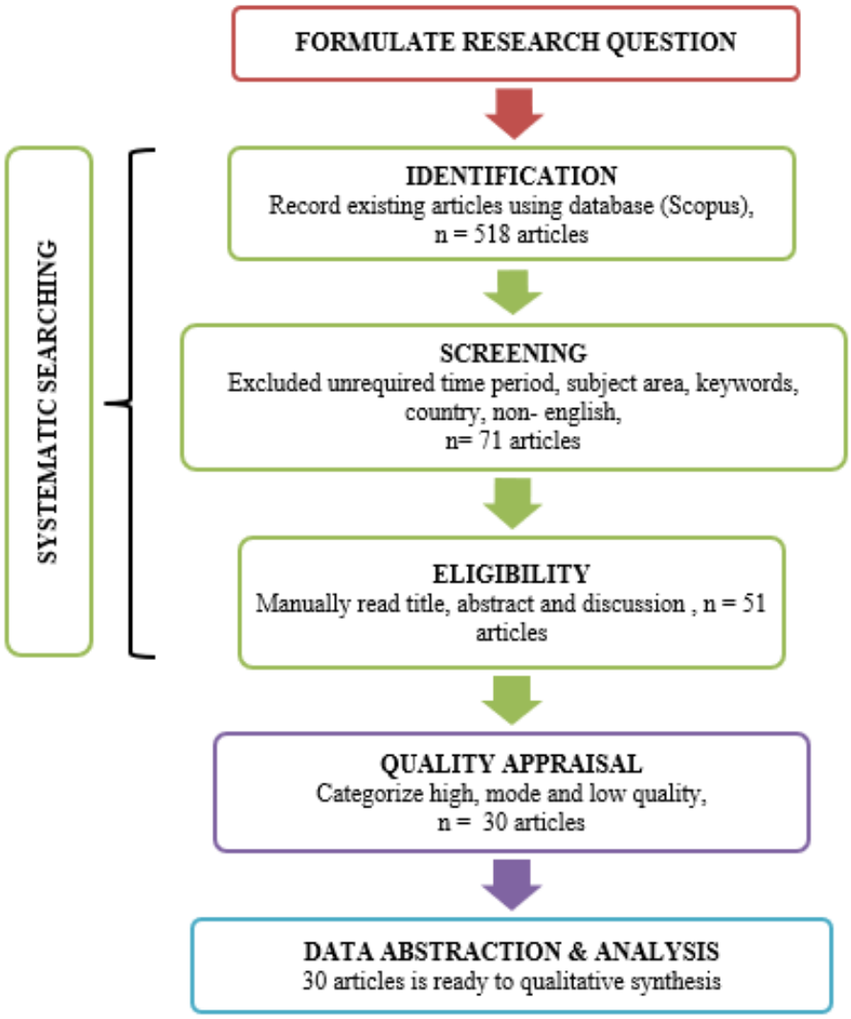

FIGURE 2. Research methodology of SLR

FORMULATE RESEARCH QUESTION

Formulate of the research question is based on the PICo tool, which denoted based on three main elements, *i.e.*, Problem, Interest and Context. This tool was adopted to evolve research question suitable for the review. Based on this tool, the three main elements of this review are bonding types (Problem), the quality of the bonding types (Interest), and the uses of bamboo reinforced concrete (Context) which then was used as a guideline in developing the main research question, *i.e.*, What is the best treatment and preparation procedure for producing the high bonding strength in bamboo reinforced concrete?

SYSTEMATIC SEARCHING STRATEGIES

In this second SLR procedure, three sub-processes, *i.e.*, identification, screening and eligibility procedures for searching the suitable and related articles of this review is presented herein.

IDENTIFICATION

Identification is a process to search any same meaning, related to the terms, and various main keywords for the study. It aims to provide more choice for the selected database to search for any related articles for the review. The keywords are established based on the research question, and the identification process depends on the two online thesauri, *i.e.*, Scopus and Google Scholar. The authors managed to vary existing keywords and create full search string. The keywords used to search the related articles are based on the research question. Table 1 shows the search string used in this study to find the existing articles based on the keywords. Total of 518 articles was collected from Scopus using the developed search string.

