INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

IJIE

Vol. 16 No. 6 (2024) 165-171
https://publisher.uthm.edu.my/ojs/index.php/ijie

Moisture and Compression Properties of Different Composition of Kenaf/Bamboo/Polyester Thermal Bonded Nonwoven Web for Mattress Filler

Noraishah Zulhizad[1], Azrin Hani Abdul Rashid[1]*, Nurul Arisya Abd Haris[1], Muhammad Farid Shaari[1], Mohd Afzanizam Mohd Rosli[2], Ahmad Safuan A Rashid[3], Abdussalam Al-hakimi Mohd Tahir[4], Abdul Waqar Rajput[5]

[1] *Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Campus, 84600 Pagoh, Johor, MALAYSIA*
[2] *Faculty of Mechanical Technology and Engineering, Universiti Teknikal Malaysia Melaka, 76100, Durian Tunggal, Melaka, MALAYSIA*
[3] *Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310, Johor Bahru, Johor, MALAYSIA*
[4] *Biocon Sdn Bhd, 79200, Iskandar Puteri, Johor, MALAYSIA*
[5] *BZU College of Textile Engineering, Faculty of Engineering and Technology, Bahauddin Zakariya University, Multan, PAKISTAN*

*Corresponding Author: azrin@uthm.edu.my
DOI: https://doi.org/10.30880/ijie.2024.16.06.016

Article Info

Received: 26 August 2024
Accepted: 14 October 2024
Available online: 4 November 2024

Keywords

Bamboo, compression properties, kenaf fibre, mattress filler, moisture content, nonwovens, thermal bonding.

Abstract

This study assesses the performance of kenaf, bamboo, and polyester nonwoven web in various mattress filling formulations. The influence of moisture and compression qualities on the web structure with a predefined thickness and the number of stacking layers is evaluated. Carding and thermal bonding techniques were employed to create the kenaf/bamboo/polyester web. Physical properties such as thickness (ASTM D177-96), areal weight (ASTM D6242), density (ASTM D3776), and moisture content (ASTM D2495-01) were determined, while the compressive performance was evaluated according to ASTM D471-00. Compressive strength decreased with higher ratios of untreated bamboo to kenaf, whereas moisture content increased with both higher kenaf and treated bamboo ratios. The compressive strength of kenaf/bamboo/polyester nonwoven web was minimally impacted by the treated bamboo. Consequently, the areal weight and density of the web were significantly influenced by a predetermined characteristic, the number of stacking layers and thickness of the web. Evidence suggests that a composition of 30% kenaf, 20% bamboo and 50% polyester is the optimal ratio to obtain the firmest mattress filler, as it exhibited a compressive percentage of 39% at a force of 2kN.

1. Introduction

Most developed and industrialized countries dedicated time to mattress research and development since one-third of a person's life is spent sleeping. Relevant physical variables associated with sleep comfort include spinal alignment, contact pressure or weight distribution, interface skin temperature, and vapor exchange between the sleeper and the bedding system [1]. The use of a dense and firm mattress significantly enhances sleep quality and comfort [2]. Due to global environmental concerns and a better understanding of renewable green resources, eco-friendly and biodegradable materials are increasingly being developed. Consequently, natural fibres are being used more in nonwoven products. Nonwoven materials, known for their versatility and wide range of applications, are increasingly utilized in products such as mattress fillers due to their unique properties. Among the natural fibres, kenaf and bamboo have gained attention for their environmental benefits, availability, and mechanical properties [3], [4].

Compression mattresses made from new materials have some drawbacks, such as a lack of comfort and performance. Kenaf-based mattresses are less studied because more synthetic mattresses are made. Hence, this work investigates the potential of kenaf fibre as the main material for mattress filler. Considering the relatively lower strength of natural fibres compared to synthetics, kenaf alone cannot exceed the compressive strength of mattresses produced from synthetic materials. This study explores the potential hybridization of kenaf with 6 Denier (6D) and 4 Denier (4D) polyester and treated and untreated bamboo fibre to strengthen natural fibres, particularly in their physical and mechanical qualities. Natural fibres are renewable and biodegradable making them attractive to the textile industry despite being weaker than synthetics [5]. The bedding industry has developed various technological solutions to reduce the use of synthetic fibres in mattress manufacturing by utilizing natural fibres [6]

