Uluslararası Teknolojik Bilimler Dergisi, 15(3), 103-110, 2023 DOI: 10.55974/utbd.1322745

ISPARTA UYGULAMALI BİLİMLER ÜNİVERSİTESİ

Uluslararası Teknolojik Bilimler Dergisi

International Journal of Technological Sciences

UTBD IJTS

Araştırma Makalesi/Research Article

3-Point bending behaviors of sandwich panels with hemp fibers

Onur KELTEN [1], **Abdulmecit GÜLDAŞ** [2],

[1] Gazi University, Faculty of Technology, Department of Manufacturing, Ankara, Türkiye
[1] Turkish Aerospace Industries, Inc., Ankara, Türkiye
[2] Gazi University, Faculty of Technology, Department of Manufacturing, Ankara, Türkiye

Keywords
Hemp fiber
3 Point bending test
Sandwich model
Statical analysis

Article history:
Received: 04.07.2023
Accepted: 27.12.2023

Abstract: The article discusses the increasing interest in natural fibers as a substitute for synthetic fibers in the development of composites due to the depletion of crude oil reserves, environmental concerns and regulations targeting the reduction of carbon emissions. The mechanical properties of natural fibers are closely linked to their chemical composition and structure, which can be influenced by various factors such as harvesting time, growth conditions, storage practices, extraction techniques and pre fabrication chemical treatments. The article also explains the finite element analysis steps for a sandwich structure created using hemp fibers with a 3 mm diameter and 20 mm spacing between two carbon prepreg layers for a 3-point bending test.Finally, numerical analysis outputs of sandwich structures created with hemp fibers at intervals of 10 mm, 20 mm, and 30 mm, and diameters of 2 mm, 3 mm, and 4 mm, are presented graphically to demonstrate the effects of changes in hemp fiber spacing and diameter on stress.

Atıf için/To Cite: Kelten O. Güldaş A. 3-Point bending behaviors of sandwich panels with hemp fibers. International Journal of Technological Sciences, 15(3), 103-110, 2023.

Kenevir lifli sandviç panellerin 3 nokta eğilme davranışları

Anahtar Kelimeler
Kenevir elyaf
3 Nokta eğilme testi
Sandviç model
Statik analiz

Makale geçmişi:
Geliş Tarihi: 04.07.2023
Kabul Tarihi: 27.12.2023

Öz: Bu makale, ham petrol rezervlerinin azalması, çevresel endişeler ve karbon emisyonlarının azaltılmasına yönelik düzenlemeler gibi nedenlerle, kompozitlerin geliştirilmesinde sentetik liflerin yerine doğal liflerin artan ilgisini tartışmaktadır. Doğal liflerin mekanik özellikleri, kimyasal bileşimleri ve yapısı ile yakından ilişkilidir ve hasat zamanı, büyüme koşulları, depolama uygulamaları, çıkarma teknikleri ve ön üretim kimyasal işlemler gibi çeşitli faktörler tarafından etkilenebilir. Makalede ayrıca iki karbon prepreg tabakası arasına 3 mm çapında 20 mm aralıklarla kenevir lifleri kullanılarak oluşturulan bir sandviç yapının 3 nokta eğilme testi için sonlu elemanlar analiz adımları anlatılmıştır. Son olarak da kenevir lifi aralıklarındaki değişimin ve kenevir lifi çapındaki değişimin gerilime etkilerini göstermek için 10 mm, 20 mm ve 30 mm aralıklarla; 2 mm, 3 mm ve 4 mm çaplarındaki kenevir lifleri kullanılarak oluşturulan sandviç yapılara ait nümerik analiz çıktıları grafik olarak verilmiştir.

1. Introduction

Over the last century, the invention and development of artificial polymers have signifcantly propelled the advancement of society and technology, while providing immense convenience in people's daily routines and occupations [1]. In addition to this plastics are considered the main cause of pollution of river, sea and ocean ecosystems [2]. The perception of the depletion of crude oil reserves, combine with fresh regulations targeting the reduction of carbon emissions and amplified demands from consumers for sustaninable products, has intensified the pursuit of natural materials as a feasible substitute [3]. Because of increasing environmental concern and preservation, an expanding body of research is exploring the potential applications of natural fibers in te development of thermoset and thermoplastic composites. Furthermore,

* İlgili yazar/Corresponding author: onur.kelten@hotmail.com

the investigation of physical and chemical surface treatments to enhance the mechanical properties of these composites is gaining momentum [4]. Natural fibers are currently considered to be conventional fibers with some advantages including but not limited to renewability, widespread availability and cost effectiveness [5].

