Hindawi
Journal of Nanomaterials
Volume 2022, Article ID 3758212, 5 pages
https://doi.org/10.1155/2022/3758212

Research Article

An Investigation on the Activation Energy and Thermal Degradation of Biocomposites of Jute/Bagasse/Coir/Nano TiO_2/Epoxy-Reinforced Polyaramid Fibers

H. Fayaz,[1] K. Karthik,[2] K. G. Jaya Christiyan,[3] M. Arun Kumar,[4] A. Sivakumar,[5] S. Kaliappan,[6] M. Jinnah Sheik Mohamed,[7] Ram Subbiah,[8] and Simon Yishak[9]

[1]*Modeling Evolutionary Algorithms Simulation and Artificial Intelligence, Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam*
[2]*Department of Mechanical Engineering, Vel Tech Rangarajan Dr Sagunthala R&D Institute of Science and Technology, Chennai, Tamil Nadu 600062, India*
[3]*Department of Mechanical Engineering, M S Ramaiah Institute of Technology, Bengaluru, Karnataka 560054, India*
[4]*Department of Electrical, Electronics and Communication, GITAM Deemed to be University, Bengaluru Campus, Karnataka 561203, India*
[5]*Department of Electrical and Electronics Engineering, Panimalar Engineering College, Chennai, Tamil Nadu 600123, India*
[6]*Department of Electrical and Electronics Engineering, Kumaraguru College of Technology, Coimbatore, Tamil Nadu 641049, India*
[7]*Department of Mechanical Engineering, Nellai College of Engineering, Tirunelveli, Tamil Nadu 627151, India*
[8]*Department of Mechanical Engineering, Gokaraju Rangaraju Institute of Engineering and Technology, Hyderabad, Telangana 500090, India*
[9]*College of Engineering and Argo-Industrial Technology, Arba Minch University, Sawla Campus, Ethiopia*

Correspondence should be addressed to Simon Yishak; simon.yishak@amu.edu.et

Received 16 March 2022; Accepted 17 May 2022; Published 23 June 2022

Academic Editor: Palanivel Velmurugan

Polyaramid is a type of aromatic polyamide that is used to strengthen materials due to its great thermal stability. The effect of adding 2 wt% of nano titanium oxide and 5% polyaramid fibers to an epoxy matrix composite reinforced with three distinct natural fibers (jute, bagasse, and coir fibers) on the structure and characteristics of the composite was examined in this study. Hand lay-up approach was used to manufacture 40 wt. percent each fiber, separately reinforced biocomposites with the addition of polyaramid, and TGA experiments were used to investigate the thermal stability of jute/bagasse/coir composites with polyaramid. The thermal degradation of the polymer took place in five steps, according to the Broido plots, with the second step being the slowest and rate determining. Because less energy is used to remove hemicellulose and loosely binding water contained in bagasse fiber, Broido plots revealed that the first step heat degradation had the lowest activation energy (Ea).

1. Introduction

In recent decades, researchers have focused more on environmentally friendly alternatives for engineering applications. The development of biocomposites in the realm of material science has led to enormous progress in green technology. This is done in order to safeguard the environment and to ensure long-term sustainability [1, 2]. The creation of high-performance materials from natural resources has gained momentum recently. The intrinsic advantages of natural banana fiber, such as its biodegradability, availability, flexibility, environmental friendliness, and ease of processing, have made it a valuable research tool for scientists. The automotive and biomedical industries both use a lot of these fiber-based materials.

Natural fiber polymer composites are a reasonable choice for both reusing waste materials and delivering new value that changed up its uses. Melting bagasse fibers with

business polymers like polyethylene or polypropylene at temperatures over the plastic's melting point is an average practice. Wood flour, kenaf fiber, squander paper, rice frames, and bagasse fiber are for the most part instances of bagasse strands [3, 4]. Limited quantities of added substances like epoxy, compatibilizers, stabilizers, and oils are likewise utilized to work on mechanical properties, UV solidness, and processibility, as it may be used in liquid state to coat, laminate, and permeate materials for waterproofing, sturdiness, and endurance. When epoxy dries, or hardens, it transforms into resin, which gives a wide variety of benefits in addition to other things, contingent upon the prerequisites of the finished item and the handling framework [5].