Having a firm mattress is crucial for relieving discomfort and reducing body tension. The ideal mattress should balance firmness and softness. Pressure points, especially on the buttocks, hands, and overall body, significantly influence the perception of both firmness and comfort. Factors such as space, mattress compression or decompression, bed system posture limits, and micro movements impact sleep quality. Mattresses commonly utilize a combination of natural and synthetic materials [1]-[4], [6], [7]. Nonwovens are versatile textile structures formed by interlocking or joining fibres using mechanical, chemical, thermal, solvent, or combined methods. They exhibit various characteristics such as rigidity, compactness, two-dimensionality, paper-like texture, thickness, elongation, and porosity. The random structure of nonwovens is influenced by the Fibre Distribution Function (FDF) and fundamental weight, which represents mass per unit area. Unlike traditional textiles, nonwovens do not rely on inter-fibre interaction for internal cohesion, giving them unique qualities and enabling a wide range of applications [1]-[4], [6]-[8].

Natural fibres offer an excellent alternative to synthetic materials for energy-saving and lightweight applications [9]. Chemical treatments are being studied to enhance the surface properties of natural fibres and address their weaknesses, including poor fibre-matrix compatibility and high moisture absorption [10]. Kenaf (Hibiscus Cannabinus) is a fibrous natural plant that is stiff, strong, tough, and resistant to insects [11]. It can grow over 3 meters in height with a base diameter of 3-5 cm within just three months of sowing the seeds, making it suitable for various climates. Kenaf has three types of fibres in its bark, core, and pith. The bast fibre found in kenaf stalks is used for making paper, textiles, and rope, accounting for 35-50% of the plant's dry weight [3]. Kenaf fibre is highly beneficial among natural fibres due to its rapid growth, affordability, availability, and tolerance to different climates [12].

Bamboo, one of the strongest and fastest-growing plants on Earth, covers 22 million hectares of land [13]. Bamboo fibre, known for its thermal conductivity and microbial resistance, finds numerous applications in textiles, including cloth, yarn, beds, blankets, and towels [14]. In contrast, polyester (polyethylene terephthalate), the most popular synthetic fibre, is a thermoplastic substance derived from a chemical reaction involving petroleum, air, and water. It is not considered sustainable or biodegradable and often has a poor wicking rate due to its complex geometric structure. Textured polyester fibres are commonly used in quilting, pillows, outerwear, and sleeping bags due to their excellent insulating properties and hypoallergenic nature [15].

Creating a highly compact mattress benefits both the industry and the user by enhancing mattress longevity, pressure distribution and overall comfort. This study aims to explore new features of kenaf fibre-based mattress fillers to contribute to the development of high-quality kenaf-based mattresses alongside bamboo-based ones. This project aims to manufacture thermal bonded nonwoven web with varied kenaf/bamboo ratios and assess their physical features and compression strength for mattress filling.

2. Methodology

2.1 Materials

Kenaf/bamboo/polyester nonwoven webs were properly prepared. The materials used were recorded, the web construction process followed specified procedures, and testing was conducted in accordance with the American Standard Testing Method (ASTM). The kenaf (6 Denier) and polyester fibres (4 Denier) were supplied by Eadeco Sdn. Bhd. The bamboo fibres were obtained from the Nonwoven Technology Laboratory, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia. Two types of bamboo fibres were used in this research; treated and untreated. For the treated bamboo fibres, the fibres were chemically treated with 20% NaOH for 2 hours, 10% acetic acid for 6 hours, Clorox with 5% concentration commercial (0.5%) + NaOH at pH 9 for 15 minutes, 35% industrial peroxide (1%) + NaOH at pH 9 for 15 minutes, 10% softener for 30-45 minutes, followed by a silicone oil spray for 24 hours, and then dried at room temperature. In this study, a total of five samples of the kenaf/bamboo/polyester nonwoven webs were produced, as detailed in Table 1.

