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Tensile Properties of Natural Fibre Reinforced Polymer Composite Foams: A Systematic Review

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Abstract: Biodegradable foam packaging was chosen as an alternative food packaging material due to non-toxic and produced from renewable sources. Researchers has turned to incorporate natural fibre to enhance the mechanical properties of polymer composite foam. In this study, the objective is to identify the studies which investigated on the tensile properties of natural fiber incorporated polymer composite foam and analyzed the effect of natural fibre content and size on tensile properties. Further correlation between the natural fibre content and size on tensile properties of composite polymer foam was conducted. The studies on the natural fibre incorporated polymer composite was identify via PRISMA method. The effect of natural fibre content and natural fibre size on tensile properties of polymer composite foam were analyzed in terms of qualitative analysis via systematic review. This study employs systematic review method on the existing literature. This study has utilized supplementary databases such as SAGE Journals, ScienceDirect, Taylor & Francis, Emerald Insight, ERIC ProQuest, SpringerLink and IEEE Xplore to cater all the possible relevant literature for a comprehensive review. The systematic review method comprised of the steps that explain on the review process in the sequence of the (identification, screening, eligibility), data analysis and data abstraction. From the article used in this systematic review, most of the result shown the increased tensile properties on natural fibre reinforced polymer composite foams. The study by Texteira et al. (2014) shows that the softwood fibre with 33% of PLA loading has the highest elongation at break, and highest natural fibre size (2470 µm). While the study by Long et al. (2019) has the highest tensile strength with 30% of ABF fibre content. The composition of 20 wt% BF with 80 wt% PLA composites were concluded to have the optimum tensile properties

Keywords: Cellulose, foam, tensile properties

1. Introduction

1.1 Project Background

The plastic industry in Malaysia has increased significantly especially in the sector of automotive, manufacturing parts of electronics, materials for construction, household goods, kids' toy, and material for food packaging. In 2010, the Malaysian Plastics Manufacturer Association (MPMA) stated that the plastic industry of Malaysia produced approximately two million tonnes of plastic resin annually for the local industry. Recently, there is an increasing demand for plastic packaging due to the development of food industry. However, the use of petroleum-based foam for

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food packaging has brought up concern among the public, especially on the usage of single use plastic for the packaging purposes [4]. Non-biodegradable food plastic packaging will lead to huge environmental problem such as landfill disposal as it contributes to the top three of the largest waste [5].

The environmental problem generates include air pollution from burning of petroleum-based plastic and their resistance to biodegrade naturally [6]. Apart of the environmental problem, the feedstocks of petroleum that are not renewable and the increasing rate of non-biodegradable plastics disposal have attracted many researchers to explore on the potential of biodegradable plastics [7]. This issue has gain interest of many researchers and industries in developing biodegradable packaging materials using renewable natural biopolymers. Biodegradable plastic is usually made for usage on disposable product for example cutlery, packaging, container for the food services and tableware [7].

The waste of agro-industrial are useful as the natural fibre reinforcement of the biopolymer at low price. The by-products such as corn stalk, leaves and fruit peels remain unused and dispose as the waste normally contain 31% to 61% of cellulose. Several studies show that the use of natural fibres reinforced can increase the mechanical and physical properties of packaging based on the starch for example the bagasse of sugarcane fibre [6]. It was reported that with addition of natural fibres in the starch-based foam can reduce rigidity, improve the elongation and increase the chance of biodegradation of the composites. Good natural fibre can reduce the cohesive forces and brittleness and lessen the tension [6]. However, at high concentration of natural fibre, the ability to expand was affected and encourage discontinuity in the polymer matrix results in less mechanically resistant [6]. Thus, this study will describe the tensile properties of natural fibre reinforced from polymer composite foam. Besides, it will identify the suitable mode of test and analyse the tensile properties based on available data extracted from the existing literature.

This study employs systematic review method on the existing literature. A systematic review deals with evaluating clearly formulated questions through systematic methods to recognise, select and critically analyse relevant literature included in the review process. Studied stated that statistical method is an option to analyse and summarise the literature [7]. Systematic review allows researcher to justify claim of rigor research, hence allowing the recognition of gaps and future directions of future studies. Hence, this study outstands since there is no collective systematic review on the tensile properties on natural fibre reinforced of polymer composite foam.