TABLE 1. The developed search string

Database	Search string
Scopus	TITILE-ABS-KEY (("bamboo" OR "dendrocalamus giganteus" OR "bambusa vulgaris" OR "phyllostachys bambusoides" OR "Moso bamboo" OR "phyllostachys edulis" OR "dendrocalamus asper" OR "gigantochloa scortechinii" OR "dendrocalmus strictus") AND ("bamboo reinforcement" OR " braces" OR "support" OR "shore" OR "stay" OR "pillar" OR "prop" OR "column" OR "beam") AND ("bonding strength" OR "adhesive force" OR "adhesive power" OR "adhesive strength" OR "bond strength" OR "adhesion force" OR "binding force" OR "adhesive property" OR "seal strength" OR "cohesion strength"))

SCREENING

This study filtered all the 518 articles by selecting the chosen criteria for articles selection. The procedure was automatically done based on the sorting function available in the database. The selection standard was based on the research question developed in the previous procedure. The screening procedure is an impossible task for a researcher to review all the existing published articles by determining the range of period, publication timeline, language, and type of document. The articles were collected between the year 2011 to 2020 (i.e., range of period), and only English published articles was selected from Scopus and Google Scholar. In this process, about 467 articles were excluded because the articles failed to fit the inclusion criteria. A total of 51 remaining articles were used for the third process, i.e., eligibility process.

ELIGIBILITY

The third process is the eligibility, wherein this study, the retrieved articles was manually checked to ensure all the remaining articles (after the screening process) are in line with the requirement. The process was completed by reviewing the title and abstract of the selected articles as recommended by Azril et al. (2020). Throughout this process, a total of 20 articles were excluded because the main objective of each article is not clear and does not have significant climate change. The remaining 31 articles were selected for the next stage process, *i.e.*, quality appraisal.

QUALITY APPRAISAL

In order to choose the high quality content of the articles, they were presented using the quality assessment. In this process, the articles were ranked into three quality categories, namely high, moderate, and low. High and medium articles were reviewed based on the methodology of the articles to determine the rank of quality. At the end of this process, about 30 articles were selected for the last process in this review, *i.e.*, data abstraction and analysis.

DATA ABSTRACTION AND ANALYSIS

The researcher read 30 articles directly, particularly in the part of abstract, results, and discussions. The data abstractions were managed based on the research questions; it denotes that any data from reviewed studies are able to answer the research questions were abstracted and placed in a table.

RESULT AND ANALYSIS

Based on the analysis, a total of 30 articles were selected for review. According to the systematic analysis, four aspects were established, namely mechanical properties, bamboo reinforced concrete, types of bonding, and surface preparation for the treatments. Each of the results presented was reviewed from the selected previous researches which related to four chosen themes.

MECHANICAL PROPERTIES

Two mechanical properties bamboo was compared, *i.e.*, compressive and tensile strength, as shown in Figures 3 and 4, respectively. Based on the results, it is noted that the mechanical properties of the bamboo are modified depending on the species of bamboo. (Sakaray, Togati & Reddy, 2012; Sethia & Baradiya 2014) investigated the mechanical properties of the *Moso bamboo*, and they

proved that this species of bamboo promised the highest result of compressive strength, *i.e.*, 108.19 kN/mm^2 and 87.7 kN/mm2 compared to other species of bamboo. Meanwhile, research conducted by Awalluddin et al. 2017 investigated the properties of four different species of bamboo, named *Dendrocalamus Asper, Bambusa Vulgaris, Gigantochloa Scortechinii, Schizostachyum Grande*, however all of the bamboo samples provide a moderate to low compressive strength.

On the other hand, for tensile strength, Dey & Chetia (2018) studied a bamboo type called Bambusa tulda and achieved the highest result of tensile strength compared to the other previous researches. However, Trictus (2014) stated that the lowest result of tensile strength is a bamboo species named *Dendrocalamus strictus*. Based on the obtained results, it is highlighted that each species of bamboo has different strength. Selection of suitable bamboo species is an important procedure to be satisfied before the utilization of bamboo as reinforcement in concrete.