Natural fibers have the potential to be derived from a variety of sources, including plants, animals and minerals. In most cases, plant or vegatable fibers are used to reinforce polymer matrices [6]. Flax, hemp, sisal, jute and coconut are frequently utilizedas natural fiber reinforcement materials in the development of thermosetting and thermoplastic polymer matrix composites [7]. The hemp plant is native to India and Persia. However, it can be grown in almost all temperate climatic conditions. Russia holds the distinction of being the most significant global producer of hemp fiber, contributing approximately one-third of the annual yield. Thanks to its exceptional strength and rigidity, hemp fiber holds significant promise as a highly effective reinforcement material in composite applications. The physical and mechanical properties of natural fibers and the primary type of glass fiber (E-Glass) are presented in Table 1 [4].

Table 1. List of plant fibers, physical and mechanical properties and glass fiber [4]

Fiber	Length (mm)	Density (g/cm^3)	Failure Strain (%)	Tensile Strength (MPa)	Young's Modulus (GPa)	Moisture Content (%)	Specific Stiffness (E/ρ) (GPa)
Hemp	5–55	1.4	1.6	550–1110	30–70	8	21–50
Jute	2–120	1.3–1.5	1.5–1.8	393–800	10–55	12	6–34
Sisal	900	1.3–1.5	2.0–2.5	507–855	9.4–28	11	6–18
Flax	5–900	1.5	1.2–3.2	345–1830	27–80	7	18–53
Ramie	900–1200	1.5	2.0–3.8	400–938	44–128	12–17	29–85
E-glass	Continuous	2.5	2.5	2000–3000	70	<0.1	28

Bast fibers, which include flax, hemp and ramie fibers, are emerging as a promising substitute for synthetic fibers across a range of automotive, hosehold and industrial applications. These fibers offer several benefits, including low cost, reduced density, low energy consumption, superior specific strength and specific modulus. Additionally, they are biodegradable of natural fiber reinforced composites is influenced by various factors such as moisture, temperature, UV exposure and the activities of microorganisms in outdoor environments. The life-cycle assessment and environmental impact assessment studies on plant fibers and bio-composites can serve as a valuable guide for researchers in the quest to develop new materials that minimize their impact on the environment [8].

The mechanical characteristics of natural fibers are closely linked to their chemical composition and structure, which can be influenced by various factors such as harvesting time, growth conditions, storage practices, extraction techniques and pre-fabrication chemical treatments. Optimum harvesting time is crucial, as delaying by just five days beyond the recommended window may lead to a reduction in mechanical strength by as much as 15% [9].

The impact of different fiber volume ratios on the dynamic, mechanical, structural, and free vibration characteristics of hemp fiber composite has been investigated. Results show that a composite with 30% volume fraction exhibits the highest damping factor. Further, the research examines the influence of weaving patterns of fibers in natural fiber composite on the free vibration behavior of woven banana and jute fiber composite using experimental analysis [10].

The use of natural and synthetic fibers in combination can help to overcome any weaknesses or deficiencies in either type of fiber, resulting in a stronger and more versatile material. The properties of a hybrid composite can be adjusted by varying the fiber structure, orientation, content, length, fabric-matrix bonding, and arrangement. Hybridizing composites can be achieved in two ways: interlaminate and intralaminate. Interlaminate involves depositing layers of lamina on top of each other to create a simple laminate. On the other hand, intralaminate involves reinforcing different fibers in a single matrix or layer [11]. Hybrid composites incorporate glass fibers instead of carbon fibers due to the former's comparatively lower cost and higher stiffness, strength, toughness, and impact resistance [12].

Effective fiber-matrix adhesion is a crucial factor that contributes to the superior mechanical properties of composite materials. Weak interfacial bonding is commonly attributed to insufficient surface adhesion between fibers and the matrix. Several studies have been conducted to investigate the efficacy of various chemical treatments in reducing the hydrophilicity of natural fibers (e.g. hemp, flax, sisal, kenaf, coir, and jute) to enhance their surface adhesion to the matrix and minimize moisture absorption [13]. The presence of hydrophilic surfaces in natural fiber composites can lead to weak bonding with hydrophobic polymer matrices. This, in turn, can lead to dimensional changes such as swelling due to moisture absorption, resulting in decreased mechanical performance. The alkali treatment is a widely used, cost-effective technique that effectively modifies the surface of natural lignocellulosic fibers (NLFs) to enhance their mechanical properties. An emerging approach to surface modification of NLFs is the application of graphene-oxide coating. Graphene, a one-atom-thick material, displays exceptional properties like high mechanical strength, specific surface area, and electrical conductivity [14].

