Proceedings of 8th International Conference on Mechanical Engineering and Renewable Energy 2025
10-12 December, 2025, Chattogram, BANGLADESH

SciEn Conference Series: Engineering Vol. 4, 2026, pp 593-599 https://doi.org/10.38032/scse.2026.4.274

Improving the Mechanical Properties of Jute Fiber-Mat Reinforced Epoxy Composite Incorporating Water Hyacinth Ash

Arda Arefin Nir[1], Md Arifuzzaman[1,], Sopnil Ahmed[1], Md Jahid Hasan[2], Md Shariful Islam[1]*

[1]Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh
[2]Department of Mechanical Engineering, University of Wyoming, Wyoming, USA

ABSTRACT

Natural Fiber Reinforced Epoxy composites are quite popular because of their eco-friendliness, cost-effectiveness, low weight, low density, bio-degradability, efficiency in application with improved mechanical aspects. Adding fillers to them not only can improve their mechanical, chemical and thermal properties but also reduce moisture absorption. In this study, water hyacinths, an environmental waste are used as ash form as a filler with jute fiber reinforced epoxy (JFRE) composite. They grow profoundly in ponds causing pollution which eventually necessitates sustainable utilization to develop sustainable, high-performance JFRE composites. The main goals were to prepare eco-composites incorporating it, test their tensile, flexural, and interlaminar shear and determine the most suitable filler formulation. WHA was prepared from dried water hyacinth plants by controlled combustion at 500 °C, followed by grinding and sieving through a 45 µm mesh. The composites were fabricated using a hand lay-up process with four layers of jute fiber mats and varying WHA loadings (0–2 wt %). The findings show that filler type and concentration have significant impact on mechanical properties of the composites. An optimum loading of 0.5 wt% WHA showed improvement in tensile strength (18%) and flexural strength (12%), while short-beam shear strength increased by about 12 %. Higher filler contents led to property degradation due to agglomeration and reduced interfacial adhesion. This research confirms the effectiveness of agricultural waste as fillers to improve mechanical properties of jute fiber reinforced composites, giving a foundation to the construction of sustainable, high-performance natural fiber composites, to be used in advanced engineering applications.

Keywords: Agricultural Waste Utilization, Eco-composites, Jute Fiber Reinforced Epoxy, Sustainable Materials, Water Hyacinth Ash.

1. Introduction

Recent development and growing demand for polymer reinforced composites can bring revolutionary change in industries like, automotive components, aerospace parts, sporting goods, and construction industries [1]. High-performance fiber reinforcements, including carbon fibers, aramid fibers, liquid crystalline polymers, and ultrahigh-molecular-weight polyethylene, have been of particular interest to demanding industries such as aerospace and military. Fiber-reinforced polymer (FRP) composites are a particular composite of polymer, in which the polymer base is strengthened by high-strength fibers to augment its characteristics. Recent years have seen the introduction of composite technology leading to the development of numerous fiber-reinforced composite systems manufactured by many production techniques in order to gain improved material behaviors [2]. The energy consumption in terms of glass and natural fibers, vegetable fibers can save up to 60% of the energy used in a product per ton, according to research by Pervaiz and Sain [3]. Some of the reasons why natural fibers are always a good alternative to synthetic is eco-friendliness, economically cheaper, low-weight and efficient in applications, biodegradable with good mechanical aspects. Along with synthetic fibers natural fibers such as ramie, jute, sisal, tamarind, corn, hemp, basalt, coir, and kenaf fiber could be used to improve the properties of the composites [4]. Some of the ideals natural fibers that can be incorporated in polymer composites include the jute fiber. The degree of insulation that is achievable by using jute can be beneficial in applications such as car interior door/ceiling lining or in separating the engine and the passenger part of the car [5]. Chemically treated fibers can contribute to enhance the fiber properties more, therefore improving the natural fiber composite's characteristics [6]. Research analyzed the substitution of conventional fiber composites with natural-fiber composites, the latter being Jute Fiber Reinforced Epoxy Composites. All of these were prepared using hand layup method and were compared with GRC and neat epoxy composites in mechanical and tribological properties. Swallow pointed towards the endless possibilities of using jute fiber for composites and urged the developers to comprehend the behavior of the later under certain industrial grades [7]. The introduction of a filler into a natural fiber reinforced epoxy composite (NFREC) can dramatically improve the properties such as higher strength, stiffness, thermal conductivity, and dimensional stability, and it may also decrease the level of moisture absorption. Recently in response to environmental safety, reduction in pollution and waste and to ensure sustainability, organic waste fillers and bio-fillers such as, discarded custard apple seed powder, neem seed, groundnut shell, portunus sanguinolentus shell powder, pistachio shell powder, tea leaf

