Progress in Engineering Application and Technology Vol. 3 No. 2 (2022) 023–036
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PEAT

Homepage: http://penerbit.uthm.edu.my/periodicals/index.php/peat
e-ISSN : 2773-5303

The Effect of Surface Modification on Mechanical and Thermal Properties of Bamboo Fiber Polymer Composite: A Systematic Literature Review (SLR)

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DOI: https://doi.org/10.30880/peat.2022.03.02.003
Received 26 January 2022; Accepted 20 July 2022; Available online 10 December 2022

Abstract: Bamboo fiber polymer composite was expanded as an environmentally friendly materials that are biodegradable and can replace use of synthetic polymer. The main objective of this study was to identify the modified bamboo fiber and fiber content used as reinforcement in various type of polymer matrices, focusing on the effect of thermal and mechanical properties. Selection of study through PRISMA method, finalized twenty-eight studies to be used for systematic literature review (SLR). The quality of selected articles was evaluated in order to come out with data related to the objectives of the study by correlate the surface modification and fiber content on the performance of bamboo fiber polymer composite. Two sub-group were highlighted in this study; the performance of mechanical properties such as tensile and flexural strength and thermal properties such as thermal decomposition and glass transition of bamboo fiber polymer composite was compared to untreated bamboo fiber. As the conclusion, this study applied the systematic literature review provided comprehensive information and act as reference on the determination of the range of fiber content which is 30wt % to 40wt % was identified. Furthermore, various type of surface modification used to enhance the tensile and flexural strength of the bamboo fiber polymer composite. In addition, the thermal decomposition and glass transition has been analyzed as the proven of the surface modification applied can boost the performance of bamboo fiber polymer composite on thermal properties.

Keywords: Bamboo Fiber, Surface Modification, Mechanical and Thermal Properties, Fiber Content, Polymer Composite, Systematic Literature Review

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1. Introduction

1.1 Background of study

The utilization of natural fiber in polymer composite either as reinforcing fiber or as filler has grown rapidly for a few decades. Natural fiber offers many advantages which include being abundantly available from agriculture sources, and relatively cheap, leads to the high demand from industrial player to produce sustainable product. Bamboo is one of the woody plants that rapidly growth in the world and the largest sources of bamboo come from southeast Asia which is 64% follow by 33% from south America and the rest of bamboo source come from Africa and Oceania [1]. Bamboo fiber consist of chemical composition such as cellulose, hemi-cellulose and lignin are main components which is contributing 95% of its mass [1] [2]. The researchers examined into the possible applications of bamboo fiber in polymer composite and investigated the impact of various parameters on the mechanical and erosion wear performance of bamboo fiber reinforced polymer composite [2]. Natural fiber from the other hand is involve limitation and have significant property deficiencies. The natural fiber structure consists of (lignin, pectin, cellulose, hemicellulose and waxy substances) and allowing the absorption of moisture from the surrounding which contribute inadequate bindings between the fiber and polymer [3] [2]. Several treatments were conducted to bamboo fiber to increase fiber-matrix adhesion and the influence on mechanical and thermal performance of the resulting composite [4]. Physical and mechanical approaches have been used to modify bamboo fiber in order to improve interfacial bonding and reduce moisture absorption.

In polymer composite processing, it is important to produce good thermal stability properties. Thermal stability is indicating by thermal degradation temperature. Few researchers reported that good thermal stability of polymer composite foams can be achieve by higher degradation temperature when reinforced with certain amount cellulose content [5] [6] [7]. The effects of bamboo fiber influence by the fiber size and content on the mechanical properties and physical properties, as well as the shape of bamboo fiber in matrices.

Thus, in this study the systematic review was conducted in order to determine the effectiveness of bamboo fiber thermal and mechanical properties on polymer composite, the suitable of surface treatment applied on bamboo fiber and fiber content and fiber size in order to generate bamboo fiber polymer composite.

2. Materials and Methods

The methodology for carrying out a systematic review is presented in this section. The guidelines, along with the search and analysis of the literature, are clarified. Preferred reporting items for systematic analyses statement have been used. The approach involves a range of stages such as literature retrieval and review process steps. These stages contain identification, screening and eligibility, data abstraction and analysis.