Table 1 *Sample's name and code*

Sample name	Sample code
50% Bamboo/ 30% 6D/ 20% 4D	5B
30% Bamboo/ 20% Kenaf/ 30% 6D/ 20% 4D	3B2K
30% Kenaf/ 20% Bamboo (untreated)/ 30% 6D/ 20% 4D	3K2B
30% Kenaf/ 20% Bamboo (treated)/ 30% 6D/ 20% 4D	3K2BT
50% Kenaf/ 30% 6D/ 20% 4D	5K

2.2 Preparation of Nonwoven web

Each kenaf, bamboo, and polyester fibre underwent manual opening, followed by processing through a nonwoven machine opener. The fibres were weighed and mixed according to their predetermined ratio. Next, the nonwoven carding method was employed to create the webs. These webs were then cut into dimensions of 50 cm x 36 cm and stacked to form 40 layers. Prior to thermal bonding, the stacked webs were securely clamped to maintain a 10 cm thickness and subjected to a thermal bonding process at 150°C for 20 minutes. The resulting thermal bonded nonwoven webs were subsequently sectioned into 10 cm x 10 cm specimens. To address structural damage caused by fibre underbonding, which led to fibre detachment during cutting, the thermal bonding process was repeated once more [4].

Thickness, areal weight, density, moisture, and compression tests were conducted on the kenaf/bamboo/polyester webs, with an average of five readings taken for each sample. The assessment of moisture content performance in the nonwoven web was carried out in accordance with the established standard, and the results were quantified using the moisture content formula. Compressive strength was evaluated utilizing a Universal Testing Machine, applying a consistent rate of 50.00 mm/min for a 2kN force. Density is calculated as indicated in Equations (1) and (2), while the calculation for areal weight follows the methodology outlined in Equations (3) and (4). Moisture content determination is based on Equation (5). The compressive percentages on the other hand were calculated using Equation 6 demonstrating the materials' resistance to compression and their shape retention properties.

$$\rho = m / V \quad (1)$$
$$V = \text{length} \times \text{width} \times \text{thickness} \quad (2)$$

where, ρ = density (g/cm^3), m = mass of sample (g), V = volume of sample, cm^3.

$$M = S / (A \times C) \quad (3)$$
$$A = L \times W \quad (4)$$

where, M = mass per unit area (g/m^2), S = mass of specimen (g), C = 0.000001, A = area of specimen, (mm^2).

$$MC\ (\%) = [(W_1 - W_x) / W_1] \times 100 \quad (5)$$

where, MC = moisture content (%), W_1 = weight after conditioned (g), W_x = weight after 20 minutes interval (g),

$$\text{Compressive percentage (\%)} = (\text{sample's deformation length} / \text{sample's initial thickness}) \times 100 \quad (6)$$

3. Results and Discussion

3.1 Physical Properties of Kenaf/Bamboo/Polyester web

Table 2 presents the findings regarding the physical properties of the kenaf/bamboo/polyester nonwoven webs. The web's thickness has decreased from an initial 10 cm to an average range of 7.82 cm to 8.54 cm, attributed to the cutting process. This cutting process resulted in deterioration of the sample structure due to fibre underbonding. In Figure 1 (a), the average thickness of the nonwoven web is depicted. The error bars, representing the standard deviation, overlap among various samples, indicating no significant variation in thickness. This suggests that the re-bonding process has improved the dimensional stability of the samples.

Table 2 *Physical properties of kenaf/bamboo/polyester nonwoven*

Sample code	Thickness (cm)	Density (g/cm³)	Areal weight (g/m²)	Moisture content (%)
5B	7.82 ± 0.20	0.053	4098.73 ± 173.42	4.11 ± 0.11
3B2K	8.30 ± 0.69	0.053	4484.53 ± 719.24	4.33 ± 0.27
3K2B	7.86 ± 0.27	0.051	3585.47 ± 575.87	4.51 ± 0.20
3K2BT	8.30 ± 0.22	0.055	4102.33 ± 236.22	4.93 ± 0.15
5K	8.54 ± 0.63	0.050	4353.60 ± 653.71	4.52 ± 0.24

Table 2 also reveals that the average density results are nearly identical across samples. Despite kenaf having a higher density compared to bamboo, it was expected that the kenaf/polyester nonwoven web would demonstrate the highest density among the samples [12]. However, the observed data contradicts this expectation, possibly due to regions where bamboo fibres contributed to a higher density than kenaf. Non-uniformities in the structure can inherently lead to changes in geometry and void volume [17]. Furthermore, the error bars in the areal weight graph in Figure 1 (c) also indicate an absence of significant differences between the values.