*Corresponding Author Email Address: arif48@me.kuet.ac.bd

powder, eggshell powder, walnut shell powder, pomegranate peel powder, pineapple and watermelon peel nanoparticles are introduced to the world as an alternative to synthetic fillers [8], [9], [10], [11], [12], [13], [14]. Researches have been expanded to finding more natural filler including, azadirachta indica seed, camellia sinensis leaf particles, brown algae particles, almond shells, clam shells, hazelnut shells, rice husk and citrullus vulgaris peel powder were introduced to the world. They not only have shown improved mechanical and thermal performance but also have great impact on environment by utilizing those wastes, [15], [16], [17], [18], [19], [20], [21], [22]. Another newly discovered natural material Water Hyacinth Ash or powder can also be added as a filler in epoxy resin. Water hyacinths, which are aquatic plants, are particularly notable in that these form a nuisance mainly because of their rapid growth and develop thick coverts that hinder sunlight and water and results in major environmental and economical disasters all across the world. Apart from being used to generate biomass, the mentioned water wastes can also be used to increase strength. Water hyacinth composites particularly ash composites suggested for various commercial uses since a study shows a promising future for the use of the composite material. The results also showed that water hyacinth ash composites goals have increased resistance and mechanical properties; allow using them in various industrial field instead of conventional materials. It has been shown that the ash composite's mechanical properties are superior to those of the powder composite sample because the ash particles have a lower density compared to the powder samples, allowing them to adhere well to the epoxy resin matrix material and, thereby, densely packing the micro gaps and, in doing so, increasing the mechanical strength [23]. A study examines the chemical potential of water hyacinth ash (WHA) as an environmentally-friendly cement substitute [24].

Till now there is no work on incorporating water hyacinth ash in natural fiber reinforced epoxy composite. The aim of this work is to manufacture jute fiber mat-reinforced epoxy composites with varying water hyacinths ash and to evaluate the mechanical properties for comparison. The hypothesis is that the water hyacinths ash would reduce epoxy in manufacturing jute fiber mat-reinforced epoxy composites without affecting or improving the mechanical properties. This research seeks to pave the way for sustainable composite development while prioritizing environmental safety.

2. Materials & Method

2.1 Materials

For this study, jute fiber mats were purchased from a local supplier near jute mills in Dakbangla, Khulna. The mats were then cut into the 127 mm ×177.8 mm to be used in the process of composite fabrication having an aerial density of 0.0297 g/cm^2.

Fig. 1 represents the stepwise procedure for preparing water hyacinth ash (WHA) from raw water hyacinth plants. Water hyacinths were collected from a local pond. The plants were then cleaned and the leaves, stems and roots were then cut into small portion. The parts were then dried in sun for at least 15 days which can be seen in Fig 2(a) which reduced the moisture presented in the plant the most. The sundried water hyacinths were the dried in an electric oven for 3 days for complete reduction of moisture left in the plants which is presented in Fig 2(b). The smaller sections were then ground and burned in 500°C, for 2 hours in a closed container inside the muffle furnace to obtain water hyacinth ash (WHA) (illustrated in Fig 2(c)). The ash was then ground, and sieved through a 45-µm mesh, producing fine WHA particles (illustrated in Fig 2(d)).