Figure 1 highlights the demand for natural fiber-based materials in the automotive industry. However, it has been noted that automobile manufacturers worldwide have increasingly prioritized cost-effectiveness without compromising quality. The growing interest in replacing petroleum-based synthetic materials with renewable resources like natural fibers in automotive applications stems from the benefits of recyclability and biodegradability. Additionally, natural fiber-reinforced composites can significantly reduce costs by approximately 20% and weight by 30% for automotive components [15].

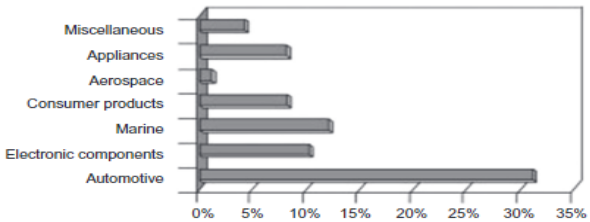

Figure 1. The use of natural fibers in automotive and other sectors [15]

Despite their potential benefits, the use of natural composites in the aircraft industry is still limited due to various challenges that need to be addressed. This is especially true for critical structural components, where safety standards for fire retardancy and crash safety pose significant barriers to the wider adoption of natural composites in this industry. However, certain interior components of commercial aircraft, such as in-cabin parts, have successfully incorporated natural fibers due to their advantageous properties of strength and lightness [16].

In light of the above information, it can be said that natural fibers are open to development, and therefore, their use is expected to increase.

2. Materials and Methods

This study focuses on investigating whether hemp fiber can serve as a viable alternative to inorganic and synthetic reinforcement materials. Specifically, the study examines the impact of incorporating hemp fiber, arranged in a grid-spine configuration, on the mechanical properties of a composite structural element. The composite structure consists of an epoxy matrix reinforced with woven carbon fiber. To create a mesh structure, hemp fibers of varying diameters were strategically positioned at different intervals. Epoxy resin, widely employed in the aerospace industry due to its resistance to environmental conditions, exceptional electrical and thermal properties, and high modulus, was chosen as the matrix material. The resulting composite material forms the core of a sandwich structure, with carbon prepregs positioned above and below. A CAD environment was utilized to model the constructed sandwich structure, followed by conducting comprehensive structural analyses.

The hemp fiber, chosen as the reinforcement element, was studied in three different diameters: 2 mm, 3 mm, and 4 mm. The objective was to analyze the impact of diameter variation on the strength characteristics of the samples. Furthermore, the investigation also examined the effect of grid spacing on sample strength by introducing gaps of 10 mm, 20 mm, and 30 mm between fiber weaves.

A sandwich structure was created for finite element analysis by incorporating hemp fibers with diameters of 2 mm, 3 mm, and 4 mm at intervals of 10 mm, 20 mm, and 30 mm between two layers of carbon prepreg. The sample preparation strictly adhered to the guidelines specified in ASTM D 7264 standard. Three-dimensional models of the designated dimensions were meticulously designed using CATIA V5 software to facilitate accurate modeling.

*2.1. **Creation of finite element models***

The construction of the finite element model for the samples and subsequent analysis were conducted utilizing the ABAQUS software. Following the transfer of models acquired from the CAD environment to the ABAQUS platform, a series of essential steps were taken. Initially, material properties were defined for each model, and subsequently, contact definitions were established to account for the interfaces formed between the models (Figure 2).

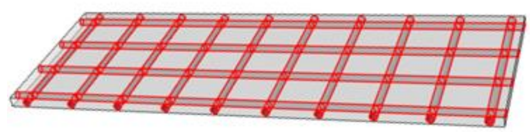

Figure 2. Representation of the interface between epoxy matrix and hemp fibers

The material properties assumptions for the sample are as follows:

- The range of elastic modulus values for hemp fibers, obtained from the literature, is 30-70 GPa. Therefore, seperate analyses were conducted for elastic moduli of 30 GPa, 50 GPa, and 70 GPa. Additionally, a Poisson's ratio of 0.40 was assumed, in accordance with the literature.
- The elastic modulus for epoxy, taken from the literature, is 3 GPa, and the Poisson's ratio was assumed to be 0.37, also in line with the literature.
- The engineering constants for the prepreg material, obtained from the literature, are as Table 2:

Table 2. Mechanical properties of the carbon prepreg

E1	E2	E3	Nu12	Nu13	Nu23	G12	G13	G23
133500	8000	8000	0.3	0.3	0.3	3750	3750	3750

Hemp fibers and epoxy matrix are considered isotropic and homogeneous materials, so when defining the materials in ABAQUS, the elastic modulus and Poisson's ratio were deemed sufficient.