Bagasse fibers have a lower cost, effortlessness of handling, and surface alteration, as well as environmental benefits. Aside from these issues, there is also the issue of low bulk density and agglomeration, as well as water absorption and the thermal instability of natural fibers during high-temperature processing [6–8]. For two main reasons, the degradation of natural fibers during processing can have a significant impact on the mechanical properties of composites: it alters the fiber's structure, which has a detrimental impact on its mechanical properties [9].

Natural and biodegradable, jute is the second most common fiber on the market. As far as thermal conductivity is concerned, jute fiber is a great choice. Jute fibers are also environmentally beneficial. Jute fiber-reinforced polymer composites have become a major research focus in recent years [10, 11]. Jute fiber is typically utilized in low-quality textiles. Jute's characteristics could be altered to produce high-value and high-tech textiles, which would have a positive impact on both the environment and the economy. It is composed of cellulose (45–71.5%), hemicelluloses (13.6–21%), and lignin (12–26%). Mechanical support is provided by lignin because of its numerous aromatic rings. Other than cellulose, a substance is classified as "gum" when it interferes with the smoothness, pliability, or fineness of jute [12].

The husk of the coconut palm tree (Cocos nucifera) from which coir fiber is derived is a thick and coarse fiber that is abundant in tropical countries. As much as they grow all over the tropical world, coconut trees are only found in a few places: Indonesia, the Philippines, India, Brazil, Sri Lanka, Thailand, and Vietnam; Malaysia is the only country in the region that produces a significant amount of the commercially available coir fibers [13].

It is vital to consider thermal degradation in the improvement of natural fiber composites since it will significantly affect the greatest temperature at which the composites might be handled [14]. Thermal stability of polymer composite materials can be studied using thermogravimetric analysis (TGA). Polyaramid composites with bagasse, groundnut, and sisal have been the subject of numerous studies on thermal stability. Composites reinforced with natural fiber-reinforced polymer show signs of heat deterioration. The thermal decomposition profiles of distinct natural fibers would differ as a result of the different constituent percentages in each one. Thermal deterioration of natural fibers will be discussed in this chapter [7, 15]. It is an aromatic polyamide that can be used to strengthen fabrics because of its excellent thermal stability. The great thermal stability of PAF is a result of aromatic stacking interactions between various chains as well as intermolecular hydrogen bonding between carbonyl groups and NH centers.

2. Experimental Method

2.1. Materials. The natural fibers jute, bagasse, and coir were acquired from the Bharatiya Natural Fibres, Coimbatore, located at Tamil Nadu, India. An alkali-treated 5 percent NaOH solution was used for 45 min on the fiber to remove oily particles and hemicelluloses and then dried in sunshine, and it is shown in Figure 1.

Polyaramid (PAF) biocomposites reinforced with 40% jute, bagasse, and coir/nano TiO_2/epoxy biocomposites are studied in this work. Titanium dioxide has tuning of surface characteristics and effective heat conductivity characteristics. The kinetic and thermal properties of this polymer are also examined. The kinetic parameters of the graph were assessed utilizing Broido technique. Thermal properties might well be assessed by thermogravimetric analysis.

2.2. Fabrication of Polyaramid-Treated Jute, Bagasse, and Coir/Epoxy Biocomposites. Epoxy matrix reinforced with modified jute fiber biocomposites was made by hand using a $290 \times 290 \times 3$-mm steel mold for composite fabrication. Composites were made with LY556 epoxy resin and HY951 hardener [16, 17]. Stirred at low speed, these two substances were thoroughly blended in a 10 : 1 weight ratio. Mixed with the matrix were modified PAF jute fibers at 40% by weight. To avoid air pockets, the matrix material was poured into the mold slowly. Between the mold surface and the composite specimen, wax was employed as a release agent. A 24-hour room temperature cure was given to the mold after it was bolted down. The same procedure followed other two fiber biocomposites [18]. The designation and detailed composition of the biocomposites are shown in Table 1.