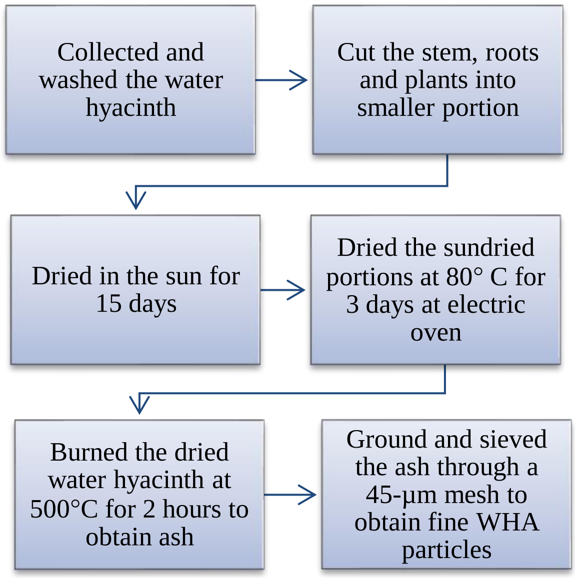

Fig.1: Process flow diagram of preparing water hyacinth ash from raw water hyacinth plant

The sieve grade of 45 µm was chosen following initial screening of several sieve grades (25-75 µm) to allow introduction of uniform dispersion of particles without agglomeration. The test on particle size revealed that more than 90 percent of the WHA particles went through the 45 µm sieve to give a consistent size distribution that could facilitate good interfacial bonding with the epoxy matrix.

Fig.2: (a) Sundried water hyacinth after 15 days; (b) Oven dried water hyacinth after 3 days; (c) Water hyacinth ash after burning at furnace; (d) Water hyacinth ash after sieve.

Epoxy resin and hardener of 2:1 ratio was used, which is Lapox, commercially manufactured by Atul Ltd., India.

2.2 Fabrication Process

The entire fabrication process is briefly illustrated in process flow diagram of Fig 3.

Four layers of cut jute mat, illustrated in Fig 4(a) were used on each composite samples. Thereafter, the mats were first cut and left in an electric oven overnight before molding. Initially, epoxy resin was mixed with the hardener in a container in 2:1 ratio to prepare the base sample. Base samples were first molded incorporating 0% of WHA. In the case of filler-containing composites, the WHA were initially mixed with the epoxy resin in 0.5%, 1%, 1.5% and 2% respectively, using a glass rod during 1-2 minutes.

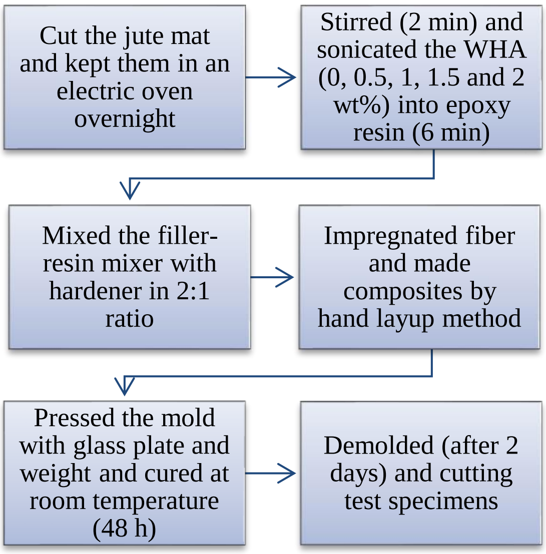

Fig.3: Process flow diagram of the fabrication of JFRE composites incorporating WHA

Each mixture was then sonicated approximately 6 minutes, shown in Fig 4(b), in order to ensure dispersal of the particles. Hardener was then mixed with filler-resin mix in the same proportion of 2:1. The accurate weight of epoxy resin, hardener and weight percentage of filler was measured by digital weight balance. The composites were hand lay-up into a 127 mm ×177.8 mm silicone mold. The epoxy-hardener mixture was rolled between successive layers of pre-cut jute fiber layers in the form of a roller, and this method was applied to allow an equal impregnation of each layer. As shown in Fig 4(c), the laminate was then pressed with a glass plate, plastic sheet, and additional weights to minimize the presence of voids and achieve a homogenous thickness. The hardened composites were demolded two days after being allowed to cure at room temperature and the demolded sample is illustrated at Fig 4(d).

