Replacement of Metal Springs with Kenaf Fiber Reinforced Springs for Improved Vehicle Suspension

1. Dr.G.Sulochana, 2.CH. Lakshmana

1. Dr. G.Sulochana Mechanical Engineering Department, University College of engineering narasaraopet, palnadu District, Andhra Pradesh, India
2. . CH. Lakshmana, Mechanical Engineering Department,Students of University College of engineering narasaraopet, palnadu District, Andhra Pradesh, India

Abstract

A significant advancement has been achieved in the manufacturing of helical springs using natural fibers, specifically Kenaf fiber, derived from the stem of the Kenaf plant. Kenaf fiber has been selected for its unique properties, including UV protection, heat insulation, and its environmentally friendly nature. Replacing traditional metal springs with Kenaf fiber offers several advantages, such as reduced weight, increased corrosion resistance, and the availability of raw materials in nature .To enhance the properties of Kenaf fiber, it is treated with a sodium hydroxide (NaOH) solution at a concentration of up to 10%. Following this treatment, the fiber is immersed in a matrix and shaped into a spring using a lathe machine. The Kenaf-reinforced composite spring is then used as a replacement for the metal spring in bicycle seats.The mechanical properties of the Kenaf fiber-reinforced helical spring are subjected to rigorous testing to optimize parameters such as ultimate compression strength, stiffness, and elasticity. A common challenge with natural fiber-reinforced composites, however, is their relatively lower mechanical strength compared to synthetic materials. To address this limitation, one effective strategy is to increase fiber loading, thereby improving the interfacial properties and overall performance of the composite. In this study, hybrid polyester composites reinforced with jute and Kenaf fibers are fabricated through the hand layup process. Fiber loadings in the composite vary from 30%, 50%, to 70% by volume. Additionally, the fibers are treated with alkali solutions (NaOH) at concentrations of 3% and 5% before the composite formation process. Laboratory testing is conducted to evaluate the impact, flexural, and tensile properties of these hybrid jute/Kenaf reinforced polyester composites, providing valuable insights into their potential applications. This research highlights the promising use of natural fibers, like Kenaf, in composite materials for automotive and other mechanical applications, contributing to both performance enhancement and sustainability.

Key words: Natural fiber, Kenaf fiber, NAOH, Spring

1. INTRODUCTION Composites are highly versatile materials that combine unique mechanical and thermal

properties not achievable by a single material. Over the past decade, scientists have increasingly turned to natural fibers as reinforcements in polymer composites. The key advantage of natural fibers is their renewability, biodegradability, and minimal environmental impact, unlike petroleum-based products that are finite and environmentally harmful. Natural fibers, when integrated into synthetic polymers, form bio-composites. These materials are used in various applications, such as energy absorption, insulation, noise reduction, and even in automotive designs for collapsible areas. An early example of bio-fiber-reinforced plastics dates back to 1908 with cellulose fibers in phenolic resin. As shown in fig1.1 and 1.2.