3. Results and Discussion

The weight loss curves for 40 wt. percent PAF/jute, PAF/bagasse, and PAF/coir composites are shown in Figure 2. Figure 2 shows that PAF/bagasse biocomposites with 40 wt% PAF content had significantly higher thermal stability than PAF/jute and PAF/coir biocomposites. There was slight deviation in thermal stability among PAF/jute and PAF/coir biocomposites. From room temperature to 75°C, all of the samples showed excellent thermal stability. From 130 to 142°C, all samples lost a small amount of weight (3.8%). Because of the initial decomposition of cellulose and hemicellulose, as well as the heat of evaporation of moisture in the sample, the weight reduction of the samples began around 200 to 300°C. The significant parts of hemicelluloses, cellulose, and lignin are answerable for the disheartening huge weight reduction from 220 to 470°C for 40 wt. percent of PAF/Bagasse [19, 20]. In the samples as a whole, the temperature scope of 500°C was seen to bring about the total

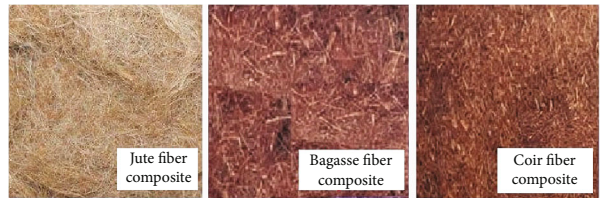

Figure 1: Materials for fabrication.

Table 1: Shows detailed composition of the biocomposites.

S.no	Sample	Fiber	Composition
1.	S1	Jute	40 wt% PAF jute/2 wt% nano TiO_2/58 wt% epoxy
2.	S2	Bagasse	40 wt% PAF bagasse/2 wt% nano TiO_2/58 wt% epoxy
3.	S3	Coir	40 wt% PAF coir/2 wt% nano TiO_2/58 wt% epoxy

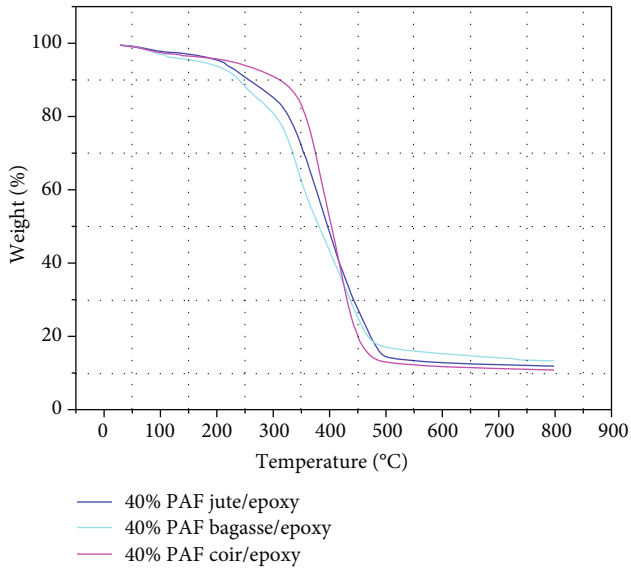

Figure 2: TGA curves for 40 wt. % PAF jute/bagasse/coir/nano TiO_2/epoxy biocomposites.