2.1 Criteria for study selection

PRISMA specifies the eligibility and dismissal conditions. Only articles with certain standards have been eligible for the review process. First, criteria would be journal papers and case studies mainly since they include a rather more comprehensive and complete research report. Next, manuscripts in English only to facilitate data extraction and synthesis. The third criteria are manuscripts relevant to bamboo fiber, various surface modification and fiber content and performance of mechanical and thermal properties. These criteria are displayed in Table 1.

Table 1: Eligibility and exclusion criteria

CRITERIA	ELIGIBILITY	EXCLUSION
Literature type	Journal article	Chapter in book Case study Conference proceeding
Language	English	Except English
Discipline	All	None
Focus of study	The effectiveness of bamboo fiber toward mechanical & thermal properties on polymer composite	Non bamboo fiber Not relate to chemical & thermal properties Non polymer composite
Publication year	2010-2021 (The recent 11 years)	2009 and below

2.2 Search technique

To provide the best manuscripts with qualitative and mixed method, integrated systematic review should be implemented. This systematic review method became popular because it provided a detail summary of the manuscripts with specific procedure research. An integrative systematic review was completed in December 2021 and mainly using WoS and Scopus database. The systematic review utilizes comprises four steps. First, started with the prior research, thesaurus and recommended keyword from Scopus, relevant keywords linked to bamboo fiber, surface modification, thermal and mechanical properties and polymer composite was reported. Inside of query section such as tittle, abstract and keywords, the extensive functionality of database allowed the customization and prioritization of certain over the others. The search strings from various database are shown in Table 2.

Table 2: The search strings applied for systematic review

JOURNAL DATABASE	SEARCH STRING	FREQUENCY OF HITS
Scopus	TITTLE-ABS-KEY ((“bamboo”) AND (“bamboo fiber” OR “natural fiber” OR “plant fiber”) AND (“surface modification” OR “surface treatment” OR “chemical treatment” OR “biological treatment”) AND (“mechanical properties” OR “thermal properties”) AND (“fiber content”) AND (“polymer composite” OR “bio-polymer” OR “composite”))	90
Web of Science (WoS)	TOPIC: (bamboo) AND TOPIC: (bamboo fiber OR natural fiber OR plant fiber) AND TOPIC: (surface modification OR surface treatment OR chemical treatment OR biological treatment) AND TOPIC: (mechanical properties OR thermal properties) AND TOPIC: (fiber content) AND TOPIC: (polymer composite OR biopolymer OR composite)	9

The search string from both data base suited 99 and the eventually the manuscripts are accessed. The identification stages provide the elimination of 17 duplicate manuscripts. 51 further manuscripts omitted during the screening stage and another 22 were excluded during the eligibility process. Finally, only 24 were remained and bamboo fiber, chemical modification, thermal and chemical properties, size and fiber content and polymer composite were firmly oriented on quality manuscripts to resolve the objective. Figure 1 illustrate the process flow.