Fig. 1.1 KENAF FIBER PLANT

Fig.1. 2 KENAF FIBER

[1]Aneta Raszkowska-Kaczor, Krzysztof Moraczewski, Wojciech Głuszewski, Volodymyr Krasinskyi, and Lauren Wedderburn found that the structure and mechanical properties of composite materials were influenced by three key factors: processing conditions, the quality and quantity of the dispersed phase, and the electron radiation dose. The final fiber structure was closely related to processing conditions and fiber content in the polymer matrix. While electron radiation did not significantly alter the composite structure, it did affect adhesion between the dispersed phase and the matrix. Increased radiation doses led to decreased impact strength and elongation at break but enhanced flexural modulus, showcasing a synergistic effect with natural fiber addition. [2] Elango Natarajan, Kalaimani Markandan, Chun Kit Ang, and Gerald Franz noted that the impact of kenaf fiber alignment on composite mechanical properties remains underexplored. Investigating techniques for fiber alignment could enhance directional properties. Additionally, additive manufacturing of kenaf-fiber-reinforced composites offers benefits such as reduced material waste, lower costs, and faster production. However, studies indicate that very high fiber loading can deteriorate mechanical properties, emphasizing the need for further research into stress transfer and interfacial bond strength to better understand composite performance. [3] Shanmugavel Sudarsan, Elumalai Parthiban, Evgeny Trofimov, and Sridhar B concluded that kenaf/flax fiber-reinforced composites, using biopolymer and epoxy resin, exhibit excellent mechanical properties such as tensile and flexural strength. The kenaf and flax fibers, when combined with similar matrix materials, demonstrate the mechanical properties of hybrid composites. The bio-composites were fabricated using CA, MA, and AA with glycerol through simple polymerization with hybrid mixtures of CA-MA-AA. [4] Sivaji Das, Debarshi Mallick, and S.S. Gautam conducted a comparative study on predicting the elastic properties of kenaf fiber-reinforced polymer composites. In this study, polystyrene and epoxy were used as the matrix materials, while kenaf fiber served as the reinforcement. Elastic properties were predicted for kenaf fiber-epoxy and kenaf fiber-polystyrene composites based on the fiber volume fraction using the Rule of Mixtures, Halpin-Tsai, and Nielsen elastic models. The elastic properties of both composites were compared at a fiber volume fraction of 80%. It was found that the kenaf fiber-epoxy composite predicts a higher longitudinal Young's modulus (56.69 GPa) compared to the kenaf fiber-polystyrene composite (56.66 GPa) at 80% volume fraction.[5] Kim L. Pickering and Shen Him Lim concluded that 5 wt.% NaOH improved the tensile strength and Young's modulus of kenaf fiber by 51%. They recommended high-temperature treatment for stronger, stiffer fibers in natural fiber composites. Various tests, including tensile strength, thermal analysis, SEM, and FTIR, showed a 51% improvement in tensile strength and Young's modulus. NaOH pellets were used for alkali treatment. High-temperature alkali treatment improved fiber strength and crystallinity index compared to ambient temperature treatment, suggesting better cellulose chain packing and resistance to degradation.

2. MATERIALS USED

2.1 KENAF FIBER: Kenaf fiber, derived from the stem of the Cannabis sativa plant, has been integral to humancivilization for millennia. Its cultivation dates back thousands of years, with evidence of itsuse in textiles, rope making, and other applications found in ancient civilizations around theworld. This versatile fiber has garnered attention for its robustness, sustainability, and diverse applications from fig.2.1.

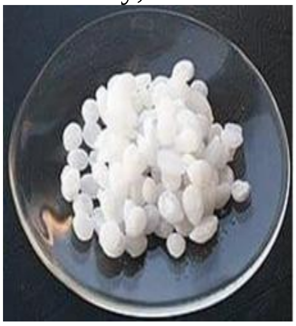


Fig. 2.1. PROCESSED KENAF FIBER **Fig.2.2.SODIUM HYDROXIDE PELLET**

2.2. SODIUM HYDROXIDE PELLETS: In addition to its role in purifying kenaf fibers and enhancing their mechanical properties, alkali treatment with NaOH pellets also serves to modify the surface chemistry of the fibers from fig.2.2

2.3. RELEASE AGENT: In the realm of composite materials manufacturing, release agents play a pivotal rolein facilitating the production process and ensuring the quality of the final product. These agents are substances applied to mould surfaces or tools involved in composite fabricationto prevent adhesion of the composite material to the mould. Here, we delve into the significance and usage of release agents in composite manufacturing processes from fig.2.3

Fig.2.3. RINSING AGENT **Fig2.4 HARDENER HY951** **Fig.2.5. Lathe Machine**

2.4. ARALDITE LY556 (EPOXY): Araldite LY556 is a high-performance epoxy resin from Huntsman Advanced Materials, known for its exceptional mechanical strength, thermal stability, and chemical resistance. It excels in structural adhesives, composite materials, and high-performance bonding applications, offering strong adhesion to metals, ceramics, plastics, and composites. Its durability and toughness make it ideal for demanding industrial uses, ensuring long-lasting, reliable performance in harsh environments

2.5. HARDENER HY951: Hardener HY951 is a curing agent specifically designed for epoxy resins, particularly Araldite LY 556, ensuring optimal curing, crosslinking, and the creation of strong, durable composites, adhesives, and coatings from fig.2.4.

2.6. LATHE MACHINE: The lathe machine is essential for shaping and refining natural fiber reinforced springs, ensuring precision, strength, and durability in production from fig.2.5.