For carbon prepregs, characterized by their anisotropic nature, the material was defined using the aforementioned engineering constants. During the model construction process, a "Tie" contact definition was established between the components to ensure proper interfacial connectivity.

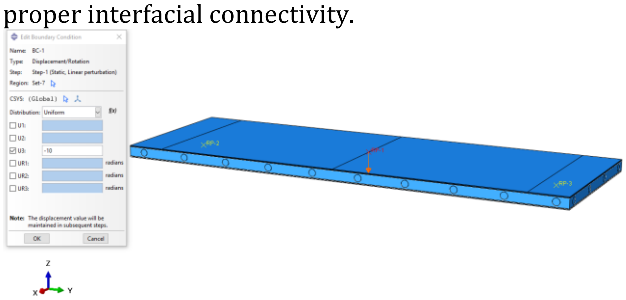

Figure 3. Load representation

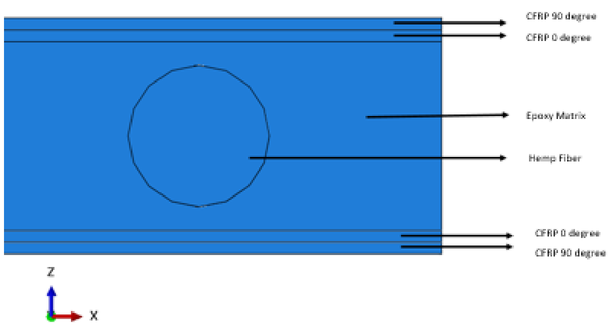

Figure 4. Sandwich model representation

The analysis of the specimen is conducted with fixed supports at two points. Additionally, to induce bending, a displacement of "-10mm" along the Z-axis at the center of the specimen was prescribed (Figure 3).
During the meshing process, each subcomponent was individually organized. Accordingly, starting with the simplest geometry, the meshing of carbon prepregs was performed. The hexahedral element ("Hex") was chosen, which is commonly preferred for prismatic geometries. A unit mesh size of 4 was selected (Figure 5)

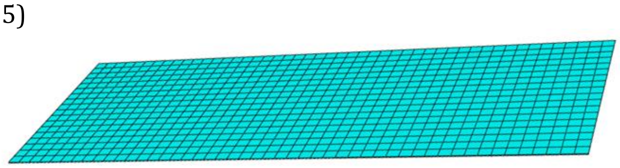

Figure 5. Meshing for carbon prepreg

Next, the meshing of the hemp fiber model with a more complex geometry was performed. The tetrahedral element ("Tet") was selected as the mesh shape, which is commonly preferred for intricate geometries. A unit mesh size of 2 was chosen (Figure 6).

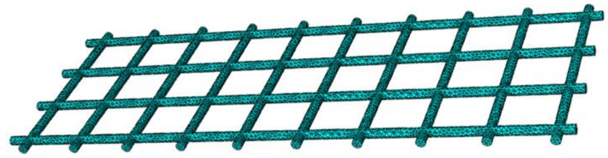

Figure 6. Meshing for hemp fibers

Finally, the meshing of the epoxy resin was performed. The tetrahedral element ("Tet") was selected as the mesh shape, which is commonly preferred for complex geometries. In order to enable the analysis, two different unit mesh sizes were utilized in this model. The unit mesh size of 0.8 was employed for the interface between the hemp fiber and epoxy matrix, while a unit mesh size of 2 was used for the remaining parts of the model. The tetrahedral element was chosen for both mesh patterns (Figure 7).

Figure 7. Meshing for epoxy matrix

All analysis studies were conducted under the same conditions. The difference in the number of unit meshes between the samples arises from variations in sample dimensions. Separate analyses were performed for each hemp fiber diameter, with hemp elastic modulus values of 70 GPa, 50 GPa, and 30 GPa, respectively.

3. Results

Stress values were obtained after conducting the analysis of the 3-point bending test. Based on these findings, it was observed that the maximum tensile stress occurred in the sandwich model comprised of hemp fibers, epoxy resin, and carbon prepregs, specifically in the structure with a 90-degree fiber alignment, woven at a diameter of 3 mm and spaced at 20 mm intervals. However, this study primarily focused on analyzing the stresses applied to the hemp fibers and their resistance to these stresses. Due to the isotropic and ductile nature of hemp, the evaluation was performed according to the Von Mises stress theory.
Figures 8 and 9 present an examination of the maximum stresses experienced by the sandwich model. The results revealed that the highest stress concentrations were observed in the outermost layer of the sandwich model, particularly in the carbon prepregs with a 90-degree fiber orientation.