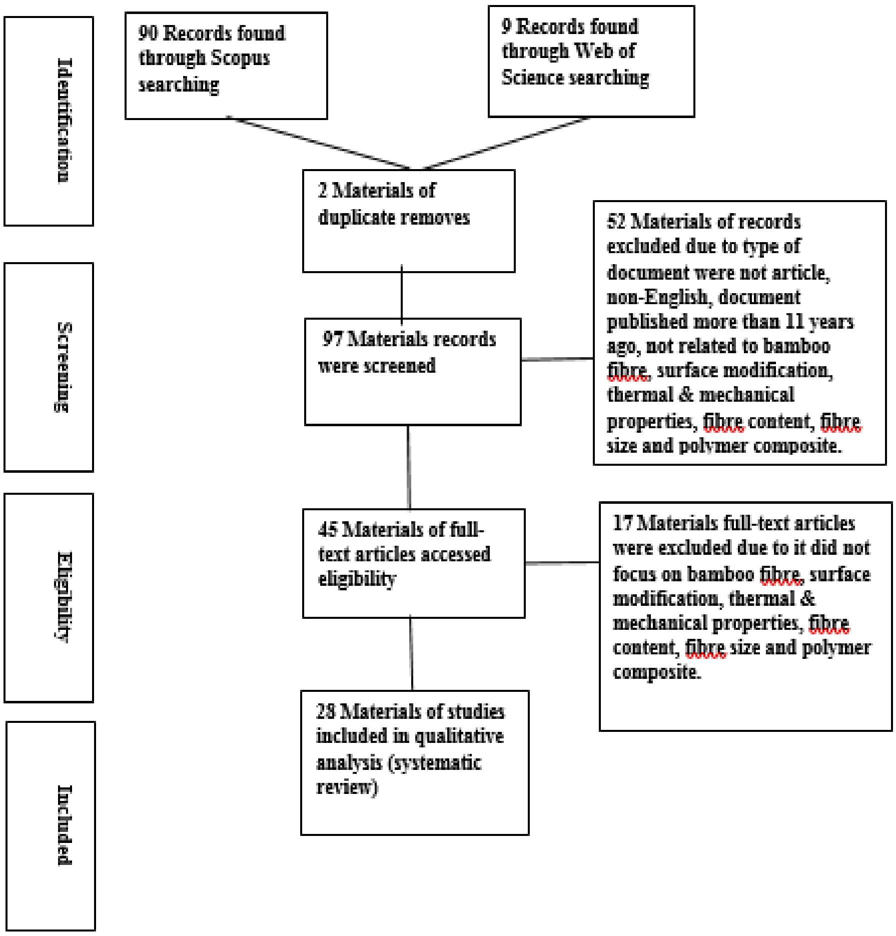

Figure 1: The flow diagram of study

3. Results

3.1 Included studies

Twenty-eight studies have been used for systematic review and their characteristics are presented in table and figure below. In Table 3, the findings related to this study were reported i.e., type of surface modification, flexural and tensile strength and fiber content while in all the figure below are stated the findings related to this study were reported i.e., type of surface modification, glass transition, thermal decomposition and fiber content. All included systematic review studies were evaluated using qualitative analysis focused on comparison of the performance.

3.2 The effect of surface modification and fiber content on mechanical properties of bamboo fiber reinforced polymer composites.

Untreated and surface modified bamboo fiber composites are compared in terms of their characteristics. Wang F et al, [8] observed the results reveal that natural fiber composites with an alkali surface modification have higher tensile and flexural strength than untreated composites. The surface modified fibers enhanced the adhesive force between natural fiber and matrix while simultaneously lowering the bamboo fiber reinforced composites water absorption capabilities [9] [10]. Surface modified fiber composites demonstrated better tensile characteristics than untreated fiber composites.

Table 3: The effect of various type of surface modification and fiber content on mechanical properties of bamboo fiber

Author	Surface modification	Mechanical properties		Fiber content	Findings
		Tensile strength	Flexural strength		
(Ma H., 2011)	Untreated	51.88±7.58	n/a	30wt%	Higher tensile strength value than untreated bamboo fiber for each surface modification
	Direct silane coupling	74.20±6.27			
	Silane coupling after plasma	83.56±6.45			
	Silane coupling during UV irridation	88.82±6.49			
(Reale Batista M.D., Surface modification of bamboo fiber with sodium hydroxide and graphene oxide in epoxy composites, 2021)	NaOH treatment coated with graphene oxide	n/a	334.6	40wt%	Higher flexural strength value than untreated bamboo fiber for each surface modification
	NaOH treatment		327.5		
	Untreated		259.9		
(Guo W., 2019)	NaOH treatment with boric acid	124.3±4.8	n/a	20wt%	Higher tensile strength value than untreated bamboo fiber for each surface modification
	NaOH treatment	135.4±9.3			
	Untreated	53.2±3.5			