3. EXPERIMENTAL SETUP:

3.1 EXTRACTION OF KENAF FIBER: The extraction of kenaf fiber involves several steps to separate the desirable fibers fromthe woody core (hurds) and other impurities.

3.2. HARVESTING: Kenaf plants are typically harvested at the optimal stage for fiber extraction, which varies depending on the intended use of the fibers. Generally, the plants are harvested before they reach full maturity to ensure the fibers remain long and strong from fig3.1.

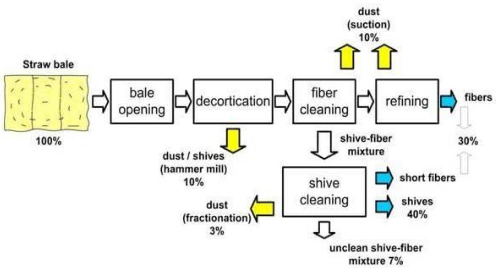


Fig.3.1. HARVESTING OF KENAF FIBER

3.2 Retting: Retting is a process that breaks down pectin, lignin, and other compounds binding fibers to the woody core of the kenaf plant. Methods include dew retting (exposure to elements), water retting (immersion in water), and chemical retting (using enzymes/chemicals), each with distinct benefits and drawbacks as shown in fig.3.2.

Fig.3.2. RETTING PROCES

3.3. DRYING: After retting, kenaf stalks are dried to prevent mold and decay.

3.4. DECORTICATION: Decortication is the process of separating the outer fibers (bast fibers) from the inner woody core (hurds) of the kenaf stalks. This can be done using mechanical decorticators, which crush and strip away the outer fibers while leaving the hurd intact. Alternatively, manual methods or specialized equipment may be used for small-scale operations.

3.5. FIBER SEPERATION: Once the kenaf stalks are decorticated, the fibers need to be further cleaned and separated from any remaining impurities, such as dust, debris, and short fibers. This may involve additional mechanical processing, such as combing or scutching, to refine the fibersand remove unwanted materials.

3.6. FINISHING: The extraction of kenaf fiber requires careful attention to detail and proper handling at each stage of the process to produce high quality fiber suitable for a wide range of industrial and commercial applications, including textiles, paper, bio-composites and construction materials. Advancements in technology and processing techniques continue to improve the efficiency and sustainability of kenaf fiber extraction, making it an increasinglyviable and environmentally friendly alternative to traditional fibers.

3.7. ALKALI TREATMENT: Alkali treatment, also known as alkaline hydrolysis or alkali retting, is a chemical process commonly used to break down lignin and other non-cellulosic components in natural fibers,such as kenaf or flax, to separate the desirable fibers from the woody core. Treating fibers with sodium hydroxide (NaOH), commonly known as caustic soda, is one of the most widely used methods for alkali treatment.

3.8. HEAT TREATMENT: After Drying of the kenaf fibers, the kenaf fibers are baked in an oven at 70°C for about an hour. This process will eliminate any excess moisture in the fiber and also helps in increase of the mechanical properties.Alkali treatment, such as alkali cleaning or alkali etching, is often employed to remove contaminants, oxides, or other surface impurities from materials like metals or polymers. Heat treatment may be necessary afterward for several reasons.Heat treatment can activate the surface of the material, making it more receptive to subsequent processes like coating, plating, or adhesion. This activation enhances the bonding properties of the material, ensuring better adhesion and performance inapplications where surface bonding is critical from fig.3.3.



Fig.3.3. Heat Treatment Equipment Fig.3.5. Fabrication of spring on lathe machine fig3.6.Alkali treated kenaf fiber3.9.

SEALED IN ZIP LOCK COVERS:

The heat-treated fibers are then locked and packed in zip lock covers to prevent the atmospheric moisture and chemical composition in the air to react with the fibers. Sealing the fibers can protect them from contamination by airborne particles, dust, or other environmental impurities. This is particularly important if the fibers are sensitive to contamination or if cleanliness is crucial for subsequent processes. Sealing in zip lock covers can help preserve the effects of the alkali treatment. By protecting the fibers from recontamination or alteration of the treated surface before further processing, the sealing process ensures the treatment's integrity. Sealing the fibers can helpmaintain their temperature stability after baking. This is important for fibers that require gradual cooling or for processes where temperature fluctuations could affect their propertiesor dimensions.