In Figure 1 (d), 5K showed higher moisture content compared to 5B. This supports the findings of Ismail et al. [10], indicating that kenaf tends to absorb more water than bamboo due to its higher hemicellulose concentration of 17.8%, compared to bamboo's 11.2%. Although the combination of kenaf and bamboo decreased moisture content overall, sample 3K2BT exhibited higher moisture content than 3K2B. This could be attributed to the hydroxyl group in treated bamboo's cellulose, hemicellulose, and lignin, which form numerous hydrogen bonds between nonwoven macromolecules [16]. Treating bamboo with a high NaOH solution typically reduces the size of hydroxide ions, but prolonged exposure, such as three minutes, may have the opposite effect [17]. The treated bamboo in our study might have experienced this reversed effect. Additionally, the physical characteristics of treated bamboo fibre are finer than untreated bamboo, which may cause it to seep into the surroundings during nonwoven processes.

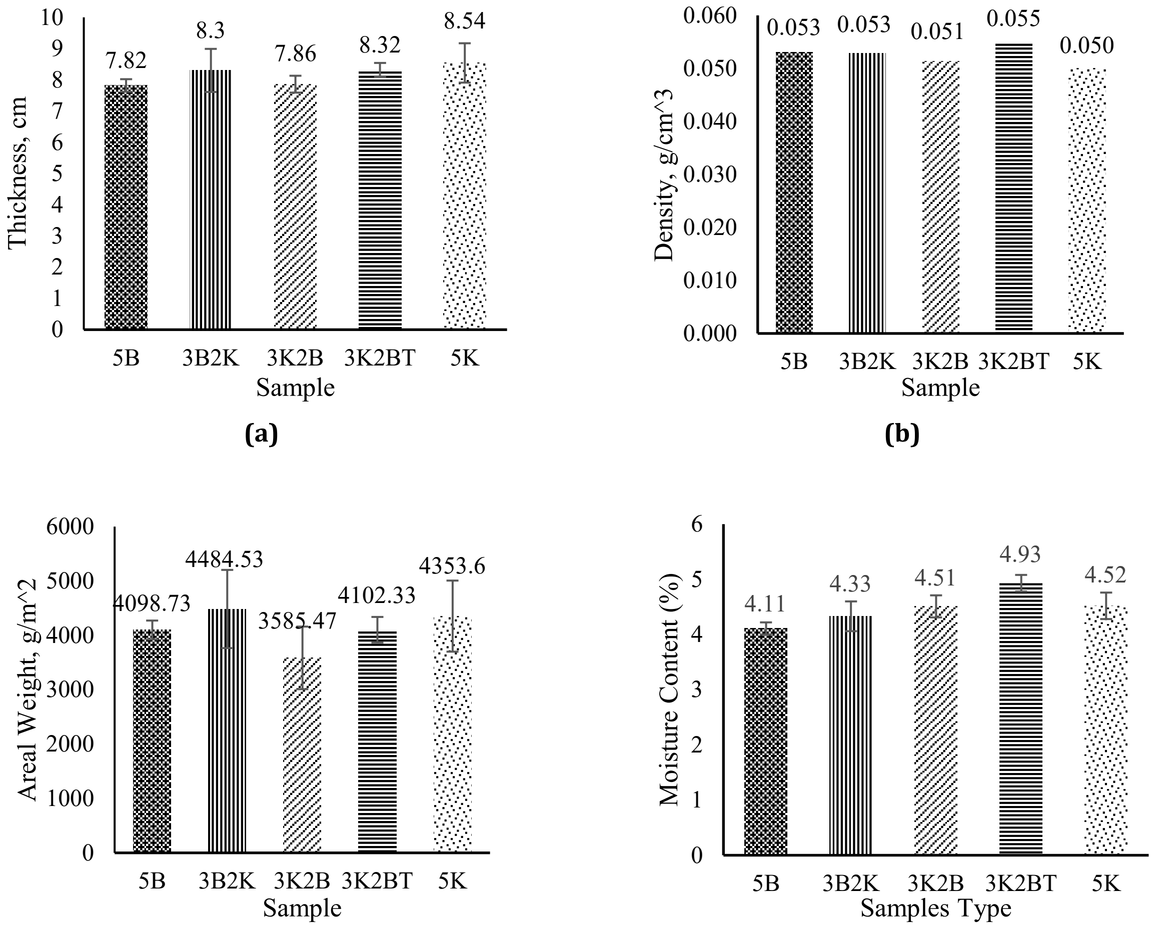

Fig. 1 *Physical properties of kenaf/bamboo/polyester nonwoven sample; (a) Thickness; (b) Density; (c) Areal weight; and (d) Moisture content*

3.2 Mechanical Properties of Kenaf/Bamboo/Polyester web