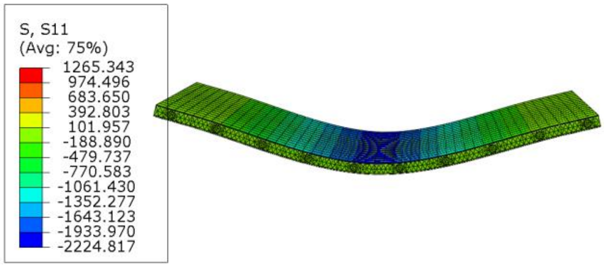

Figure 8. Maximum compression stress on the sandwich model

In Figure 8, when examining the stresses in the X-direction on the sandwich model, it is observed that the highest compressive stress occurs at the center of the specimen, with a value of 2224.8 MPa.

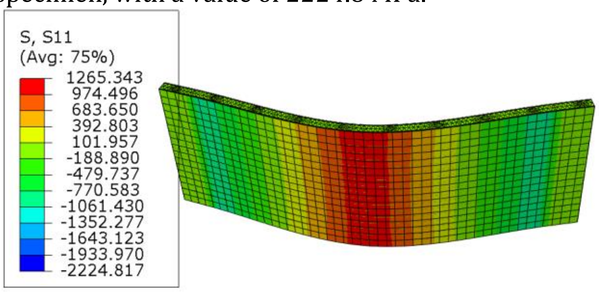

Figure 9. Maximum tensile stress on the sandwich model

In Figure 9, it is determined that the maximum tensile stress value on the sandwich model is located beneath the specimen, with a value of 1265.3 MPa.

Table 3. Tensile properties of hemp fibers as reported by different authors [4]

Tensile strength (MPa)	Tensile modulus (GPa)	Elongation at break (%)
690		1.6
1235		4.2
310–750	30–60	2–4
550–900	70	1.6
690		1.6
895	25	
500–1040	32–70	1.6
920	70	
690–1000	50	1.0–1.6
920	70	1.7
270–900	20–70	1.6

Different tensile strength values have been given with Table 3. In this study, the tensile strength value has been within the range of 310-1040 (MPa) for the 30-70 GPa tensile modulus

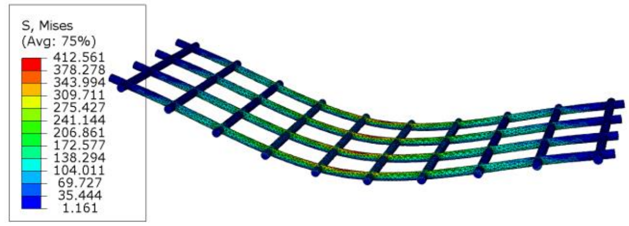

Figure 10. Von mises stresses on hemp fibers

Figure 10 examines the Von Mises stresses applied to the hemp fibers. The stress applied to the hemp fibers with an elastic modulus of 30 GPa is 412.6 MPa. This value is above the tensile strength of hemp fiber, which is 310 MPa.

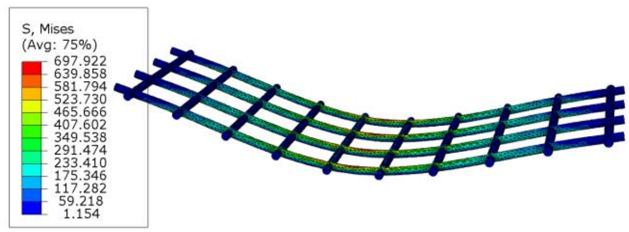

Figure 11. Von mises stresses on hemp fibers

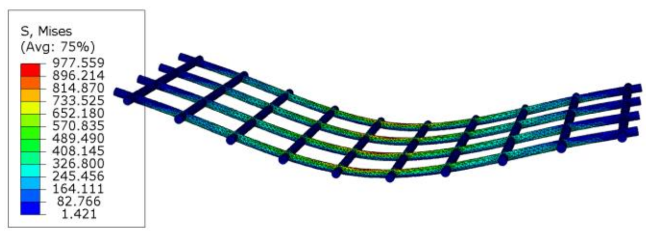

Figure 12. Von mises stresses on hemp fibers

Figure 11 and Figure 12 present the analysis results based on elastic modulus values of 50 GPa and 70 GPa for the hemp fibers. When examining the Von Mises stress applied to the hemp fibers, it is observed that the stress remains below the tensile strength of 675 MPa (for 50 GPa tensile modulus). However, observed stress on hemp fibers for 70 GPa is lower than tensile strength (1040 MPa).