4. FABRICATION OF KENAF FIBER REINFORCED SPRING

4.1. FABRICATION: Firstly, the treated kenaf fiber is taken from zip lock covers and dipped into the matrix (Epoxy Resin & Hardener). The resin choose for this natural fiber is Epoxy Resin LY556 and Hardener used is HY951.The spring used as a die is a two-wheeler shock absorber.The Fabrication setup consists of Mild steel shaft, Die, chuck key, chuck along withLathe Machine setup. The shaft and dies are covered totally with aluminum foil without any irregularities. The edges of the shaft are supported between the centers of the lathe. Thesurface of the spring is applied with petroleum jelly. The petroleum jelly acts a lubricant and is useful in the ensuring easy separation of die and the product at the end as shown in fig3.5.

4.2. Removal Of Kenaf Fiber Reinforced Spring : After curing process, the die mounted on the shaft is removed from the chuck and separationof die from shaft is taken place and it is easily removed due to application of petroleum jelly. The same procedure is repeated for another two springs.The die is taken along with the spring and the aluminium foil is removed using thegrinding machine at the edges. The spring die and composite spring is separated by turningthe springs in opposite direction as shown in fig.3.6.

5.TESTING:

5.1. COMPRESSION TEST: In this test, the kenaf fiber reinforced spring is subjected to gradually increasing compressive force until it reaches its maximum load-bearing capacity or until it fails. The force applied and the corresponding deformation are recorded throughout the test.The data obtained from the compression test is to be analyzed to determine various parameters such as compressive strength, modulus of elasticity, and deformation characteristics of the material. This analysis provides insights into the material's structural integrity and its suitability for specific applications from fig 5.1.

5.2.SEM Analysis With EDAX: SEM with EDAX is a powerful technique used to examine the microstructure and elemental composition of materials at high magnification. It provides detailed informationabout the surface morphology, fiber orientation, and distribution of elements within the kenaf fiber reinforced spring.The sample is prepared and mounted onto a specimen holder, then placed in the SEM chamber. A focused electron beam is scanned across the surface of the sample, and the interactions between the beam and the sample surface produce signals that are used and shown in fig.5.2

Fig.5.1 UNIVERSAL TESTING MACHINE

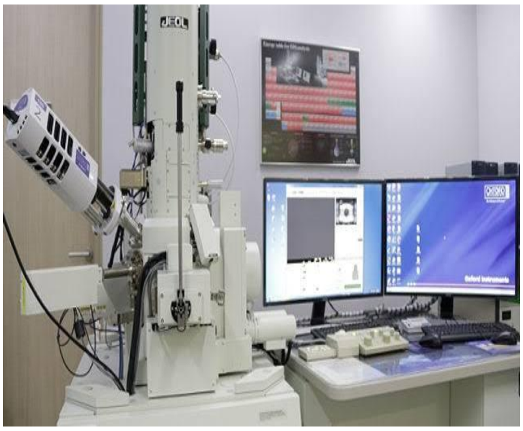


Fig.5.2 SCANNIG ELECTRON MICROSCOPY

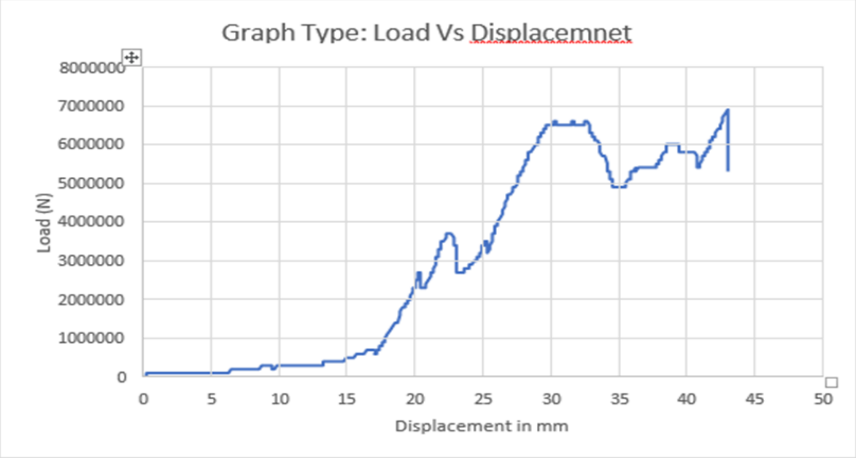
5.3. FATIGUE TESTING: Fatigue testing is performed to evaluate the durability and resistance of the kenaf fiber reinforced spring to cyclic loading. It simulates the repetitive loading conditions that the material may experience during its intended service life. The spring is subjected to cyclic loading and unloading at a specified load level orstress amplitude. The number of cycles to failure or the change in mechanical properties over a certain number of cycles is recorded. The data obtained from fatigue testing is analyzed to determine the fatigue life, fatigue strength, and any changes in material properties such as stiffness or failure mode under cyclic loading conditions. This information is crucial for assessing the long-term performance and reliability of the material in practical applications