Author	**Surface modification**	**Mechanical Properties**				**Fiber content**	**Findings**
		Tensile strength		**Flexural strength**			
		Bamboo fiber epoxy	Bamboo fiber polyester	Bamboo fiber epoxy	Bamboo fiber polyester		
(Kushwaha P.K., 2011)	Maleic anhydride	107	65	103	105	40wt%	The highest value for tensile strength is 125Mpa while for flexural strength is 150Mpa compared to untreated bamboo fiber
	Permanganate treatment	133	115	155	133		
	Benzoyl chloride	105	125	120	150		
	Benzyl chloride	105	78	117	100		
	Pre-impregnation	118	110	165	125		
		Untreated	Treated	Untreated	Treated		
(Yan L.B. & Yuan, 2012)	NaOH treatment	48.7	53.7	85.3	90.0	30wt%	Higher value than untreated fiber
(Liu W., 2016)	Chemical treatment	28.4±1.0	35.0±1.0	52.3±1.0	59.0±1.0	30wt%	Higher value than untreated fiber
(Mukherjee T., 2011)	Sodium hydroxide treatment	44.2		84.0±1.0		n/a	Improve properties of bamboo fiber compared to untreated
	Maleic anhydride (0.5%)	47.6		73.0±0.5			
	Untreated	39.8		69.2±0.5			
		Untreated	Treated	Untreated	Treated		
(Qian S., 2015)	NaOH treatment followed by maleic anhydride	43.9	47.6	84.2	72.61	n/a	Higher value than untreated fiber

Author	Surface modification	Mechanical properties		Fiber content	Findings
		Tensile strength	**Flexural strength**		
(Song W., 2021)	Mussel-inspired polydopamine	17.2	35.0	40wt%	Higher both properties than untreated fiber
	Untreated	12.9	27.0		
(Hu G., 2018)	Untreated	60.6±1.5	72.1±2.4	30wt%	Higher in tensile and flexural strength value than untreated fiber
	NaOH treatment with silane coupling agent	76.3±2.4	97.6±2.4		
	NaOH treatment with titanate coupling agent	80.8±2.0	105.8±2.3		
(Wang D., 2019)	Untreated	50.0	45.0	25wt%	Higher in tensile and flexural strength value than untreated fiber
	NaOH treatment	63.1	71.4		
	Silane treatment	68.0	86.0		
(Chin S.C., 2020)	NaOH treatment	119.4	170.5	40wt%	Higher value than untreated fiber
	Untreated	105.0	148.5		
(Sánchez M.L, 2020)	Mercerization	28.5±2.9	56.7±5.3	30wt%	Compare different treatment for best performance
	Ozone	24.8±2.5	70.9±8.4		
	Plasma	32.2±1.5	62.0±9.3		

Author	Surface modification	Mechanical properties		Fiber content	Findings
		Tensile strength	Flexural strength		
(Wang Q., Improved mechanical properties of the graphene oxide modified bamboo-fiber-reinforced polypropylene composites, 2020)	Untreated	31.5±0.5	43.0±0.5	n/a	Compare different types of surface modification on bamboo fiber. Higher value for both properties than untreated fiber
	Alkali treatment	33.0±0.5	44.2±0.3		
	Graphite oxide-alkali treatment	36.9±0.5	52.9±0.3		
(Wang Q., Effect of silane treatment on mechanical properties and thermal behavior of bamboo fibers reinforced polypropylene composites, 2020)	Untreated	31.3±0.6	44.3±1.9	n/a	Compare different types of surface modification on bamboo fiber. Higher value for both properties than untreated fiber
	Coupling agent terminated with amino functional group	35.7±1.1	50.5±1.5		
	Coupling agent terminated with epoxy functional group	34.6±0.5	50.6±0.8		
	Coupling agent terminated with methyl functional group	36.1±1.0	54.7±1.0		