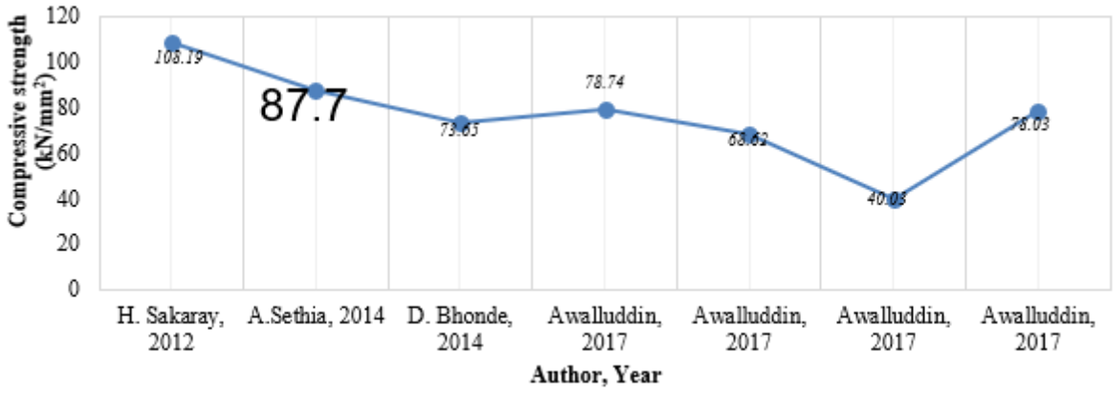

FIGURE 3. Compressive strength of bamboo reviewed from previous work

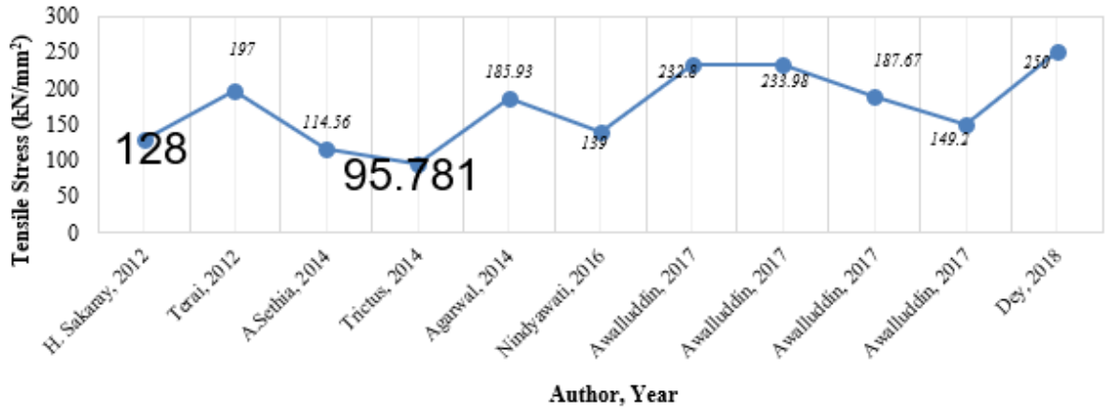

FIGURE 4. Tensile strength of bamboo reviewed from previous work

BAMBOO REINFORCED CONCRETE

In this review study, from the 30 selected articles, about 26 articles presented the uses of bamboo reinforcement in the structural component. The studies include 13 articles (Ghavami 2005; Terai & Minami 2011; Rahman et al. 2011; Mark & Russell 2011; Sevalia et al. 2013; Nayak 2013; Agarwal et al. 2014; Ahmad et al. 2014; Khan 2014; Dey & Chetia 2018; Murni 2019; Muhtar 2019; Qaiser et al. 2020) investigated the use of bamboo as beam reinforcement, seven articles (Ghavami 2005; Terai & Minami 2011; Adegbite & Ikponmwosa 2011; Nayak 2013; Agarwal et al. 2014; Daniel 2015; Daniel 2016) as column reinforcement and six articles (Ghavami 2005; Nayak 2013; Bhonde et al. 2014; Terai & Minami 2012; Datta 2018; Ismail et al. 2018) as slab reinforcement. Figures 5, 6 and 7 show the utilization of bamboo as slab panel reinforcement (Mali & Datta 2018), bamboo beam reinforcement (Qaiser 2020), and bamboo column reinforcement (Ghavami 2005), respectively.

FIGURE 5. Bamboo slab panel reinforcement

(*Source*: Mali & Datta 2018))

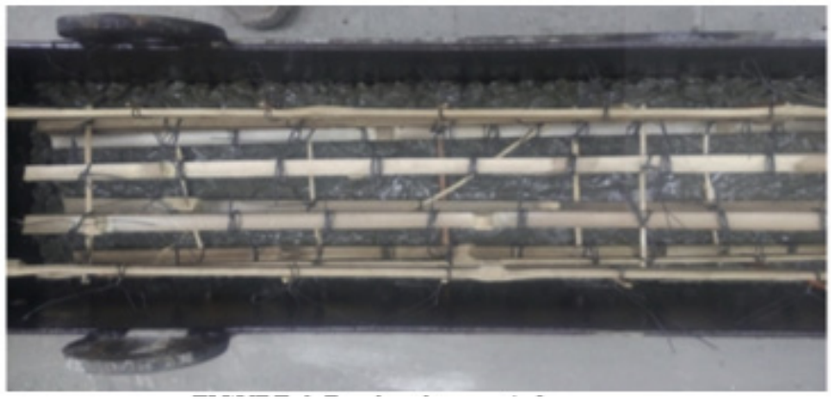

FIGURE 6. Bamboo beam reinforcement

(*Source*: Qaiser 2020))