6. RESULTS AND DISCUSSION

6.1. COMPRESSION TEST RESULTS: After completion of fabrication of kenaf fiber reinforced spring, the compression test is performed on the samples. According to the test results, we observed that S2 results is greater than S1 why because the spring is manually made without any automation.

S.NO	SAMPLE	COMPRESSIVE STRENGTH(N/mm²)
1	S1	24.58
2	S2	64.13

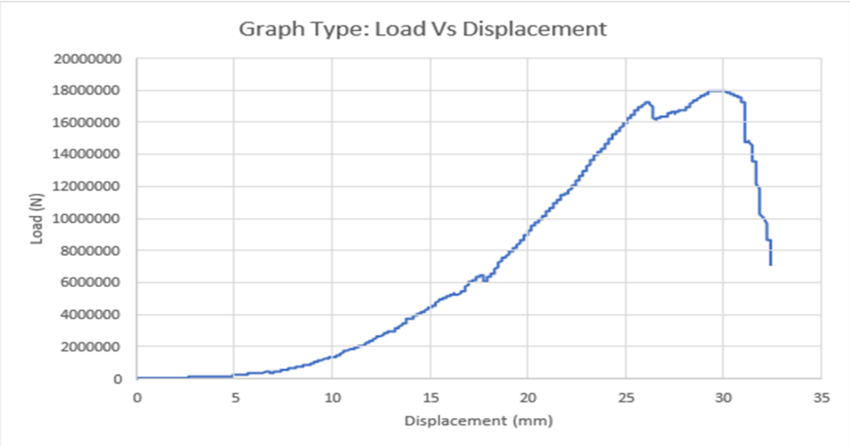
That is why the values of S1 and S2 are varied. The following table is drafted
Table.1.Compressive Strength***GRAPH 1: (S1)***



Graph.**1. LOAD VS DISPLACEMENT**

With the above graph, we can conclude that the maximum load that the kenaf fiberreinforced spring can bear is 6.9 KN and the Compressive strength is 24.58 MPa. and observed that values as shown in table.1.and graph 1&.

GRAPH 2: (S2)



Graph.2. LAOD VS DISPLACEMENT

With the above graph we can conclude that the maximum load the kenaf fiber reinforced spring sustained is 18 KN and the Compressive strength is 64.13 MPa.