The findings of this study are relevant towards the appraisal of literature related tensile properties and cellulose fibre. With the aim to focus on tensile properties of natural fibre reinforced in the polymer composite foam, next section presents the methodology of the study. The subsequent sections describe the findings on the systematic review of the existing selected articles. Next, the findings were discussed. Future direction of the study is next described before conclusion is made upon the whole study.

2. Materials and Methodology

The methodology for the retrieving and analysing of the literature that has been exist will be conducted in this section. Researchers utilized a method namely PRISMA that caters the resources (Scopus, SAGE Journals, ScienceDirect, Web of Science (WoS), Taylor & Francis, Emerald Insight, ERIC ProQuest, SpringerLink and IEEE Xplore) as the way to search for the literature that has been exist before proceeding to the steps that explain on the review process in the sequence of the (identification, screening, eligibility), data analysis and data abstraction.

2.1 PRISMA

PRISMA Statement (Preferred Reporting Items for Systematic Review) were used as the guideline for the method of systematic review. Hence, it enables rigorous search of literature related to tensile properties of natural fibre reinforced in polymer composite foam.

2.2 Resource

The review mostly relies on the two (2) main databases, i.e Web of Science (WoS) and Scopus which offer comprehensive searching tools. WoS established by Clarivate analytics has more than 33, 000 journals which contain over 100 years of the most relevant and impactful multidisciplinary research discoveries (Web of Science, 2019). Scopus includes more than 75 million records and 24, 600 peer-reviewed journals from over 5, 000 publishers. With smart tools to analyse, track and visualize the research, Scopus is the largest abstract and citation peer-reviewed literature database (Scopus, 2019). This study has utilized supplementary databases such as SAGE Journals, ScienceDirect, Taylor & Francis, Emerald Insight, ERIC ProQuest, SpringerLink and IEEE Xplore to cater all the possible relevant literature for a comprehensive review.

2.3 Eligibility and Exclusion Criteria

This study applies several eligibility criteria i.e (i) only the journal articles were retrieved as they are more complete and contain more mature report of research (ii) only English publications were included to ease the search and analysis of literature, (iii) the retrieved articles were only focused on the cellulose, pullulan, mechanical properties and foam. These criteria were presented in Table 1.

Table 1 - Inclusion and exclusion criteria

Criterion	Eligibility	Exclusion
Language	English	Non-English
Discipline	Engineering, Material Science	Other than Engineering and Material Science
Literature type	Journal articles	Review articles, conference proceeding.
Focus of study	Cellulose, pullulan, foam, mechanical properties	Film, bio-film, resins

2.4 Systematic Review Process

The collection of systematic review based on 9 databases was performed in December 2020. The first stage of systematic review comes with the identification of suitable keyword for the searching purposes. Using suggested keyword of database such as thesaurus, previous studies and Scopus, there were several keywords related to cellulose, pullulan, foam and tensile properties were identified. It was easier to retrieve the metadata from the Scopus and WoS with the comprehensive feature. However, on other databases, the researchers required to customize on the specific search section such as title, abstract and keyword section. The search strings for this study have been provided as in Table 2.

Table 2 - The search string used for systematic literature reviewing

Journal database	Search string	Frequency of hits
WoS	TS = (“cellulose” AND “pullulan” AND “foam” AND “mechanical”)	0
Scopus	TITLE-ABS-KEY(“cellulose” AND “pullulan” AND “foam” AND “mechanical”)	379
ScienceDirect	(“cellulose” AND “pullulan” AND “foam” AND “mechanical”)	0
SAGE Journals	[All “cellulose”] AND [All “pullulan”] AND [All “foam”] AND [All “mechanical”]	0
Emerald Insight	(“cellulose” AND “pullulan” AND “foam” AND “mechanical”)	0
Taylor & Francis	[All “cellulose”] AND [All “pullulan”] AND [All “foam”] AND [All “mechanical”]	21
SpringerLink	‘(“cellulose” AND “pullulan” AND “foam” AND “mechanical”)’	40
ERIC ProQuest	(“cellulose”) AND (“pullulan”) AND (“foam”) AND (“mechanical”)	0
IEEE Xplore	(((("All Metadata":cellulose) AND "All Metadata":pullulan) AND "All Metadata":foam) AND "All Metadata":mechanical)	0