Figure 13 demonstrates the effect of fiber spacing on stress for a fiber diameter of 2 mm.

Figure 14 illustrates the impact of fiber spacing on stress for a fiber diameter of 3 mm.

Figure 15 displays the influence of fiber spacing on stress for a fiber diameter of 4 mm.

According to numerical analysis results of all specimens are given as MPa unit below Table 4 And Table 5

Table 4. Specimen numbers

No	Specimen
1	Dia.=2 mm; Fiber Interval=10 mm
2	Dia.=2 mm; Fiber Interval=20 mm
3	Dia.=2 mm; Fiber Interval=30 mm
4	Dia.=3 mm; Fiber Interval=10 mm
5	Dia.=3 mm; Fiber Interval=20 mm
6	Dia.=3 mm; Fiber Interval=30 mm
7	Dia.=4 mm; Fiber Interval=10 mm
8	Dia.=4 mm; Fiber Interval=20 mm
9	Dia.=4 mm; Fiber Interval=30 mm

Table 5. Von mises stress presentation

No	E=70 GPa; Tensile Strength=1040 MPa		E=50 GPa; Tensile Strength=675 MPa		E=30 GPa; Tensile Strength=310 MPa	
	Von Mises	Status (%)	Von Mises	Status (%)	Von Mises	Status (%)
1	1089,38	4,75	781,15	15,73	465,70	50,22
2	1125,27	8,20	804,23	19,15	476,05	53,57
3	1169,08	12,41	836,31	23,90	495,51	59,84
4	931,08	-10,47	668,97	-0,89	402,61	29,87
5	977,56	-6,00	697,92	3,40	412,56	33,08
6	957,44	-7,94	683,15	1,21	404,97	30,64
7	852,62	-18,02	608,04	-9,92	360,17	16,18
8	859,86	-17,32	614,40	-8,98	363,41	17,23
9	873,99	-15,96	624,01	-7,55	369,99	19,35

In the course of our analysis according to Table 5, wherein an elastic modulus of E=30 GPa was presumed for hemp fibers, it was observed that damage manifested universally across all tested specimens. Upon revising our considerations to E=50 GPa, it was observed that all specimens featuring 2 mm diameter fibers exhibited damage, whereas specimens composed of 3 mm diameter fibers displayed damage solely at intervals of 10 mm. Notably, in specimens with a 4 mm diameter, damage remained entirely absent. When extending our assessment to E=70 GPa, a consistent pattern emerged: damage was evident across all specimens employing 2 mm diameter fibers, while specimens employing 3 mm and 4 mm diameter fibers remained entirely free from damage.