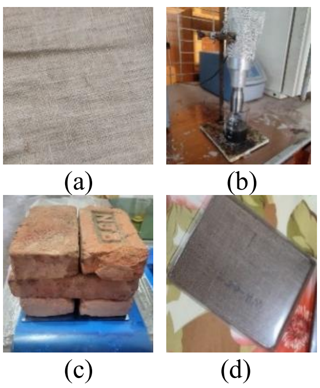

Fig.4: (a) Used jute mat; (b) Sonication of epoxy and WHA; (c) Mold preparation through hand layup method and pressing with weight; (d) Demolded sample

2.3 Test Methods

The tensile and flexural tests were performed on a Universal Testing Machine (Shimadzu AGX 300kN, Japan) with a top load limit of 300 kN at a constant crosshead speed of 2.0 mm/min. ASTM D3039 standard were used to assess the tensile properties of the composites. Specimens were cut to approximately 184 mm length, 13 mm wide and 4 mm thick prior to testing. Samples are attached by grip in between the jigs. To test, a constant gage length of 100 mm was maintained in order to ensure that the specimens were put under an equivalent stress. ASTM D790 standard is followed to assess the flexural properties. Specimens were cut to approximately 92 mm length, 13 mm wide and 4 mm thick prior to testing. Short Beam Shear Test of the composites was conducted by following the ASTM D2344 standard. The tests were performed with a Universal Testing Machine (Shimadzu AGX 10kN, Japan) with a load capacity of 10 kN. The test speed was 1.0 mm/min. Specimens were cut to approximately 30 mm length, 13 mm wide and 4 mm thick prior to testing.

3. Results Analysis

3.1 Density

The average density of the composites is given in Table 1. It was observed that the density increased slightly with the incorporation of fillers in the composite although the increase in density is not significant.

Table 1: Density of composites for various filler content

WHA Content	0%	0.5%	1%	1.5%	2%
Density (g/cm^3)	1.025	1.147	1.105	1.130	1.096

3.2 Tensile Properties

The tensile strength and specific tensile strength are plotted in Fig.5 for various WHA content. The tensile strength of the base composite without filler is 37.33 ± 1.455 MPa, while the tensile strength of 0.5 wt.% WHA filler is 44.16 ± 1.115 MPa representing an 18.30 % improvement. Further increase in WHA content causes a drop in tensile strength reaching a lower value than the base composite at 2 wt.% of WHA filler loading. The specific tensile strength showed a similar trend.

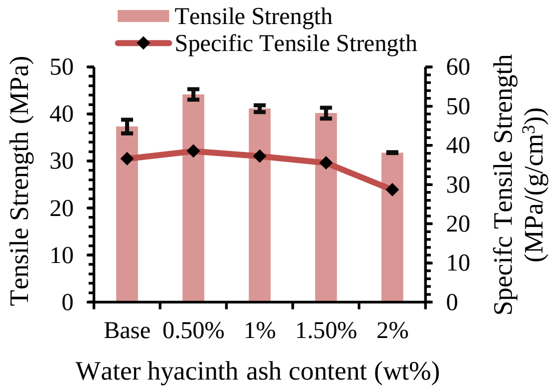

Fig.5: Effect of filler weight percentage on Tensile Strength and Specific Tensile

Fig.6 shows the tensile modulus and specific tensile modulus for the composites with various WHA content. It is seen that the variation in tensile modulus and specific tensile modulus is insignificant due to the change in WHA filler content because the modulus of the composites is primarily the contribution of the jute fiber mat. Fig.7 represents the toughness and specific toughness of the composites for various WHA content. The trend of toughness is similar to the tensile strength of the composites. The maximum toughness and specific toughness increased significantly at 0.5 wt.% of WHA filler content. The increase in toughness at 0.5 wt.% of WHA is found to be approximately 24.29 %.