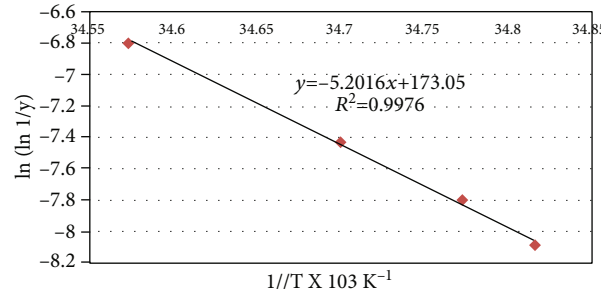

Figure 3: Broido plot for the determination of activation energies involved step 1.

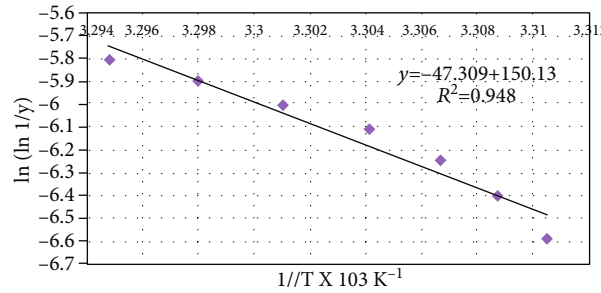

Figure 4: Broido plot for the determination of activation energies involved step 2.

deterioration of every combustible material and the arrangement of roast. Obviously the decompositions brought about all-out weight losses of 86, 87, and 82 wt. percent for 40 PAF/jute and PAF/coir biocomposites, individually. The 40 wt. percent of PAF/bagasse that showed up had the least weight loss of the three samples [21]. This suggests that a fiber incorporation level of 40 wt. percent PAF/Bagasse was a better optimized level.

Using the Broido equation, the activation energy associated with the thermal degradation of the polymer composite was calculated.

$$\ln\ (\ln 1/y) = -(\mathrm{Ea}/R)1/T + \mathrm{Constant}, \quad (1)$$

where $y = \mathrm{mt} - \mathrm{mx}/\mathrm{m0} - \mathrm{mx}$, mt is the weight of the sample at time, m0 is the initial weight of the sample, and mx is the final weight of the sample.

Figures 3–7 illustrate charts based on equation (1). Five straight lines with various slopes were found, indicating that the composite was degraded in five steps. The slope of the straight line is given as $-Ea/R$, and the computed activation energy is shown in Table 2.

The value of activation energy is largest for the second step and lowest for the last step, as shown in Table 2. The order was followed by the decreasing order of activation energy for several phases. The second stage could have been the breakdown of bonds in the composite, which could have determined the rate of heat disintegration. 2 step > 4 step > 3 step > 1 step > 5 step.

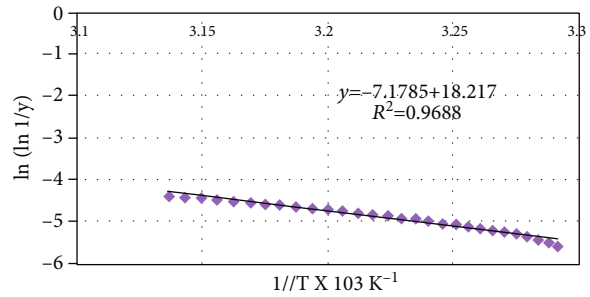

Figure 5: Broido plot for the determination of activation energies involved step 3.

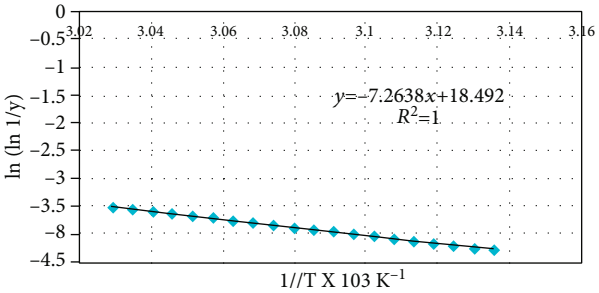

Figure 6: Broido plot for the determination of activation energies involved step 4.