441 articles matched the search strings throughout 9 databases. During the identification stage, 9 duplicated articles were removed. Screening stage results an exclusion of 279 articles while 12 more articles were removed upon eligibility stage. Finally, only three (3) articles i.e. the primary studies were retained as they clearly focused on the topic of interest. PRISMA flow diagram has been illustrated as in Fig. 1.

2.5 Data Abstraction and Analysis

Three (3) primary articles were analysed. Content analysis was employed in this study. The abstracts were drafted before the analysis on full paper were conducted. Raw data will extract out to answer the objective. Manually, the extracted data were sorted out in different themes. The theme was discussed among the researchers. The whole process from raw data to final themes was recorded.

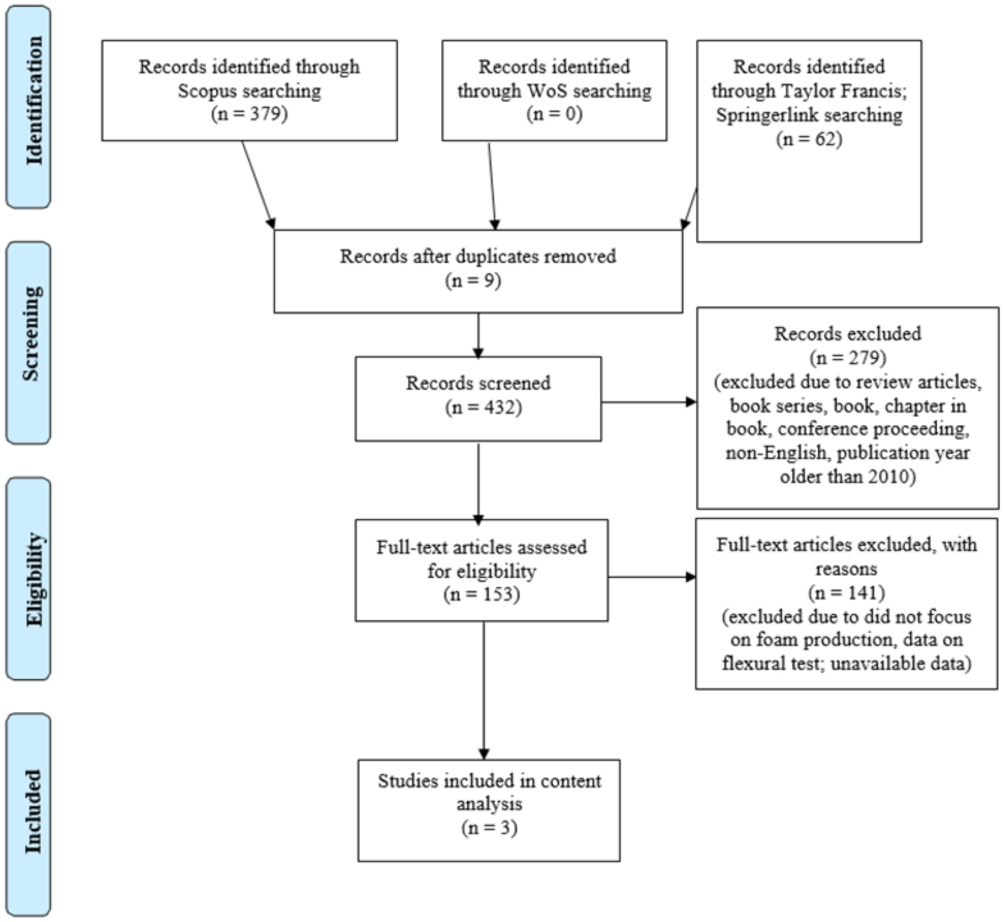

Fig. 1 - The flow diagram of the study. Adapted from Moher et al. (2009) [8]