Author	Surface modification	Mechanical properties		Fiber content	Findings
		Tensile strength	Flexural strength		
(Kang J.T., 2011)	Pristine	26.9	9.1	10wt%	Increase on mechanical properties with various surface modification and fiber content compared to untreated fiber
		18.2	6.9	20wt%	
		22.7	7.0	30wt%	
	Delignified	16.2	14.2	10wt%	
		11.8	14.8	20wt%	
		15.0	15.1	30wt%	
	Vinyl trimethoxy silane	39.3	13.3	10wt%	
		24.2	13.0	20wt%	
		39.0	14.3	30wt%	
	3-aminopropyl tri-ethoxy silane	39.9	13.3	10wt%	
		34.2	14.3	20wt%	
		39.8	17.3	30wt%	

The maximum tensile and flexure strength of bamboo fiber polymer composite can be obtained with the application of surface modification and appropriate fiber content. This is because each treatment applied to bamboo fiber is aimed at changing the physical properties of bamboo fiber that may affected on reducing the performance of bamboo fiber when combined with polymer composite. Moreover, the suitability of the fiber content in the polymer composite is also able to produce the best performance. This can be proved based on Kang J.T et al, [11], Hu G et al, [12], Kushwaha P.K et al, [13] are studying on various types of surface modification and specific fiber content toward the bamboo fiber.

3.2 The effect of surface modification and fiber content on thermal properties of bamboo fiber reinforced polymer composites.

The main cause of enhanced mechanical characteristics in this study was the solidification of adhesive inside the material. Mechanical characteristics deteriorated as phenolic resin and bamboo degraded at high temperatures. Factors impacting bamboo scrimber heat treatment should be investigated further [14] [15]. The performance of wood and bamboo products is evaluated using thermal decomposition. Emulsification of lignin, which leads to a rearrangement of lignocellulosic polymeric components, is a likely explanation for the change in surface tension of wood following heat treatment. The weight and density of bamboo scrimber may decrease as the temperature rises. From

170 to 230 °C, the effect was dramatic. When the temperature of heat-treated samples exceeded 200 °C, moisture absorption increased gradually [15].

Fiber content and processing conditions have a significant impact on the properties of natural fiber reinforced composites. In order to achieve the best composite properties, the appropriate fiber composition and manufacturing conditions must be carefully chosen [16].