6.2. SEM WITH EDAX:

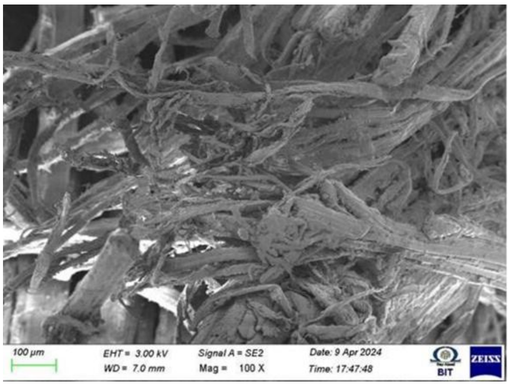


Figure 17 SEM with EDAX

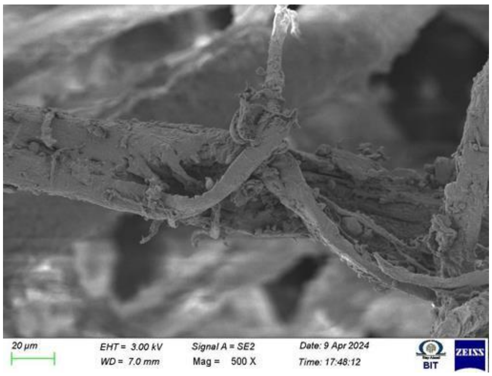


Figure 18 SEM with EDAX 2

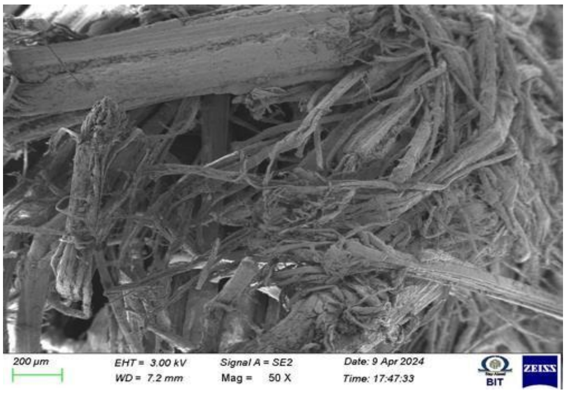


Figure 19 SEM with EDAX 3

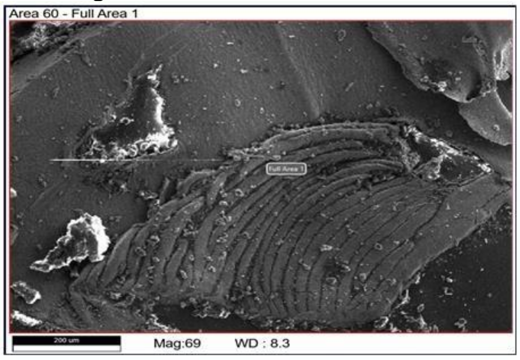


Figure 20 TREATED KENAF FIBER

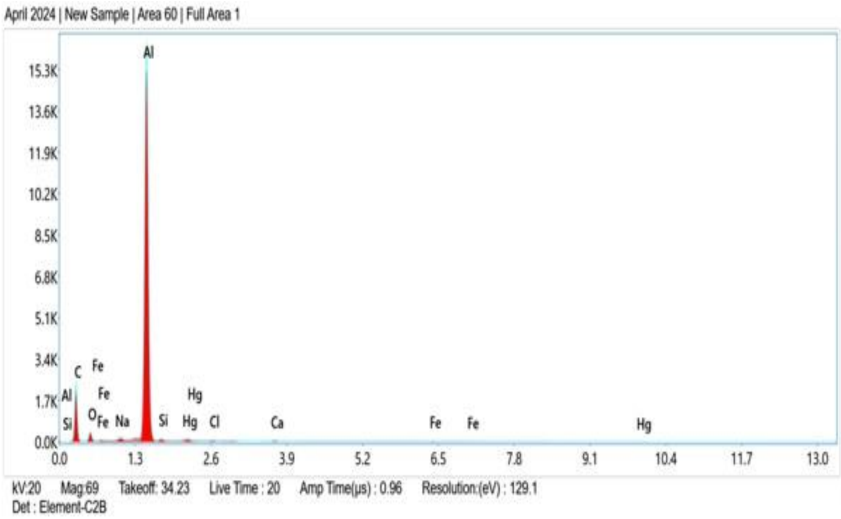


Fig.6.1 EDAX Analysis of KENAF FIBER REINFORCED SPRING

Table.2 ELEMENTAL ANALYSIS OF KENAF FIBER REINFORCED SPRING

Element	Weight %	Atomic %	Error %	Net Int.	R	A	F
C K	67.76	81.13	11.23	614.90	0.9256	0.0674	1.000
O K	5.64	5.07	13.09	115.86	0.9345	0.0636	1.000
Na K	0.35	0.22	14.81	46.67	0.9445	0.3877	1.0084
Al K	25.01	13.33	4.46	6385.5	0.9503	0.6782	1.0024
Si K	0.15	0.08	17.67	30.55	0.9530	0.5516	1.0034
Cl K	0.07	0.03	40.67	13.58	0.9602	0.8088	1.0104
Ca K	0.12	0.04	30.13	17.84	0.9665	0.9227	1.0243
Fe K	0.24	0.06	26.10	19.75	0.9775	0.9857	1.1078
Hg L	0.65	0.05	59.23	6.26	0.9918	0.9980	1.0824

