Thermal analysis of Acacia Arabica and Pencil Cactus fiber hybrid polymer composites

Sakthi Vadivel K.[1*] and Govindasamy P.[2]
1. Department of Mechanical Engineering, Builders Engineering College, Kangayam, 638108, INDIA
2. Department of Mechatronics Engineering, Dr. Mahalingam College of Engineering and Technology, Pollachi, INDIA
*ksakthivadivel@gmail.com

Abstract
Natural fiber composite materials are frequently used in all engineering areas, because of their superior properties over the conventional materials. In this research is focused on evaluating the thermal behaviors of treated and untreated Acacia Arabica and Pencil Cactus fiber and their polymer composite. Thermal properties of the fibers and their composites are analyzed using Thermogravimetric analysis (TGA) to investigate the influence of fiber alkali treatment. The thermal stability of the treated fibers and their composites are found to be higher compared to untreated fibers and their composites. The outcome of the experiments clearly shows that the fiber reinforced polymer composite is processing below 300ºC gives a better efficiency.

Keywords: Acacia, Cactus, Thermogravimetric analysis, Polymer composite.

Introduction

The usage of cellulosic fiber filled with polymer matrix composite materials are rapidly rising mainly due to their lower cost of production and enviable properties. The reinforced materials are used as natural plant fibers because of its low cost, easy availability, biodegradability, renewable and good strength and also it is a better alternate for artificial fibers. The biodegradability of cellulosic fibers is associated to physical, chemical, mechanical and thermal and moisture conditions which has increased its scope for use of in numerous applications[1].

The cellulose based natural fibers (e.g. flax, hemp, kenaf, jute and ramie) are good in mechanical properties and used as reinforced materials for various applications. Generally, the natural plant fiber properties mostly depend on chemical composition and formation and also related to fiber variety as well as growing conditions, fiber extraction process, harvesting sessions and chemical treatment methods[2]. The natural fibers are constructing as chemical constituents like cellulose, hemicellulose, lignin, wax, moisture, ash content etc. The chemical constituents considerably varied between fibers to fiber and also affect the overall mechanical properties of the natural fibers. The diameters of the fibers considerably varied from length of the individual filament[3].

The Borassus fruit fibers were extracted by water treatment process and evaluated the characterization for raw and alkali treated fibers. The hemicellulose content is reduced in the alkali treated fibers when compared to raw fibers. Thermal stability and tensile strength increased in treated fibers than the untreated fibers[4]. Date palm fibers were extracted from Date palm plant leaf and fabricated the composite plates with polypropylene matrix after that investigate the thermal and tensile properties[5].

Alkali treatment removes hemicellulose, pectin, liginin, wax and oil in the natural fiber surfaces which improves the mechanical and thermal behaviors. When the alkali (NaOH) concentration is higher than the optimum condition in fiber treatment, the result shows the excess delignification of the fiber thus weakening or damaging the fibers and also properties are dropped[6,7]. The major limitation of natural plant fibers is its hydrophilic nature which restricts the use of the fibers as reinforcement in polymer matrix composites. The inappropriateness between the hydrophilic fibers and hydrophobic matrix result in bulge due to moisture absorption and it shows the poor interfacial bonding between matrix and the fibers[8-10].

Improvement is found in the interfacial bonding between the fiber and matrix due to the chemical treatments of fibers which reduce the hydrophilicity, fiber surface cleanness, reduce the moisture absorption process and improve the surface roughness[11]. Studied the surface modification of bamboo fiber with NaOH solution. The treated bamboo fiber shows the better tensile properties than raw fibers. Hemicellulose and lignin are removed effectively due to the NaOH treatment[12].

Analyzed the mechanical, morphology and thermal properties of the waste cotton fiber (ecofriendly) as reinforcement and wheat flour as matrix composite materials. The thermal stability was studied by Thermo Gravimetric Analysis (TGA) which found that the water was evaporated in first stage and components degradation in next stage was occurred. Morphology of the agro-green-composites was studied by using X-ray diffraction and SEM[13].