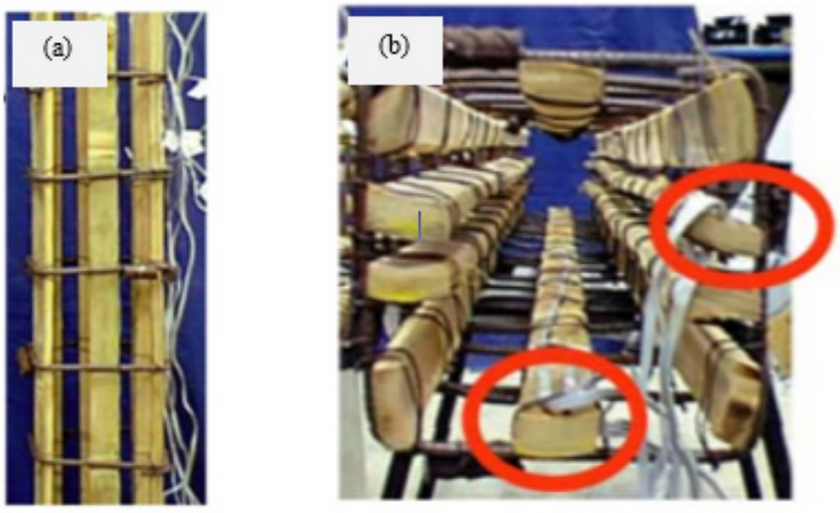

FIGURE 7. Bamboo column reinforcement (a) front view (b) top view

(*Source*: Ghavami 2005))

TYPES OF BONDING

The previous researches work on the behaviour of adhesive strength development between bamboo reinforcement, and concrete is summarised in Table 2. From the table, Ghavami (2005) stated that after the use of two-component epoxy resin, the bonding of bamboo reinforcement increased up to five times as compared to plain bamboo reinforcement. Ghavami (2005) concluded that Sikadur 32 Gel treatment was concluded as the best treatment to obtain a better result of bond strength. Terai & Minami (2012) used two types of synthetic resin and rubber as surface treatments on bamboo pull-out test in their study. The author concluded that bond strength increased from 0.60MPa to 1.34MPa when the synthetic resin was applied by using a brush. On the other studies, Sakaray et al., (2012) applied waterproof coating as bonding agent of bamboo reinforcement and reported that bond stress decrease when length of embedment increase.

TABLE 2. Types of Bamboo Bonding and Strength

Researcher	Type of bonding	Bond Strength in Pull out Test (N/mm^2)	Structure component
Ghavami 2005	Negrolin	0.52	
	Negrolin + sand	0.73	
	Negrolin + sand + wire	0.97	
IKPONMWOSAEFE 2011	Sikadur-32 gel	2.75	
	Bitumen + coir rope	N.A	
	Bitumen + sand (fine aggregate)	N.A	
Terai & Minami 2012	Synthetic Resin (Spray & Brush coating)	1.25 (Spray),1.34 (Brush Coat)	
	Synthetic Rubber (Spray)	1.18 (Spray)	
Sakaray 2012	Waterproof coating	1.45 – 1.95	Not available
Nayak 2013	Waterproofing	N.A	Slab, Beam, Column
Agarwal 2014	Araldite	0.232	
	Araldite + wire	0.539	
	Tapecrete P-151	0.315	
	Anti Corr RC	0.159	
	Sikadur-32 gel	0.588	
Ahmad et al. 2014	Coal tar + sand	N.A	
Daniel 2015	Treated bamboo + binding wire	N.A	Column
Javadian et al. 2016	Water-based epoxy coating	3.47	
	Water-based epoxy coating + fine sand	3.65	
	Water-based epoxy coating + coarse sand	3.61	
	True Grip EP &.BP	3.30 (EP), 2.42 (BP)	Not available
	True Grip EP & BP + coarse sand	3.45 (EP), 2.62 (BP)	
	Exaphen	3.36	
	Exaphen + coarse sand	3.46	
	Enamel	3.40	
Nindyawati & Baiq Sri Umniati 2016	Waterproof paint + sand	0.41	Not available
Daniel 2016	Epoxy resin + binding wire	N.A	Column
Simon et al. 2017	Bisphenol (BPA)	0.96	
	Bisphenol (BPA) + sprinkled sand	1.09	Not available
	Sikadur–31 CF	1.04	
	Sikadur–31 CF + sand	1.08	