Weight	**S1**	**S2**	**S3**
Fiber weight(g)	28	28	27
Resin weight (g)	30	32	35
Spring weight(g)	58	60	62
Fiber wt ratio	48.27	46.67	43.54

Table.3. SAMPLE WEIGHTS

7. CONCLUSION

This work reports a plausible replacement to the artificial glass fiber compression spring using a KENAF fiber reinforced spring. The KENAF fiber is treated with various NaOH concentrations to obtain optimum properties for the fabricated compression spring (especially the reduction of its hygroscopic properties for enhancing moisture tolerance of the natural fiber used). 4 wt.% NaOH treated fibre reinforced spring produces optimum stiffness of ~1 N/mm and shear modulus of 1.3 GPa. EDAX results indicate that the outer surface of the spring has an O/C ratio of 0.07 (by atomic weight). This indicates that the epoxy acts as a protective layer for the spring. Moisture absorption of the CG fiber is partially reduced using alkali treatment, and also partially arrested by the matrix of the composite spring. FEA analysis is used to rationalize the observations made.

REFERENCES

[1] Taha, Ziegmanna G. Comparison of mechanical properties of natural fiber filled biodegradable and polyolefin polymers. J Compos Mater 2006;40:1933–46.

[2] Hristozov Dimo, Wroblewski Laura, Sadeghian Pedram. Long-term tensile properties of natural fibre-reinforced polymer composites: comparison of flax and glass fibres. J Compos B Eng 2016;95:82–95.

[3] Suttiruengwong Supakij, Boonniteewanich Jessada, Pitivut Siriporn,Tongjoy Sineenat, Lapnonkawow Somjit. Evaluation of carbon footprint of bio plastic straw compared to petroleum based straw products, 11th eco-energy and materials science and engineering (11th EMSES). Energy Procedia 2014;56: 518–24.

[4] Aarti C. A review on pharmacological and biological properties of calotropis gigantean. Int J Rec Sci Res 2014;5:716–9.

[5] Lawes Michael J, Menge Enock O, Greenfield Michele Lisa, Mcconchie Cameron A, Bellair Sean M. Density-dependent reproduction and pollen limitation in an invasive milkweed, calotropis procera (ait.) R. Br. (Apocynaceae), austral. Eco J Eco South. Hemisphere 2016;42:61–71.

[6] Gassan J, Bledzk AK. Composites reinforced with cellulose based fibres. Prog Polym Sci 1999;24:221–74.

[7] Chen Qin, Zhao Tao, Ming Wanga, Wang Jing. Studies of the fibre structure and dyeing properties of Calotropis Gigantea, kapok and cotton fibres. Color Technol 2013;129:448–53.

[8] Ramasamy R, Obi Reddy K, Varada Rajulu A. Extraction and characterization of calotropis Gigantea, bast fibers as novel reinforcement for composites materials. J Nat Fibers 2017;15:527–38.

[9] Pickering KL, Aruan Efendy MG, Le TM. A review of recent developments in natural fibre composites and their mechanical performance. Compos Appl Sci Manuf 2016; 83:98–112.

[10] Shah DU, Porter D, Vollrath F. Can silk become an effective reinforcing fibre? A property comparison with flax and glass reinforced composites. Compos Sci Technol 2014;101:173–83.

[11] Mustafa A, Bin Abdullah MF, Shuhimi FF, Ismail N, Amiruddin H, Umehara N. Selection and verification of kenaf fibres as an alternative friction material using Weighted Decision Matrix method. Mater Des 2015;67:577–82.

[12] Rathod NR, Chitme HR, Irchhaiya R, Chandra R. Hypoglycemic effect of calotropis Gigantea linn. Leaves and flowers in streptozotocin-induced diabetic rats. Oman Med J 2011;26:104–8.

[13] David M, Bharath KR, Bhavani M, Study of Calotropis Gigantea R. Br. Extracts on growth and survival dynamics of selected pathogenic microorganisms. Int J Biol Eng 2011;1:1–5.

[16] Dilli Babu G, Sivaji Babu K, Nanda Kishore P. Tensile and wear behavior of calotropis gigentea fruit fiber reinforced polyester composites. In: Proceedings of elsevier, 12th global congress on manufacturing and management, GCMM; 2014.