3. Results and Discussions

In this section, only three studies include in qualitative analysis. These studies were selected for systematic review and were focused on the content analysis. The content analysis was focused on the results of mechanical properties obtained from the tensile strength, elongation at break and modulus of natural fibre reinforced polymer foam composite. The discussions were divided according to the following section. Firstly, the trend of tensile properties results of natural fibre reinforced content were analyzed. Next, the analysis was focused on the percentage of increment or decrement of tensile properties to the pure polymer foam. Further analysis was made to investigate on the effect of natural fibre reinforced content upon tensile properties. The effect of range of natural fibre reinforced size on the tensile properties of foam composites were also observed.

3.1 The Analysis on the Tensile Properties with Natural Fibre Reinforced Content of Polymer Composite Foam

In this section, the analysis on tensile properties with natural fibre reinforced content of polymer composite foam were discussed. It is important to analyse the trend as it gives guidelines for further study on the selection of the effective composition natural fibre which significantly affects the tensile properties of polymer composite foam. Based on Table 3, study conducted by Hassan et al. (2019) and Texteira et al. (2014) shows that the slight increase of the tensile properties influenced by the loading of PLA, 2.45% and 33% on the study conducted by both authors. Long et al. (2019) used the constant PLA loading (20wt%) in the sample with different alkali treated bamboo fibre (ABF).

As reported by Hasan et al., 2019), the addition of 24.3% cellulose fiber slightly increased the tensile strength of PLA composite. Similarly, the tensile strength increased with presence of 5% softwood fibre [3]. Long et al. (2019) shows that, tensile strength increased gradually up to 20wt% of bamboo fibre before being decreased from 25 to 30 wt% bamboo fibre [2]. Texteira et. al (2014), investigated on the effect of fiber content on the starch composite foam. The starch composite needs higher deformation for tensile failure compared to pure starch foam [3]. The hydrogen bonding between starch and fiber sample were increased due to higher contact area and contribute to greater tensile strength. The presence of fibre provides reinforcing effect to the starch matrix and the entanglement of the fiber. The entanglement of fiber was depending on the concentration of fiber and the aspect ratio. The fibers have dense distribution and extensive fiber pull-out. During the fiber pull out, the starch matrix was slowly disintegrated and few of the matrix remained in the loose fiber. Most likely the starch matrix has failed as the composite were stretched and freeing the fiber [3].

Table 3 - The tensile properties with natural fibre reinforced content of polymer composite foam

Author (s)	Natural fibre reinforced content	Tensile properties		Trend
		Tensile strength, MPa	Elongation at break, %	
Hassan et al. (2019) [1]	**Cellulose fibre** (24.3%)	2.50	1.867	Slightly increase with PLA loading
		2.70	2.100	
Long et al. (2019) [2]	**ABF fibre wt%**			
	0	58.5	9.5	Increase the gradually decrease
	5	58.2	9	
	10	58	8.5	
	15	60	8	
	20	65.8	7.5	
	25	64	7.3	
	30	61.8	6.3	
Texteira et al. (2014) [3]	**Softwood fibre** (5%)	18.9	2.37	Slightly increase with PLA loading
		25.3	7.23	

Note: Alkali treated bamboo fibre (ABF), Polylactide (PLA)

Another study was conducted by author Long et al. (2019), highlighted that there are 3 main factor that influenced the mechanical properties of the composite foam which are bamboo fiber (BF) strength, BF content and the interfacial bond between matrix and reinforcement. This paper clearly states that the role of fiber in the composite foam to provide mechanical strength and hold the maximum load. However, the excess of bamboo fiber content added into the formulation resulted in gradually drop of tensile strength [2].

Based on Texteira et al. (2014), the tensile strength for starch and fibre foam composites is 18.9 MPa while PLA with starch and fibre composite is 25.3MPa [3]. The percentage of elongation at break for starch and fibre foam composite is 2.37% and 7.23% for PLA with starch and fibre composite.