Investigated the tensile, flexural, impact and thermal properties of composites by reinforcing Acacia leucophloea fiber into an epoxy resin. The treated 5% NaOH and untreated fiber composites are prepared by hand layup technique by varying fiber content from 5 % to 25 wt%. The 20wt% treated fiber loading composites exhibited better mechanical properties. In thermogravimetric analysis, the residual mass of raw fiber composite was superior than the treated composite. The degradation temperature of raw fiber composite was relatively lower compared to treated fiber composite[14].

The present work focus on the thermal stability of the Acacia Arabica and Pencil Cactus fibers and its polymer composites for 25% volume fraction and 30mm fiber length.

Material and Methods

Acacia and Cactus Fiber Composites: Acacia and Cactus fibers are extracted from the Acacia Arabica tree and pencil Cactus plant from degradation process. The extracted dried fibers are kept under the 6% NaOH solution for improving the fiber roughness and removed the impurities from the fibers. The opted 25% volume fraction of fiber composites were prepared by hand lay-up method with the matrix of unsaturated polyester resin. The composite specimens used in the research work will be called as follows and showed in the Table 1.

Table 1
Designation of Acacia and Cactus fiber composites used for tests

S. N.	Designation	Fiber
1.	UAFPC	Untreated Acacia fiber polymer composite
2.	TAFPC	Treated Acacia fiber polymer composite
3.	UCFPC	Untreated Cactus fiber polymer composite
4.	TCFPC	Treated Cactus fiber polymer composite
5.	UACFPC	Untreated Acacia and Cactus fiber polymer composite (Hybrid)
6.	TACFPC	Treated Acacia and Cactus fiber polymer composite (Hybrid)

Thermogravimetric Analysis (TGA): Thermal stability behavior of the treated & untreated Acacia and Cactus fibers and their composites of 25% volume fraction were evaluated by Thermogravimetric (TG Curve) analyzer using Perkin Elmer TGA 4000 (Pyris 6 TGA) by passing nitrogen gas at 20.0 ml/min and heating range from 30˚ C to 700˚ C at a heating rate of 10 C/min. It was used to measure the weight loss and thermal degradation of the samples. The 2mg to 10mg weight of samples are crushed and kept in alumina crucible for better coupling between samples and by using thermocouple the temperature were measured.

Results and Discussion

Thermal Stability of Acacia and Cactus Fibers: Thermogravimetric performance of treated and untreated Acacia and Cactus fibers are as in TG curve shown in Figure 1. Generally, two major phase of degradation were observed in all the fibers. The initial degradation observed between 35˚C to 125˚C due to the moisture evaporated in the fibers and second stage degradation continued from 240˚C to 450˚C.

The temperature of 200˚C to 300˚C connected to thermal depolymerization of chemical consistency of hemicelluloses showed dissimilar weight loss of untreated Acacia fiber (14.24 %), treated Acacia fiber (12.52 %), untreated Cactus fiber (17 %) and treated Cactus fiber (12.1%). The depolymerization of cellulose occurred from the peak temperature range of 350˚C, 360˚C, 375˚C and385˚C with equivalent weight loss of untreated Acacia fiber (32.42 %), treated Acacia fiber (27.60 %), untreated Cactus fiber (45.10 %) and treated Cactus fiber (39.16 %) respectively. The higher energy was required to break down the hydrogen bonding of intramolecular and intermolecular which are in crystalline structure.[15]