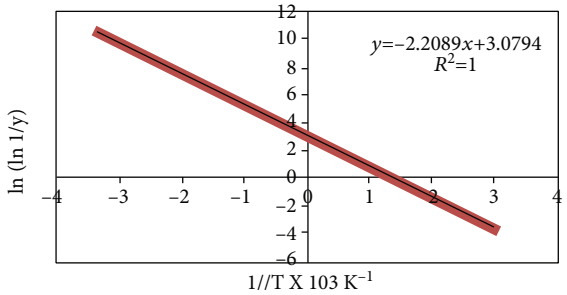

Figure 7: Broido plot for the determination of activation energies involved step 5.

Table 2: Shows computed activation energy.

S. no	Step	Y	R^2
1.	1	$-5.2016x + 173.05$	0.9976
2.	2	$-47.309x + 150.13$	0.948
3.	3	$-7.1785x + 18.217$	0.9688
4.	4	$-7.2638x + 18.492$	1
5.	5	$-2.2089x + 3.0794$	1

4. Conclusion

The following conclusions are made from this work

(i) Because of their great thermal stability, polyaramid fibers are used to reinforce materials. This is due to interfacial hydrogen bond and aromatic stacking interactions between various chains

(ii) The TGA of the jute/bagasse/coir/nano TiO_2/epoxy polymer composite revealed that it is stable at 1400°C

(iii) The thermal degradation of the polymer took place in five steps, according to the Broido plots, with the second step being the slowest and rate determining

(iv) Because less energy is used to remove hemicellulose and loosely binding water contained in bagasse fiber, Broido plots revealed that the first step heat degradation had the lowest activation energy (Ea).

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The authors appreciate the supports from Arba Minch University, Ethiopia, for the research and preparation of the manuscript. The authors thank Ton Duc Thang University, M S Ramaiah Institute of Technology, Panimalar Engineering College, Nellai College of Engineering, and Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, for providing assistance in completing this work.

References

[1] V. Mohanavel, S. Suresh Kumar, J. Vairamuthu, P. Ganeshan, and B. NagarajaGanesh, "Influence of stacking sequence and fiber content on the mechanical properties of natural and synthetic fibers reinforced penta-layered hybrid composites," *Journal of Natural Fibers*, pp. 1–13, 2021.

[2] P. Prabhu, S. Mohamed Iqbal, A. Balaji, and B. Karthikeyan, "Experimental investigation of mechanical and machining parameters of hybrid nanoclay glass fiber-reinforced polyester composites," *Advanced Composites and Hybrid Materials*, vol. 2, no. 1, pp. 93–101, 2019.

[3] R. Hsissou, R. Seghiri, Z. Benzekri, M. Hilali, M. Rafik, and A. Elharfi, "Polymer composite materials: a comprehensive review," *Composite Structures*, vol. 262, article 113640, 2021.

[4] B. Yu, V. Till, and K. Thomas, "Modeling of thermo-physical properties for FRP composites under elevated and high temperature," *Composites Science and Technology*, vol. 67, no. 15-16, pp. 3098–3109, 2007.

[5] A. O. Konuray, X. Fernández-Francos, and X. Ramis, "Curing kinetics and characterization of dual-curable thiol-acrylate-epoxy thermosets with latent reactivity," *Reactive and Functional Polymers*, vol. 122, pp. 60–67, 2018.

[6] Y. Fang, Q. Wang, X. Bai, W. Wang, and P. A. Cooper, "Thermal and burning properties of wood flour-poly (vinyl chloride)

composite," *Journal of Thermal Analysis and Calorimetry*, vol. 109, no. 3, pp. 1577–1585, 2012.

[7] J. Wan, Z. Y. Bu, C. J. Xu, H. Fan, and B. G. Li, "Model-fitting and model-free nonisothermal curing kinetics of epoxy resin with a low-volatile five-armed starlike aliphatic polyamine," *Thermochimica Acta*, vol. 525, no. 1-2, pp. 31–39, 2011.