The calculation below show the percentage of elongation based on data provided in Hassan et al. (2019) [1]:-

Example (Hassan et al., 2019) [1]:-

$$Elongation\ percent = \frac{(elongation\ at\ break)}{(initial\ gauge\ length)}\ x\ 100 \quad (1)$$

e.g.: elongation at break = 0.56 mm, gauge length = 30 mm

$$Elongation\ percent = \frac{(0.56\ mm)}{(30\ mm)}\ x\ 100 = 1.867\%$$

3.2 The Analysis on the Percentage of Increment or Decrement of Tensile Properties with Natural Fibre Reinforced Content of Polymer Composite Foam

In this section, the analysis on percentage of increment or decrement of tensile properties with increasing natural fibre content of polymer composite foam were discussed. This analysis is important as it provides information on the effective range of natural fibre content which improved the tensile properties of the composites foam. It is important to produce polymer composites foam with good tensile properties and cost effective. Although the low cost of natural fibre allows to be incorporated at high amount, other important factors, the availability of the natural fiber and the effect on the tensile properties need to be considered.

In this section, the analysis on the percentage of increment or decrement of tensile properties with natural fibre reinforced content of polymer composite foam were discussed. Based on Table 4, the study conducted by Hassan et al.

(2014), shows an increment of tensile strength up to 8% [1]. However, the addition of this fibre was fixed. Long et al. (2019) recorded about 2.56% increment on tensile strength from PLA with 15wt% of ABF fibre and negative increment for PLA with 5 and 10wt% of ABF fibre [2].

Table 4 - The analysis on the percentage of increment or decrement of tensile properties with natural fibre reinforced content of polymer composite foam

Author (s)	Natural fibre reinforced content	Tensile properties		Increment/Decrement			Trend
				% of increment		% of decrement	
		Tensile strength, MPa	Elongation at break, %	Tensile strength	Elongation at break		
Hassan et al. (2019) [1]	**Cellulose fibre** (24.3%)	2.50	1.867	0	0		Slight increment in percentage for both tensile strength and elongation at break
				8.0	0.125		
		2.70	2.100				
Long et al. (2019) [2]	**ABF fibre wt%**						Negative increment at first for tensile strength and continue to fluctuate. No increment for elongation at break.
	0	58.5	9.5	0	0		
	5	58.2	9	-0.50	-5.26		
	10	58	8.5	-0.85	-10.53		
	15	60	8	2.56	-15.79		
	20	65.8	7.5	12.48	-21.05		
	25	64	7.3	9.40	-23.16		
	30	61.8	6.3	5.64	-33.68		
Texteira et al. (2014) [3]	**Softwood fibre** (5%)	18.9	2.37	0	0		As the natural fibre content increases, both of tensile strength and elongation at break increased
		25.3	7.23	33.86	2.05		

Note: Alkali treated bamboo fibre (ABF), Polylactide (PLA)

However, Long et al. (2019) reported that the highest tensile strength of the composite materials was recorded at 65.46MPa [2]. The increase in the composite strength has the attribute of material crystallinity. The load of excess natural fibre reinforced which is ABF causing the irregularity of fibre distribution on the pure polymer matrix because the poor compatibility on the interfacial and low of interfacial adhesion, thus declined the properties of tensile. The next factor are the effects on the alkali treatment on the natural fibre. The composition of 20wt% BF with 80wt% PLA composite were concluded to have the optimum tensile properties [1]. However, Texteira et al. (2014) does not indicate any percentage of increment or decrement on tensile properties [3].

Calculation for percentage of tensile strength increment based on data provided: -

Example (Long et al., 2019) [2]:

Tensile strength of PLA without ABF fibre : 2.50 MPa
Tensile strength of PLA with ABF fibre : 2.70 MPa

$$Percentage\ of\ increment = \frac{(PLA\ with\ ABF\ fibre - PLA\ without\ ABF\ fibre)}{(PLA\ without\ fibre)} x\ 100 = \frac{(2.70\ MPa)}{(2.50\ MPa)} x\ 100 = 8\%$$

Calculation for percentage of elongation at break increment based on data provided: -