Based on Figure 2, the compressive test results indicate that the compressive strength of the kenaf/bamboo/polyester nonwoven web was improved with a higher ratio of kenaf, comprising 30% kenaf, 20% bamboo, and 50% polyester (3K2B). It was expected that the treated bamboo would have higher compressive strength [18]. However, the test results show that 3K2B demonstrates higher compressive strength (with the lowest compressive percentage) compared to 3K2BT, contradicting the expected outcome. This might be due to the loss of treated bamboo fibre during the production process, as evidenced by the difference in thickness after compression (see Table 3), where 3K2BT outperforms 3K2B in terms of compressibility rate.

There are slight improvements in sample 5K, indicating that adding treated bamboo fibre to the kenaf/polyester nonwoven composition has no significant effect. The superior performance of control sample 5K over 5B is noteworthy, as kenaf fibre has significantly greater strength than bamboo fibre [19]. Sample 3B2K exhibited the lowest compressive strength, suggesting that untreated bamboo should not surpass kenaf ratios in the kenaf/bamboo/polyester nonwoven web.

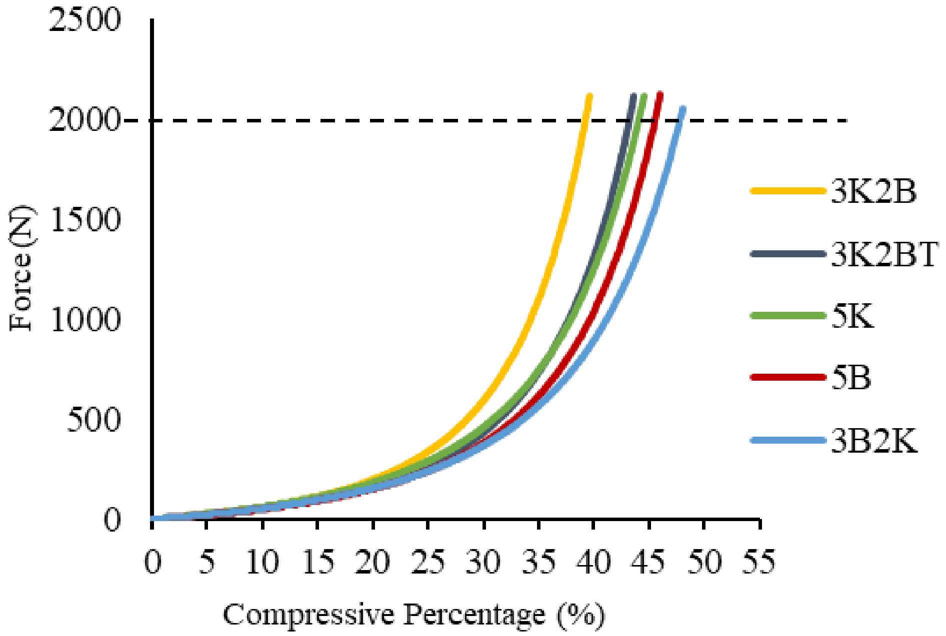

Fig. 2 *Force (F) versus compressive percentage (%)*

Table 3 *Compression test result*

Sample code	Compressive percentage at 2kN (%)	Difference in thickness after compression (%)
5B	45.0	6.65
3B2K	47.4	12.29
3K2B	39.0	15.27
3K2BT	42.9	8.89
5K	43.8	7.03