[8] A. Balaji, R. Udhayasankar, B. Karthikeyan, J. Swaminathan, and R. Purushothaman, "Mechanical and thermal characterization of bagasse fiber/coconut shell particle hybrid biocomposites reinforced with cardanol resin," *Results in Chemistry*, vol. 2, article 100056, 2020.

[9] M. Wang, Q. Tan, L. Liu, and J. Li, "A low-toxicity and high-efficiency deep eutectic solvent for the separation of aluminum foil and cathode materials from spent lithium-ion batteries," *Journal of Hazardous Materials*, vol. 380, article 120846, 2019.

[10] M. S. Ahmadi and T. Dastan, "Impact and flexural properties of hybrid jute/HTPET fibre reinforced epoxy composites," *Indian Journal of Fibre & Textile Research (IJFTR)*, vol. 42, no. 3, pp. 307–311, 2017.

[11] E. Selver, N. Ucar, and T. Gulmez, "Effect of stacking sequence on tensile, flexural and thermomechanical properties of hybrid flax/glass and jute/glass thermoset composites," *Journal of Industrial Textiles*, vol. 48, no. 2, pp. 494–520, 2018.

[12] A. K. Sinha, H. K. Narang, and S. Bhattacharya, "Mechanical properties of natural fibre polymer composites," *Journal of Polymer Engineering*, vol. 37, no. 9, pp. 879–895, 2017.

[13] M. H. Fouladi, M. Ghassem, M. Ayub, M. Jailani, and M. Nor, "Implementation of coir fiber as acoustic absorber material," *Noise & Vibration Worldwide*, vol. 42, no. 9, pp. 11–16, 2011.

[14] J. Li and S. I. Stoliarov, "Measurement of kinetics and thermodynamics of the thermal degradation for non-charring polymers," *Combustion and Flame*, vol. 160, no. 7, pp. 1287–1297, 2013.

[15] A. Khawam and D. R. Flanagan, "Role of isoconversional methods in varying activation energies of solid-state kinetics: II. Nonisothermal kinetic studies," *Thermochimica Acta*, vol. 436, no. 1-2, pp. 101–112, 2005.

[16] A. Balaji, R. Purushothaman, R. Udhayasankar, S. Vijayaraj, and B. Karthikeyan, "Study on mechanical, thermal and morphological properties of banana fiber-reinforced epoxy composites," *Journal of Bio-and Tribo-Corrosion*, vol. 6, no. 2, pp. 1–10, 2020.

[17] R. Anbarasan, G. P. Kalaignan, T. Vasudevan, and A. Gopalan, "Characterization of chemical grafting of polyaniline onto wool fiber," *International Journal of Polymer Analysis and Characterization*, vol. 5, no. 3, pp. 247–256, 1999.

[18] P. Prabhu, B. Karthikeyan, R. R. R. M. Vannan, and A. Balaji, "Dynamic mechanical analysis of silk and glass (S/G/S)/pineapple and glass (P/G/P)/flax and glass (F/G/F) reinforced *Lannea coromandelica* blender hybrid nano composites," *Journal of Materials Research and Technology*, vol. 15, pp. 2484–2496, 2021.

[19] A. Balaji, R. Saravanan, R. Purushothaman, S. Vijayaraj, and P. Balasubramanian, "Investigation of thermal energy storage (TES) with lotus stem biocomposite block using PCM," *Cleaner Engineering and Technology*, vol. 4, article 100146, 2021.

[20] A. C. H. Barreto, D. S. Rosa, P. B. A. Fechine, and S. E. Mazzetto, "Properties of sisal fibers treated by alkali solution and their application into cardanol-based biocomposites," *Composites Part A: Applied Science and Manufacturing*, vol. 42, no. 5, pp. 492–500, 2011.

[21] G. Jiang, D. J. Nowakowski, and A. V. Bridgwater, "A systematic study of the kinetics of lignin pyrolysis," *Thermochimica Acta*, vol. 498, no. 1-2, pp. 61–66, 2010.