Example (Hassan et al., 2019) [1]:-

Elongation at break of PLA without ABF fibre : 1.867%
Elongation at break of PLA with ABF fibre : 2.1%

$$Percentage\ of\ increment = \frac{(PLA\ with\ ABF\ fibre - PLA\ without\ ABF\ fibre)}{(PLA\ without\ fibre)} x\ 100 = \frac{2.11 - 1.867}{1.867} x\ 100$$
$$= 0.125\%$$

3.3 The Analysis on Effect of Natural Fibre Size on the Percentage of Increment or Decrement of Tensile Properties of Polymer Composite Foam

In this section, the analysis on the effect of natural fibre size on percentage of increment or decrement of tensile properties of composite foam were discussed. The effective size of natural fibre was determined as it influenced the dispersion in polymer matrix which subsequently affect the tensile properties. Based on Table 5, the study conducted by Hassan et al. (2019), shows that the cellulose fibre has the length of 500 to 800 µm, with percentage increment of tensile strength, which are 8% [1]. The study by Long et al. (2019), shows that the ABF fibre has size of 177 to 250 µm, with percentage increment of tensile strength of 2.56% for 15wt% of ABF fibre content [2]. Based on study by author Texteira et al. (2014), the softwood fibre has the size of 2470µm with no data on the percentage increment or decrement of tensile properties [3].

Table 5 - The analysis on effect of natural fibre size on the percentage of increment or decrement of tensile properties of polymer composite foam

Author (s)	Natural fibre size	Tensile properties		Increment/Decrement			Trend
				% of increment		% of decrement	
		Tensile strength, MPa	Elongation at break, %	Tensile strength	Elongation at break		
Hassan et al. (2019) [1]	**Cellulose fibre** Length = 500-800 µm wide = 15-34 µm	2.50	1.867	0	0		Slight increment in percentage for both tensile strength and elongation at break
				8.0	0.125		
		2.70	2.100				
Long et al. (2019) [2]	**Alkali treated bamboo fibre (ABF)** =177-250 µm	58.5	9.5	0	0		Negative increment at first for tensile strength and continue to fluctuate. No increment for elongation at break
		58.2	9	-0.50	-5.26		
		58	8.5	-0.85	-10.53		
		60	8	2.56	-15.79		
		65.8	7.5	12.48	-21.05		
		64	7.3	9.40	-23.16		
		61.8	6.3	5.64	-33.68		
Texteira et al. (2014) [3]	**Softwood fibre** = 2470 µm	18.9	2.37	0	0		As the natural fibre content increases, both of tensile strength and elongation at break increased
		25.3	7.23	33.86	2.05		

The author Long et al. (2019) state that the interface strength between matrix and reinforcement will affect the properties of composites due to role of the interface to transfer the load to reinforcements from the matrix [2]. Modified bamboo fibre (BF) will form cracks and irregular grooves on the composite surface due to movement of hemi-cellulose and pectin, thus alkali treatment can reduce the presence of impurities and increase the area of bonding between natural fibre reinforced and polymer matrix. The tensile properties will increase due to greater infiltration area and natural fibre/matrix adhesion. The cohesion and adhesion were also improved eventually lead to better tensile properties of composite foam.

4. Conclusion

This study emphasized on the incorporation of natural fibre content to be reinforced in polymer composites foams. The results obtained from this study proved that the objectives were successfully achieved. Three (3) studies on the natural fibre incorporated polymer composite foam were identified via PRISMA method. The effect of natural fibre content and natural fibre size on tensile properties of polymer composite foam were analysed in terms of qualitative analysis via systematic review. Higher natural fibre content incorporated with in polymer composite foam resulted to the higher tensile properties due to increment in tensile strength. It can be correlated that the effective range of natural fibre content which good tensile strength was in the range of 0wt% and below 20wt% for alkali treated bamboo fibre (ABF). Limitation of this study appeared to achieve the objective on analysis the optimum natural fiber size to be used in polymer composite foam. The optimum natural fibre content and natural fibre size on tensile properties of polymer composite foam were correlated via content analysis from systematic review. Overall, the findings obtained provide comprehensive information and act as reference on determination of optimum natural fibre content and size of natural fibre for further research on natural fibre reinforced foam.

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