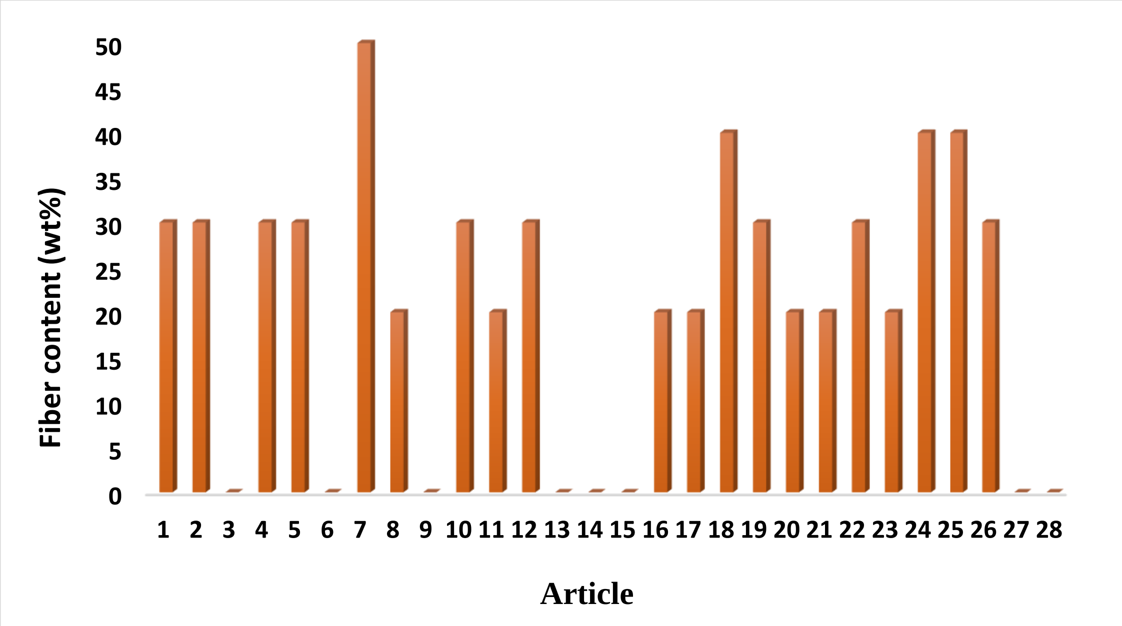

Figure 2: Fiber content against the articles

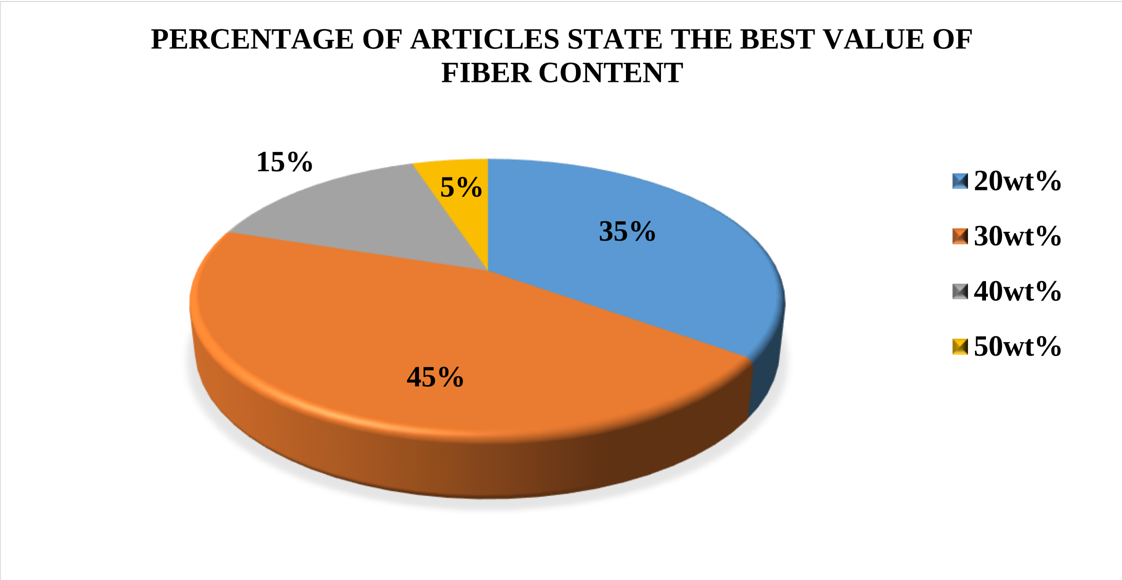

Figure 3: The percentage of articles state the best value of fiber content

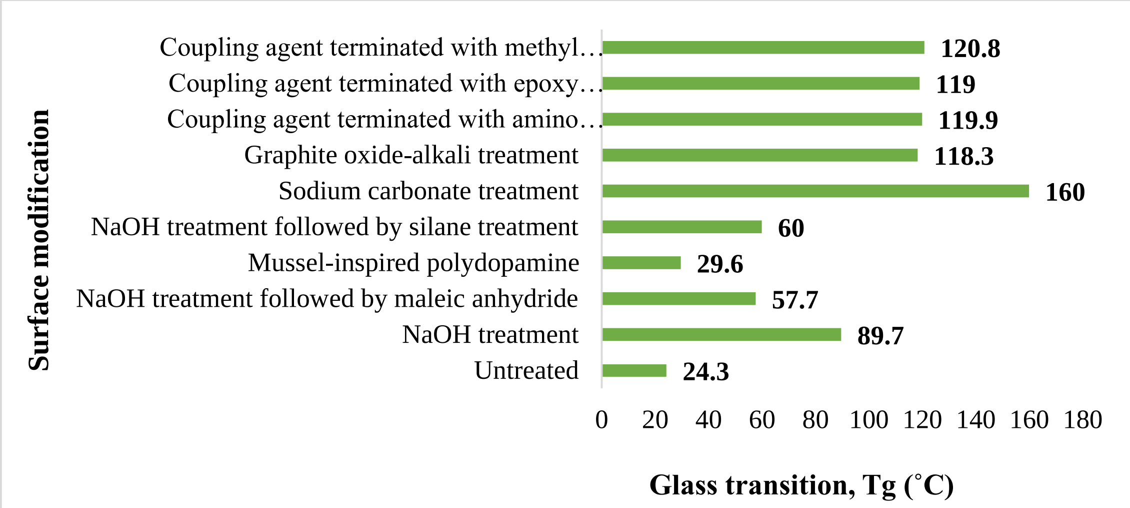

Figure 4: Surface modification against glass transition, T_g

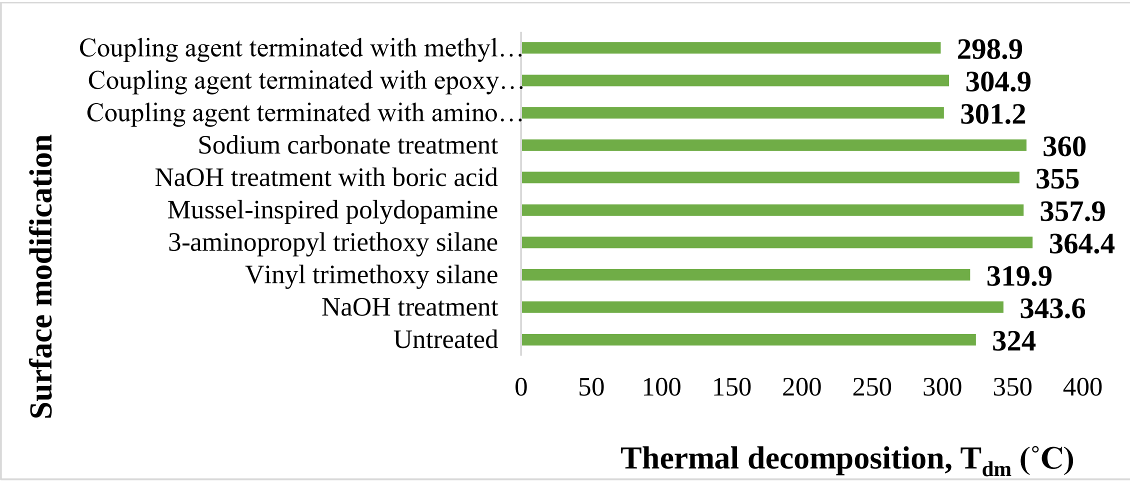

Figure 5: Surface modification against thermal decomposition, T_{dm}

4. Discussion

4.1 Systematic review

Systematic review was conducted by implemented each of the procedure accurately. PRISMA flowchart was constructed to ensure the process selection of articles and related studies that aligned with the objectives of the study. In addition, selection articles from trusted database are included in PRISMA which followed by made selection on the best articles that match with the keyword used. Therefore, 28 studies were finalized to be used in the content analysis of systematic review.

4.2 Quality of articles

Scopus and Web of Science (WoS) are known as trusted platform for searching articles and as the database for systematic review research design. Therefore, 28 articles related to the main objectives used for this study was collected from Scopus and WoS.

4.3 Overall pooled effect

The outcome of the study suggested that there was overall correlation between the effectiveness of surface modification and fiber content of bamboo fiber on mechanical and thermal properties. the most widely used chemical treatment is alkali treatment. In addition, there are various types of surface modification that are also used by researchers as an effort to improve the performance of bamboo fiber such as maleic anhydride, direct silane coupling and graphite-oxide alkali treatment, Mussel- inspired polydopamine and others. In addition, surface treatment can be combined with compatibilizers [17]. Li Y et al, [18] applied the alkali treatment on bamboo particle for enhance the interaction with poly lactic acid (PLA) with presence of maleic anhydride as compatibilizer bamboo fiber poly lactic acid (PLA) composite. This treatment improves hemicellulose and lignin solubilization and fiber separation into fibrils, increasing the accessible surface area of the fiber to be "wet" by the polymer matrix and improving interfacial adhesion.