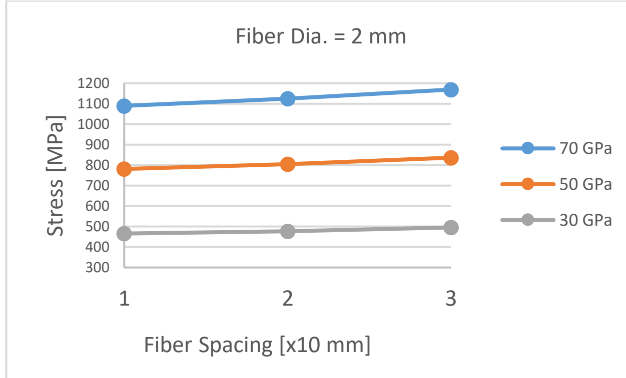

Figure 13. Effect of fiber spacing on stress distribution

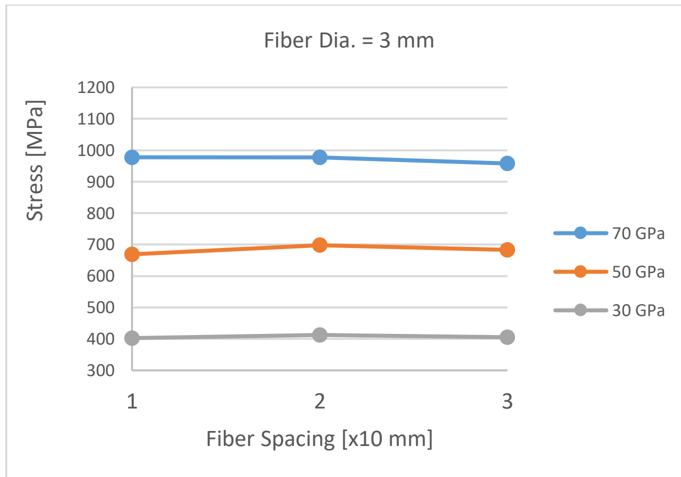

Figure 14. Effect of fiber spacing on stress distribution

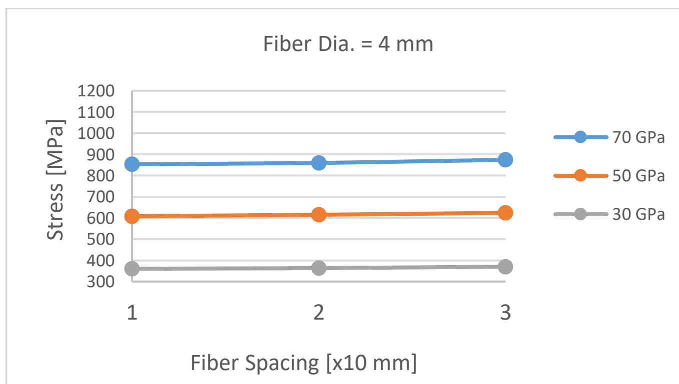

Figure 15. Effect of fiber spacing on stress distribution.

On the other hand, there is another study in the literature on composite materials reinforced with another natural fiber, flax. In this study, the bending strength of the material has been increased by using flax fiber [17].

4. Conclusions

Upon reviewing the relevant studies, it is evident that the concept of sustainability has emerged prominently, particularly considering the high production costs and environmental impact associated with synthetic fibers. As a result, the utilization of natural fibers in various industries is expected to witness a gradual increase.

This study focuses on the implementation of three different hemp fibers with diameters of 2 mm, 3 mm, and 4 mm. These fibers were woven at intervals of 10 mm, 20 mm, and 30 mm to construct a composite structure forming the core of a sandwich model. Subsequently, the sandwich composite materials underwent a three-point bending simulation to examine the influence of hemp fiber reinforcement. Based on the analyses conducted on the designed sandwich structures, it was observed that altering the fiber spacing for fibers of the same diameter did not result in significant variations in fiber stresses. The tensile strength of hemp fiber is considered to be within the range of 310-1040 MPa. When the analysis results of a specimen with a diameter of 3 mm and a spacing of 20 mm are compared to these strength values, it is observed that stress falls below the strength values for 30 GPa, 50 GPa, and 70 GPa. Consequently, no fracture is anticipated in the core of the sandwich model during the three-point bending test. However, when comparisons are made for other diameter and spacing values, it is observed that as the diameter increases, the specimen's strength also increases, and as the fiber spacing increases, the strength of the specimen decreases.

In the context of aviation applications, the weight aspect of hemp fiber implementation necessitates the optimization of mesh structures. Consequently, an optimization study is recommended to establish an optimal balance between fiber spacing, diameter, and the overall weight of the sandwich model.

Expanding the scope of this research entails potential modifications in the applied methodologies. For instance, hybrid composite materials comprising both synthetic and natural fibers can be investigated through similar analyses. Additionally, exploring the impact of epoxy quantity on specimen strength and conducting surface treatment studies to enhance the interfacial bonding between natural fibers and polymer epoxy materials are avenues worth exploring, with a focus on assessing their effects on material strength.

Acknowledgment

When preparing this article, I could not have achieved this success without the valuable support of a reputable institution like TUSAŞ. It was possible to complete this work thanks to the resources, guidance, and motivation provided by you. I sincerely thank all the employees and managers of TUSAŞ who contributed to this work.

References

[1] D. Zeng *et al.*, “Mechanical Properties and Tensile Model of Hemp-Fiber-Reinforced Poly(butylene adipate-co-terephthalate) Composite,” *Materials*, vol. 15, no. 7, Apr. 2022, doi: 10.3390/ma15072445.

[2] C. Dolza, E. Gonga, E. Fages, R. Tejada-Oliveros, R. Balart, and L. Quiles-Carrillo, “Green Composites from Partially Bio-Based Poly(butylene succinate-co-adipate)-PBSA and Short Hemp Fibers with Itaconic Acid-Derived Compatibilizers and Plasticizers,” *Polymers (Basel)*, vol. 14, no. 10, May 2022, doi: 10.3390/polym14101968.