4. Conclusion

In this study, the kenaf/bamboo/polyester nonwoven web was effectively evaluated and prepared using carding and thermal bonding techniques. The specified thickness and the number of stacking layers significantly influenced the physical properties of the web. Interestingly, higher proportions of kenaf were linked to increased moisture content and compressive strength, contrary to bamboo's behaviour. In conclusion, the optimal ratio for the kenaf/bamboo/polyester nonwoven web, suitable for mattress filler use, is determined to be 30% kenaf, 20% bamboo, and 50% polyester. This composition demonstrates promising compressive performance characteristics. In conclusion, kenaf/bamboo/polyester may emerge as a viable alternative to synthetic fibres in various applications, particularly in mattress production. This research highlights the potential of utilizing more sustainable materials in mattress applications.

Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through GPPS (Vot Q677). Communication of this research is made possible through monetary assistance by Universiti Tun Hussein Onn Malaysia and the UTHM Publisher's Office via Publication Fund E15216. The authors would also like to thank Bamboo Research Centre (BambooRC), Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia for their support in this research.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design****: Azrin Hani Abdul Rashid, Nurul Arisya Abd Haris, Mohd Afzanizam Mohd Rosli, Ahmad Safuan A Rashid and Abdul Waqar Rajput;* ***data collection****: Nurul Arisya Abd Haris, Abdussalam Al-hakimi Mohd Tahir and Muhammad Farid Shaari;* ***analysis and interpretation of results****: Noraishah Zulhizad, Azrin Hani Abdul Rashid, Nurul Arisya Abd Haris, Muhammad Farid Shaari, Mohd Afzanizam Mohd Rosli, Ahmad Safuan A Rashid, Abdussalam Al-hakimi Mohd Tahir and Abdul Waqar Rajput;* ***draft manuscript preparation****: Noraishah Zulhizad, Nurul Arisya Abd Haris, Abdussalam Al-hakimi Mohd Tahir. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] A. Naddeo and N. Cappetti (2021) Comfort driven design of innovative products: A personalized mattress case study, *Work*: *A Journal of Prevention, Assessment & Rehabilitation,* 68(s1), 139–150, https://doi.org/10.3233/WOR-208013.

[2] G. Caggiari, G. R. Talesa, G. Toro, E. Jannelli, G. Monteleone, and L. Puddu (2021) What type of mattress should be chosen to avoid back pain and improve sleep quality? Review of the literature, *Journal of Orthopaedics and Traumatology,* 22(1), https://doi.org/10.1186/s10195-021-00616-5

[3] M. D. Hazrol, S. M. Sapuan, M. Y. M. Zuhri, E. S. Zainudin, N. I. A. Wahab, and R. A. Ilyas (2021) Recent development in kenaf (Hibiscus cannabinus)-based biocomposites and their potential industrial applications: A review. In S.M. Sapuan and Muhd Ridzuan Mansor (Eds.), *Design for Sustainability - Green Materials and Process* (pp.329-368). Elsevier. https://doi.org/10.1016/B978-0-12-819482-9.00007-1

[4] C. Prakash (2020) Bamboo fibre. In Ryszard M. Kozłowski and Maria Mackiewicz-Talarczyk (Eds.), *Handbook of Natural Fibres* (pp. 219–229). Woodhead Publishing. https:// doi: 10.1016/B978-0-12-818398-4.00009-8.