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	Epoxy + rolled bamboo (sand)	5.96	
Dey & Chetia 2018	Epoxy + rolled bamboo (Coir)	8.46	Beam
	Epoxy + rolled bamboo (G.I)	9.71	
	Grooved bamboo	N.A	
Datta 2018	Hose Clamp 10 cm	1.09	Slab
	Sikadur-752	2.5	
Murni 2019	Sikadur-752 + Hose Clamp 5 cm	4.11	
	Sikadur-752 + Hose Clamp 10 cm	3.64	
	Sikadur-752 + Hose Clamp 15 cm	3.14	Beam
	Sikadur-752 + Hose Clamp 20 cm	3.01	
	Hose Clamp 10 cm	1.09	
	Sikadur-752	2.5	
	Sikadur-752 + Hose Clamp 5 cm	4.11	
	Sikadur-752 + Hose Clamp 10 cm	3.64	
Muhtar 2019	Sikadur-752 + Hose Clamp 15 cm	3.14	Beam
	Sikadur-752 + Hose Clamp 20 cm	3.01	
	Plain bamboo	0.159	
Qaiser et al. 2020	Corrugated bamboo	0.286	Beam
	Wired bamboo	0.185	

Besides that, Agarwal, Nanda & Maity (2014) studied the use of chemical treatment in bamboo bonding for improvement of the bonding strength between bamboo and concrete. Chemical treatments Sikadur 32 Gel provided the highest strength compared to the other chemical treatment. Meanwhile, in 2016, studies on bond strength between bamboo and concrete using water-based epoxy, i.e., TrueGrip EP, TrueGrip BP, and Exaphen coating was conducted by Javadian et al. (2016). The study proposed two types of bonding, whereby the water-based epoxy was applied on the surface of bamboo reinforcement with and without sand material to increase the friction on the concrete surface. Unlike Nindyawati & Baiq Sri Umniati (2016), they used waterproofing paint as a water repellent and sprinkled sand to improve the bonding between bamboo and concrete. The authors found that the average bond strength was 0.41MPa. Similar to Simon et al. (2017), they used the same method by applying sprinkled sand but using different chemical treatment, *i.e.*, Bisphenol (BPA) and Sikadur-31 CF.

Further researches on bamboo bonding strength were conducted by Dey & Chetia (2018). In their study, the result showed that the Galvanised iron (G.I) rolled denoted the highest bond stress of 9.71 MPa compared to the other researchers. Figure 8 shows the sample of rolled bamboo reinforcement in beam prepared by Dey & Chetia (2018). In 2019, new improvisation was made up by Muhtar (2019) whereby they replaced the use of sand material with a hose clamp. Figure 9 shows the sample of hose clamp bonding type. Qaiser et al. (2020) proposed corrugated bamboo, as shown in Figure 10, to reduce the usage of chemical treatment. As a result, corrugated bamboo produced high bond stress, but it experienced breakage failure when reaching the highest strength. However, the untreated and wired bamboo only experienced slippage failure, which provides better performance compared to corrugated bamboo.

From the review, this study recommended the use of epoxy with sand, coir and galvanised iron, water-based epoxy with aggregate, and Sikadur-752 with hose clamp as high quality of bonding treatment. Based on bond stress results, these treatments achieved high result compared to the other treatment. However, several previous studies concluded that the use of Sikadur 32 Gel is expensive and required high preparation and handling cost. This concluded that a cheap treatment such as epoxy, waterproof, paint, and coal tar is more appropriate to reduce the overall production cost of bamboo bonding treatment (Sabnani et al. 2013). Nevertheless, the new profile pattern of bamboo reinforcement such as corrugated and grooved bamboo may require further studies since these types of bamboo reinforcement experienced breakage failure during the laboratory testing.