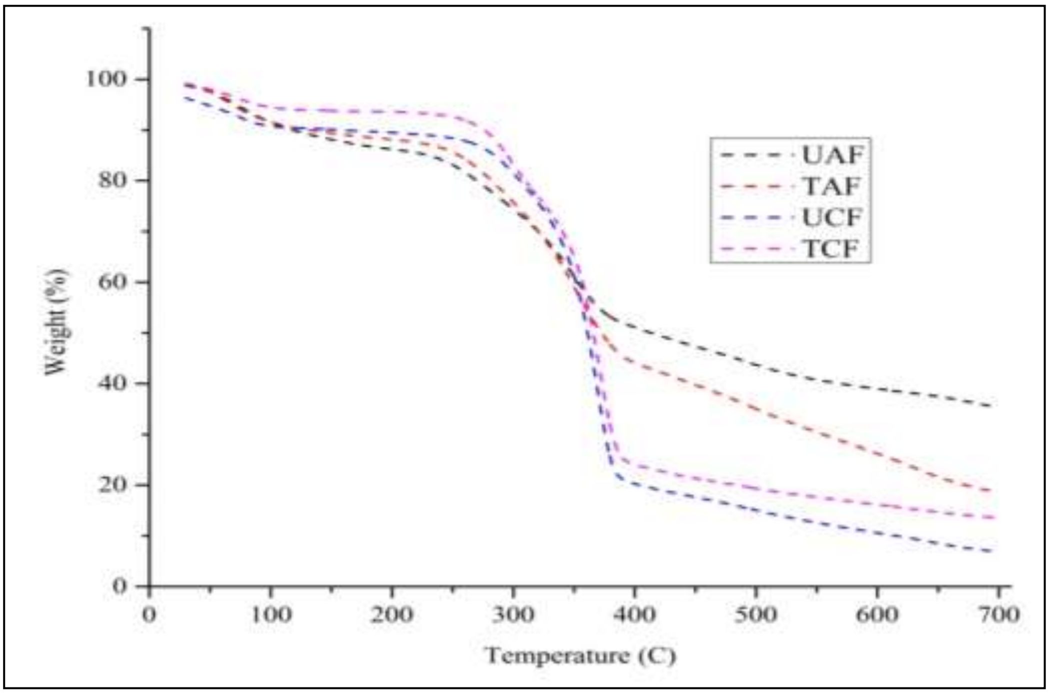

Figure 1: TG curve of the Acacia and Cactus Fibers

The thermal stability was enhanced in chemical treated Acacia and cactus fibers compared with untreated fibers due to the retention and development of the structural order and decreased in the amorphous content. The temperature range of 220˚C to 550˚C, degradation of lignin content was obtained.

At the temperature range of 200˚C to 300˚C, the weaker bonds break due to the presence of strong aromatic rings[16]. The weight loss of the treated Acacia and Cactus fibers above 500˚C were noticed to be less compared with temperature between 300˚C to 400˚C and also in untreated fibers. Therefore, the treated fibers can be used as reinforcement in polymer matrix composite.

Thermal stability of Acacia and Cactus fibers polymer composite: The Thermogravimetric analysis (TG curve) of treated and untreated Acacia and Cactus fiber polymer composite and hybrid composite are shown in Figure 2. The thermal degradation started at 32˚C up to 240˚C and the weight losses extremely reduced from 2.6% to 4.44%. Especially weight losses are lesser in the treated fiber composite compared with untreated fiber composite. The maximum degradation and weight loss occurred between 280˚C to 450˚C. Whereas, the weight loss of untreated Cactus fiber composite (UCFPC) was 82.56% which is greater than untreated Acacia fiber composite (UAFPC) which is 78.81%. Similarly, the weight of treated Cactus fiber composite (TCFPC) was 81.88% which is greater than treated Acacia fiber composite (TAFPC) which is 80.82%. Speaking about untreated Acacia/Cactus fiber composite (UACFPC), we can find the weight was 83.92% which is also greater than treated Acacia/Cactus fiber composite (TACFPC) which is 78.82%.

The maximum weight loss in natural plant fibers happened due to the thermal degradation of hemicelluloses and other glyosidic linkages from the fiber. The peak temperature observed in the derivative weight loss in the range of 396˚C, 399˚C, 392˚C, 399˚C, 395˚C and 400˚C in untreated Acacia fiber composite, treated Acacia fiber composite, treated Cactus fiber composite, untreated Acacia/Cactus fiber composite treated Acacia/Cactus fiber composite respectively.

After that, in the final stage degradation occurred between 450˚C to 630˚C and the weight losses were observed to be in very less amount between 3.5% to 4.75 %. Compared with treated fiber composite the weight losses decreased than the untreated fiber composite and it shows that the thermal stability is better in treated fiber composite and its hybrid composite as the treated fibers required higher energy to break down the hydrogen bonding of intramolecular and intermolecular which is in crystalline structure.