[5] A. Kanazawa, T. Ikeda, and T. Endo (1994) Polymeric phosphonium salts as a novel class of cationic biocides. X. Antibacterial activity of filters incorporating phosphonium biocides, *Journal of Applied Polymer Science*, 54(9), 1305–1310, https://doi.org/10.1002/app.1994.070540912

[6] M. Tascan, E. A. Vaughn, K. A. Stevens, and P. J. Brown (2011) Effects of total surface area and fabric density on the acoustical behavior of traditional, *The Journal of The Textile Institute*, 102(9), 746–751, https://doi.org/10.1080/00405000.2010.515731

[7] S.H. Kamaruddin, M.S.M.Basri, M.Rayung, F. Abu and S.Ahmad (2022) A Review on Natural Fiber Reinforced Polymer Composites (NFRPC) for Sustainable Industrial Applications, *Polymers,* 14,3698, https://doi.org/10.3390/polym14173698

[8] L. Tonetti, M. Martoni, and V. Natale (2010) Effects of different mattresses on sleep quality in healthy subjects: An actigraphic study, *Biological Rhythm Research, 42*(2), 89–97, https://doi.org/10.1080/09291010903557187

[9] M. López-Torres, R. Porcar, J. Solaz, and T. Romero (2008) Objective firmness, average pressure and subjective perception in mattresses for the elderly, *Applied. Ergonomics*, 39(1), 123–130, https://doi.org/10.1016/J.APERGO.2006.11.002

[10] B. Pourdeyhimi, B. Maze, F. Farukh, and V. V. Silberschmidt (2019) Nonwovens-Structure-process-property relationships. In Peter Schwartz (Eds.), *Structure and Mechanics of Textile Fibre Assemblies* (pp. 109-143). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-102619-9.00004-3

[11] M. R. Sanjay, G. R. Arpitha, L. L. Naik, K. Gopalakrishna, and B. Yogesha (2016) Applications of Natural Fibers and Its Composites: An Overview, *Natural Resources*, 7(3), 108–114, http://dx.doi.org/10.4236/nr.2016.73011

[12] X. Li, L. G. Tabil, and S. Panigrahi (2007) Chemical treatments of natural fiber for use in natural fiber-reinforced composites: A review, *Journal of Polymers and Environment*, 15(1), 25–33, https://doi.org/10.1007/s10924-006-0042-3

[13] Y. G. Thyavihalli Girijappa, S. Mavinkere Rangappa, J. Parameswaranpillai, and S. Siengchin (2019) Natural Fibers as Sustainable and Renewable Resource for Development of Eco-Friendly Composites: A

Comprehensive Review, *Frontiers in Materials*, 6, 1–14, https://doi.org/10.3389/fmats.2019.00226
[14] R. Arjmandi, Ilknur Yıldırım, and Norhayani Othman (2021) Kenaf fibers reinforced unsaturated polyester composites: A review, *Journal of Engineered Fibers and Fabrics,* 16, https://doi.org/10.1177/15589250211040184
[15] G. Wang and F. Chen (2017) Development of bamboo fiber-based composites, *Advanced High Strength Natural Fibre Composite in Construction*, 235–255, https://doi.org/10.1016/B978-0-08-100411-1.00010-8
[16] Y. Zhang, H. P. Wang, and Y. H. Chen (2006) Capillary effect of hydrophobic polyester fiber bundles with noncircular cross section, *Journal of Applied Polymer Science,* 102(2), 1405–1412, https://doi.org/10.1002/app.24261
[17] A. S. Ismail, M. Jawaid, M. T. H. Sultan, and A. Hassan (2019) Physical and mechanical properties of woven kenaf/bamboo fiber mat reinforced epoxy hybrid composites, *BioResources*, 14(1), 1390–1404, http://dx.doi.org/10.15376/biores.14.1.1390-1404
[18] N. N. Bonnia, M. M. Mahat, S. N. Surip, H. Anuar, N. A. Hassan, and S. Ahmad (2014, September 23-26). *Polyester/kenaf composite; effect of matrix modification* [Conference Session] 2012 IEEE Symposium on Business, Engineering and Industrial Applications, https://10.1109/ISBEIA.2012.6422940
[19] Y. Liu and H. Hu (2008) X-ray diffraction study of bamboo fibers treated with NaOH, *Fibers and Polymers, 9(6)*, 735–739, https://doi.org/10.1007/s12221-008-0115-0