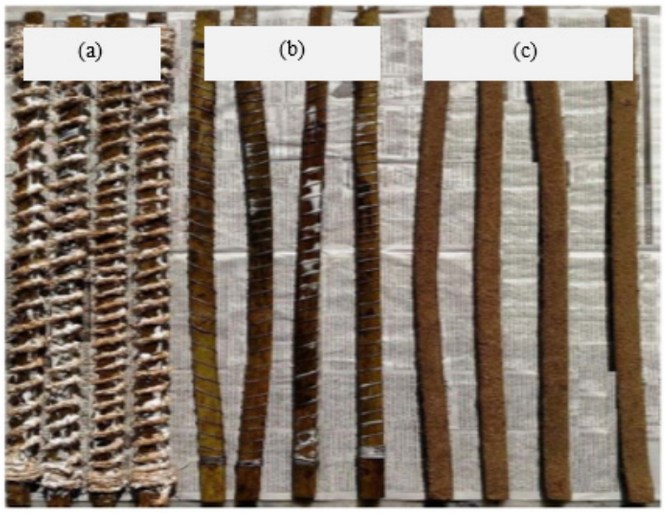

FIGURE 8. Three types of rolled bamboo reinforcement; (a) Epoxy + Coir rolled bamboo, (b) Epoxy + G.I rolled bamboo and (c) Epoxy + Sand rolled bamboo (modified from Dey & Chetia 2018)

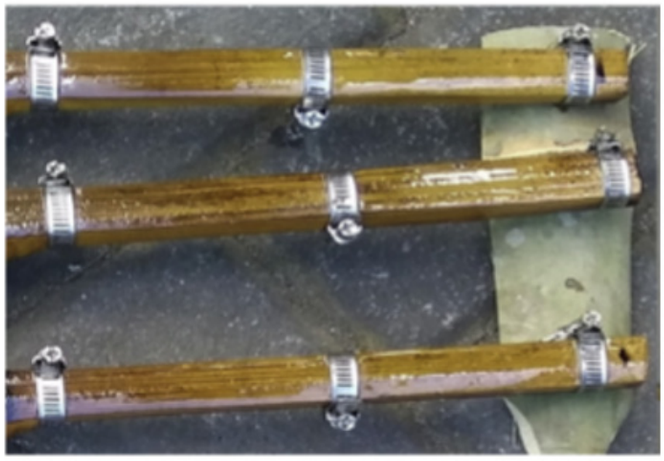

FIGURE 9. Hose clamp bonding types (modified from Muhtar 2019)

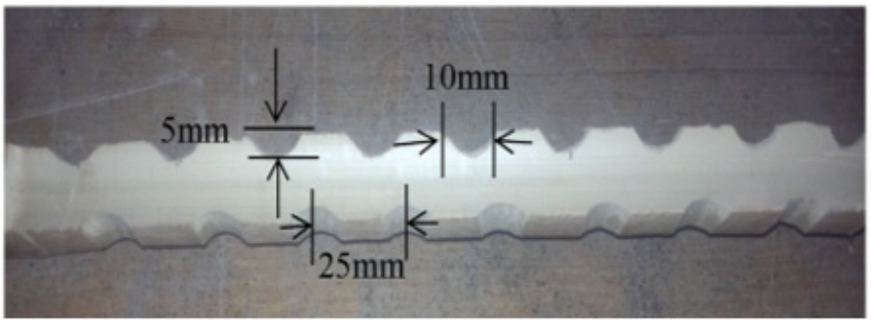

FIGURE 10. Corrugated bamboo sample

(*Source*: Qaiser et al. (2020))

CONCLUSION

The comprehensive methodologies of systematic literature review (SLR) for investigating the behaviour of bonding strength of bamboo reinforcement in concrete is presented herein. The review also highlights the recent study on the mechanical properties of bamboo as an alternative reinforcement in concrete and application of bamboo reinforced concrete. In conclusion, the bamboo promises the highest potential to be an alternative reinforcement in lightweight concrete, especially for the low-cost construction industry. From the literature survey, the study recommended the use of epoxy with sand, coir and galvanised iron, water-based epoxy with aggregate, and Sikadur-752 with hose clamp as high quality of bonding treatment. However, the use of epoxy and water-based epoxy coating is more appropriate to reduce the overall production cost of bamboo bonding treatment.

Further researches are recommended to investigate the effectiveness of chemical treatments as surface treatment for corrugated or grooved bamboo as reinforcement in concrete. Until recently, it is found that there are no documented standard operation procedures (SOP) which state the correct treatment method for bamboo reinforcement. Therefore, further research efforts are required to determine the potential of bamboo as construction materials. Variety method of treatment highlights the great potential of bamboo as reinforcement in the construction industry compared to steel reinforcement.

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DECLARATION OF COMPETING INTEREST

None.

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