The alkali treatment partly removed the impurities from the fiber, the treated fiber reinforced composites possess higher initial degradation temperature than the untreated fiber composites. The outcome of the experiments clearly shows that the fiber reinforced polymer composite is processing below 300˚C gives a better efficiency.

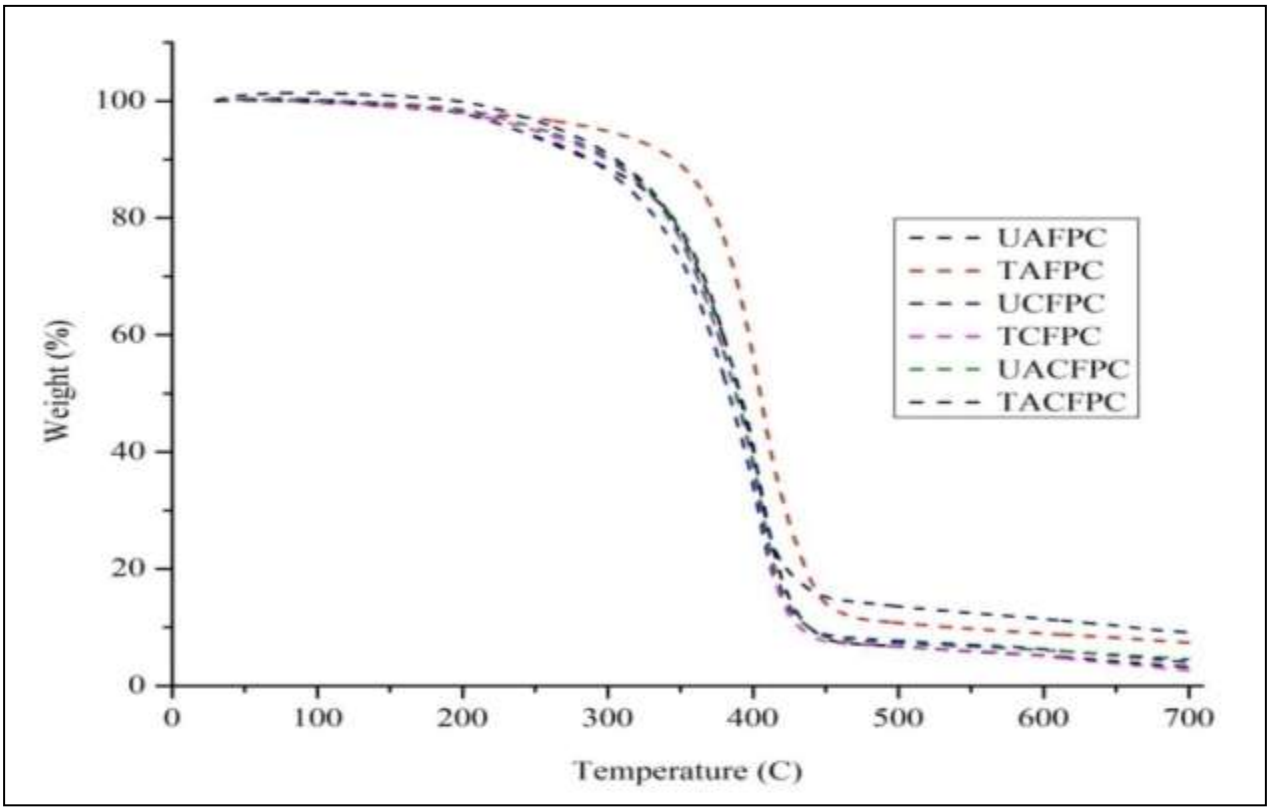

Figure 2: TG curve of the Acacia and Cactus Fiber Polymer Composites

Conclusion

The Thermal degradation and stability were analyzed for treated and untreated Acacia and Cactus fibers and its composites with 25% volume fraction and 30mm fiber length by Thermogravimetric analyzer.The maximum degradation and weight loss is occurred from 280˚C to 450˚C for all the composite specimens.The thermal stability of the treated fibers and their composites are found to be higher compared to untreated fibers and their composites. The outcome of the experiments clearly showed that the fiber reinforced polymer composite processed below 300˚C gives a better efficiency.