By disrupting hydrogen bonds and increasing the quantity of free hydroxyl groups, the treatment can also increase the chemical reactivity of the fiber [19]. All fabric-reinforced composites improve from alkali treatment in terms of tensile strength and modulus, as well as flexural strength and modulus. The composite's tensile and flexural strains, on the other hand, increased substantially [9]. The results showed that adding surface-treated bamboo fiber to polymers improved their mechanical characteristics significantly poly lactic acid) especially the tensile, flexural, and impact strengths of bamboo fiber treated with poly (lactic acid) containing NaOH treatment with titanate coupling agent were all higher than those of bamboo fiber treated with poly (lactic acid) containing NaOH and NaOH with silane coupling agent [12].

Sujaritjun W et al, [16] reported the risk of heat deterioration, natural fiber must be processed at low temperatures. The use of thermosetting resin as a surface modification for natural fiber to improve thermal stability during high-temperature procedures is now under investigation (Sujaritjun W et al, [16]. After being treated with silane, bamboo fiber and epoxy matrix developed a strong chemical bond [20]. Furthermore, the layered agglomerates on the surface of bamboo fiber improve the molecular connection between fiber and matrix by strengthening the surrounding contact zone. As a result, the strong chemical bonding of two-phase polymer effectively improves the composite's thermal properties as compared to hydrogen bonding. The glass transition (T_g) platform of the bamboo fiber epoxy composites appeared at around 100 ˚C–120 ˚C, as per DSC data. The thermal transition behavior of composites might be improved by surface-treated bamboo fiber, indicating that good interfacial interaction between the bamboo fiber and polymer–matrix could. It can be summarized on the effect of fiber content toward the mechanical and thermal properties of bamboo fiber polymer composite. from this study, the lack of reference sources related to thermal properties becomes a limited cause in making better conclusions. This is because, thermal properties are less emphasized in the study of researchers because of the use of bamboo fiber in industry.

Fiber content and processing conditions have a significant impact on the properties of natural fiber reinforced composites. In order to achieve the best composite properties, the appropriate fiber composition and manufacturing conditions must be carefully chosen [16]. Khalil et al, [2] state increasing natural fiber content, the tensile strength of coconut fiber and bamboo grass fiber reinforced PLA composites dropped. This study was provided articles relate to few values of fiber content that suitable use either as the reinforcement or filler in polymer. Overall, most of the researchers reported the similar hypothesis, 30wt % - 40wt % of fiber content is frequently used in composite. As the conclusion, if the fiber content is outside the specified range, the probability of bamboo fiber performance including thermal and mechanical properties decreases. Furthermore, increasing the fiber content led to rise of moisture content in composite, resulting on drop shelf life of the polymer composite.

5. Conclusion

This study emphasized on the incorporation of bamboo fiber polymer composite. The results obtained from this study proved that the objectives were successfully achieved. Twenty-eight articles related to surface modification on bamboo fiber, effect of surface modification on mechanical and thermal properties and fiber content in polymer composite were identified via the PRISMA method. The surface modification toward bamboo fiber resulted on enhance the interfacial bonding between bamboo fiber and matrix. Furthermore, by altering the interfacial bonding of fiber-matrix led to improvement of mechanical and thermal properties of bamboo fiber polymer composite.

The mechanical properties such as tensile strength and flexural strength is key elements use to identify the effect surface modification on bamboo fiber. The value of tensile and flexural strength is increases compared to the untreated bamboo fiber. Moreover, good interfacial fiber-matrix bonding led to enhance thermal properties such as thermal decomposition and glass transition of bamboo fiber polymer composite. Therefore, it will result to increase degradation temperature. The effective range of fiber content is identified between 30wt% to 40wt% and can be correlate with the enhance of performance of polymer composite. However, if the fiber content exceeds 50wt%, it may cause reduction of performance due to the stress occur between fiber-matrix. Overall, the findings obtained provide comprehensive information and act as reference on determination of optimum fiber content and correlation between surface modification on bamboo fiber toward mechanical and thermal properties of polymer composite.

Acknowledgement

The authors would like to thank the Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for this report.

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