[17] Ashori Alireza, Bahreini Zaker. Evaluation of calotropis Gigantea as a promising raw material for fiber-reinforced composite. In: Journal of composite materialsvol.
43. Sage Publications); 2009. p. 1297–345.

[18] Sisti L, Totaro G, Vannini M, Celli A. Retting process as a pretreatment of natural fibers for the development of polymer composites. Springer Series on Polymer and Composite Materials book series; 2017. p. 97–135.

[19] Kabir MM, Wang H, Lau KT, Cardona F. Chemical treatments on plant-based natural fibre reinforced polymer composites: an overview. J Comps 2012;43: 2883–92.

[20] Xue Li, Tabil Lope G, Panigrahi Satyanarayan. Chemical treatments of natural fiber for use in natural fiber-reinforced composites: a review. J Polym Environ 2007;15: 25–33.

[21] Oushabi A, Sair S, Oudrhiri Hassani F, Abboud Y, Tanane O, El Bouari A. The effect of alkali treatment on mechanical, morphological and thermal properties of date palm fibers (DPFs): study of the interface of DPF - polyurethane composite. S Afr J Chem Eng 2017;23:116–23.

[22] Muthukumar V, Venkatasamy R, Sureshbabu A, Arunkumar D. A study on mechanical properties of natural fiber reinforced laminates of epoxy (LY 556) polymer matrix composites. Int J Prod Technol Manag Res 2011;2:67–72.

[23] Ju Kyung Lee, Sang Won Kwak, Jung-Hong Ha, Woo Cheol Lee, and Hyeon-Cheol Kim, Research article, bioinorganic chemistry and applications, Volume 2017, Article ID 2582849, 8 pages.

[24] Ekanthappa J, Shiva Shankar GS, Amith BM, Gagan M. Fabrication and experimentation of FRP helical spring. IOP Conf Ser Mater Sci Eng 2016;149:1–5.

[25] Kara Yahya. A review: fiber reinforced polymer composite helical springs. J Mater Sci Nanaotechnol 2017;5:1–6.

[26] Kurmi RS. Machine design. In: springs, stress and deflection in helical springs of non-circular wire. fourteenth ed. 2005. p. 852 [Chapter 23].

[27] Hashim Mohd Yussni, Amin Azriszul Mohd, Marwah Omar Mohd Faizan, Othman Mohd Hilmi, Yunus Mohd Radzi Mohamed, Huat Ng Chuan. The effect ofalkali treatment under various conditions on physical properties of kenaf fiber. IOP Conf. Series: J Phys Conf Ser 2017;914:1–15.

[28] Ganeshan P, Ramshankar P, Nagaraja Ganesh B, Raja K. Calotropis Gigantea fibers
– a potential reinforcement for polymer matrices. Int J Polym Anal Charact 2018: 1–16. https://doi.org/10.1080/1023666X.2018.1439560.

[29] Chen Qin, Zhao Tao, Ming Wangand, Wang Jing. Studies of the fibre structure and dyeing properties of Calotropis Gigantea, kapok and cotton fibres. Color Technol 2013;129:448–53.

[30] Humairabano, Khan Mazher I, syed Arifkazmi. Structure and microstructure studies of epoxy coating after natural exposure testing. J Chem Soc 2011;33: 454–62.

[31] Manjunatha TS, Abdul Budan D. Manufacturing and experimentation of composite helical springs for automotive suspension. Int J Mech Eng Robotic Res 2012;1: 229–41.

[32] Clifford Mike J, Darshil UShah, Peter J Schubel, Licence Peter. Determining the minimum, critical and maximum fibre content for twisted yarn reinforced plant fibre composites. Compos Sci Technol 2012;72:1909–17.

[33] Elbadry Elsayed A, Aly-Hassan Mohamed S, Hamada Hiroyuki. Mechanical properties of natural jute fabric/jute mat fiber reinforced polymer matrix hybrid composites. Adv Mech Eng 2012:12.

[34] Pozzi1 A, Sepe R. Mechanical properties of woven natural fiber reinforced composites. Venice, Italy: 15th European conference on composite materials; 2012.
p. 24–8.

[35] Antony Sequeira Anil, Singh Ram Kishen, Shetti Ganesh K. Comparative analysis of helical steel springs with composite springs using finite element method. J Mech Eng Autom 2016;6(5A):63–70.