Acknowledgement

The authors thank the Department of Energy & Environment, National Institute of Technology, Tiruchirappalli for rendering the support to use the facilities and also I express my gratefulness to my colleagues Mrs. S. HemaMalini and Mr. C. Sivaraj, Builders Engineering College, Kangayam for their support and encouragement.

References

1. Jawaid M.H.P.S. and Khalil H.A., Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review, *Carbohydr. Polym*., **86(1)**, 1-18 **(2011)**

2. Pickering K.L., Efendy M.A. and Le T.M., A review of recent developments in natural fibre composites and their mechanical performance, *Compos. Part A Appl. Sci. Manuf*., **83**, 98-112 **(2016)**

3. Malkapuram R., Kumar V. and Negi Y.S., Recent development in natural fiber reinforced polypropylene composites, *J. Reinf. Plast. Compos.*, **28(10)**, 1169-1189 **(2009)**

4. Reddy K.O., Shukla M., Maheswari C.U. and Rajulu A.V., Mechanical and physical characterization of sodium hydroxide treated Borassus fruit fibers, *J. For. Res*., **23**, 667-674 **(2012)**

5. Zadeh K.M., Inuwa I.M., Arjmandi R., Hassan A., Almaadeed M., Mohamad Z. and Khanam P.N., Effects of date palm leaf fiber on the thermal and tensile properties of recycled ternary polyolefin blend composites, *Fibers Polym.*, **18**, 1330-1335 **(2017)**

6. Wang B., Panigrahi S., Tabil L. and Crerar W., Pre-treatment of flax fibers for use in rotationally molded biocomposites, *J. Reinf. Plast. Compos.*, **26(5)**, 447-463 **(2007)**

7. Chandrasekar M., Ishak M.R., Sapuan S.M., Leman Z. and Jawaid M., A review on the characterisation of natural fibres and their composites after alkali treatment and water absorption, *Plastics Rubber Compos.*, **46(3)**, 119-136 **(2017)**

8. Tripathy S.S., Jena S., Misra S.B., Padhi N.P. and Singh B.C., A study on graft copolymerization of methyl methacrylate onto jute fiber, *J. Appl. Polym. Sci.*, **30(4)**, 1399-1406 **(1985)**

9. Ibrahim N.A., Hadithon K.A. and Abdan K., Effect of fiber treatment on mechanical properties of kenaf fiber-ecoflex composites, *J. Reinf. Plast. Compos.*, **29(14)**, 2192-2198 **(2010)**

10. John M.J. and Thomas S., Biofibres and biocomposites, *Carbohydr. Polym.*, **71(3)**, 343-364 **(2008)**

11. Edeerozey A.M., Akil H.M., Azhar A.B. and Ariffin M.Z., Chemical modification of kenaf fibers, *Mater*., **61(10)**, 2023-2025 **(2007)**

12. Kim H., Okubo K., Fujii T. and Takemura K., Influence of fiber extraction and surface modification on mechanical properties of green composites with bamboo fiber, *J. Adhes. Sci. Technol.*, **27(12)**, 1348-1358 **(2013)**

13. Dobircau L., Sreekumar P.A., Saiah R., Leblanc N., Terrié C., Gattin R. and Saiter J.M., Wheat flour thermoplastic matrix reinforced by waste cotton fibre: Agro-green-composites, *Compos. Part A Appl. Sci. Manuf*., **40(4)**, 329-334 **(2009)**

14. Arthanarieswaran V.P., Kumaravel A., Kathirselvam M. and Saravanakumar S.S., Mechanical and thermal properties of Acacia leucophloea fiber/epoxy composites: Influence of fiber loading and alkali treatment, *Int. J. Polym. Anal. Ch.*, **21(7)**, 571-583 **(2016)**

15. Placet V., Characterization of the thermo-mechanical behaviour of Hemp fibres intended for the manufacturing of high performance composites, *Compos. Part A Appl. Sci. Manuf.*, **40(8)**, 1111-1118 **(2009)**

16. Dorez G., Taguet A., Ferry L. and Lopez-Cuesta J.M., Thermal and fire behavior of natural fibers/PBS biocomposites, *Polym. Degrad. Stabil.*, **98(1)**, 87-95 **(2013)**.