[3] C. I. Madueke, O. M. Mbah, and R. Umunakwe, “A review on the limitations of natural fibres and natural fibre composites with emphasis on tensile strength using coir as a case study,” *Polymer Bulletin*. Springer Science and Business Media Deutschland GmbH, Apr. 01, 2022. doi: 10.1007/s00289-022-04241-y.

[4] J. P. Manaia, A. T. Manaia, and L. Rodriges, “Industrial Hemp Fibers: An Overview,” *Fibers*, vol. 7, no. 12, p. 106, Dec. 2019, doi: 10.3390/fib7120106.

[5] B. Murali, P. Yogesh, N. K. Karthickeyan, and D. Chandramohan, “Multi-potency of bast fibers (flax, hemp and jute) as composite materials and their mechanical properties: A review,” *Mater Today Proc*, vol. 62, pp. 1839–1843, Jan. 2022, doi: 10.1016/j.matpr.2022.01.001.

[6] R. Sepe, F. Bollino, L. Boccarusso, and F. Caputo, “Influence of chemical treatments on mechanical properties of hemp fiber reinforced composites,” *Compos B Eng*, vol. 133, pp. 210–217, Jan. 2018, doi: 10.1016/j.compositesb.2017.09.030.

[7] M. Suriyaprakash, M. Nallusamy, K. Shri Ram Shanjai, N. Akash, and V. Rohith, “Experimental investigation on mechanical properties of Ramie, Hemp fiber and coconut shell particle hybrid composites with reinforced epoxy resin,” *Mater Today Proc*, vol. 72, pp. 2952–2956, Jan. 2023, doi: 10.1016/j.matpr.2022.08.091.

[8] C. Lu *et al.*, “Towards high-performance textile-structure composite: Unidirectional hemp fiber tape and their composite,” *Ind Crops Prod*, vol. 189, Dec. 2022, doi: 10.1016/j.indcrop.2022.115821.

[9] Md. M. Billah, Md. S. Rabbi, and A. Hasan, “A Review on Developments in Manufacturing Process and Mechanical Properties of Natural Fiber Composites,” *Journal of Engineering Advancements*, vol. 2, no. 01, pp. 13–23, Feb. 2021, doi: 10.38032/jea.2021.01.003.

[10] S. P. Singh, A. Dutt, and C. K. Hirwani, "Mechanical, Modal and Harmonic Behavior Analysis of Jute and Hemp Fiber Reinforced Polymer Composite," *Journal of Natural Fibers*, vol. 20, no. 1, 2023, doi: 10.1080/15440478.2022.2140328.

[11] J. Edwin Raja Dhas and M. Arun, "A review on development of hybrid composites for aerospace applications," *Mater Today Proc*, vol. 64, pp. 267–273, Jan. 2022, doi: 10.1016/j.matpr.2022.04.511.

[12] N. Murugu Nachippan, M. Alphonse, V. K. Bupesh Raja, S. Shasidhar, G. Varun Teja, and R. Harinath Reddy, "Experimental investigation of hemp fiber hybrid composite material for automotive application," *Mater Today Proc*, vol. 44, pp. 3666–3672, 2021, doi: 10.1016/j.matpr.2020.10.798.

[13] F. Bollino, V. Giannella, E. Armentani, and R. Sepe, "Mechanical behavior of chemically-treated hemp fibers reinforced composites subjected to moisture absorption," *Journal of Materials Research and Technology*, vol. 22, pp. 762–775, Jan. 2023, doi: 10.1016/j.jmrt.2022.11.152.

[14] P. H. P. M. da Silveira *et al.*, "Effect of Alkaline Treatment and Graphene Oxide Coating on Thermal and Chemical Properties of Hemp (Cannabis Sativa L.) Fibers," *Journal of Natural Fibers*, vol. 19, no. 15, pp. 12168–12181, 2022, doi: 10.1080/15440478.2022.2053265.

[15] D. Verma and I. Senal, "Natural fiber-reinforced polymer composites," in *Biomass, Biopolymer-Based Materials, and Bioenergy: Construction, Biomedical, and other Industrial Applications*, Elsevier, 2019, pp. 103–122. doi: 10.1016/B978-0-08-102426-3.00006-0.

[16] L. Samant, F. A. O. Fernandes, S. Jose, and R. J. Alves de Sousa, "Natural Composites in Aircraft Structures," 2022, pp. 113–126. doi: 10.1007/978-3-030-91873-6_5.

[17] Yeraltı C. *Polimer Esasli Karbon Elyaf Takviyeli Kompozit Malzemenin Keten İpliği İle Güçlendirilmesi.* Msc. Thesis, Gazi Üniversitesi, Ankara, Türkiye, 2021