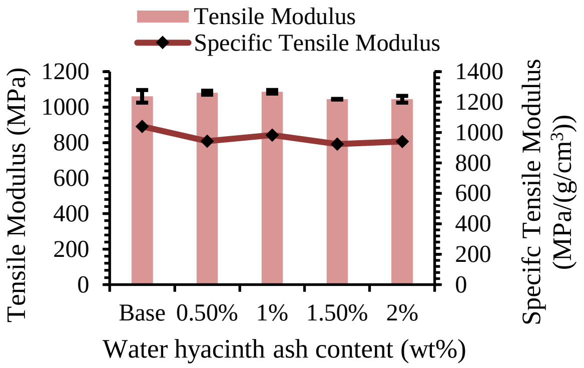

Fig.6: Effect of filler weight percentage on Tensile Modulus and Specific Tensile Modulus

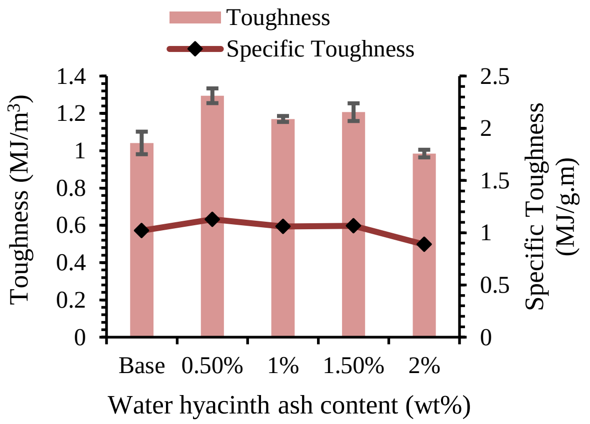

Fig.7: Effect of filler weight percentage on Toughness and Specific Toughness

For each case decrease in higher percentage is clearly noticed. So, the tensile strength and toughness are significantly improved by the addition of 0.5 wt.% of WHA while the modulus remained unaffected indicating that the WHA can be a sustainable material to be used as filler at small quantity to improve the tensile properties of jute fiber mat reinforced epoxy composite.

The enhancement in 0.5 wt% WHA is possibly due to homogeneous distribution of fillers, which increases transmission of stress between jute fibers and epoxy and inhibits formation of cracks. At higher degrees, particle agglomeration and the formation of resin-rich areas degrade the adhesion between the matrix and the fillers, forming microporous formation of micro-voids that cause premature failure and poor tensile performances.

3.3 Flexural Properties

The flexural properties are given in Fig.8-10 for various WHA content. The flexural strength showed the maximum at a WHA content of 0.5 wt.% showing an 11.97% increase compared to the base composite. Further addition of WHA in the composite showed a decrease in flexural strength that is represented in Fig.8. However, for 1% and 1.5% WHA content, the flexural strength remained approximately similar to the base composite. Conversely, at 2wt.% of WHA content the flexural strength dropped significantly. On the other hand, the specific flexural strength gradually decreased up to a WHA content of 2 wt.%. It is observed from Fig.9 that the flexural modulus and specific flexural modulus are not significantly affected by the WHA filler addition. The flexural modulus is maximum at 1.0 wt% showing a 5.99% increase compared to the base composite.

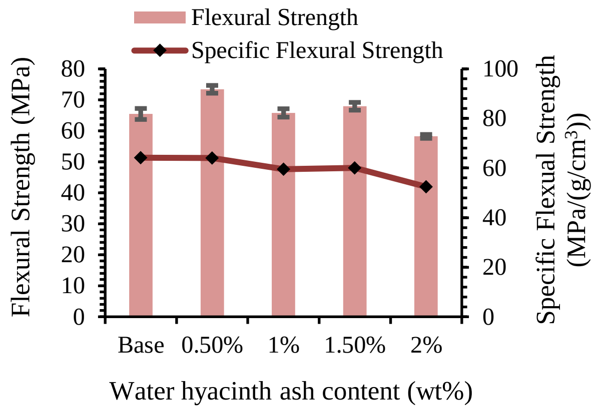

Fig.8: Effect of filler weight percentage on Flexural Strength and Specific Flexural Strength

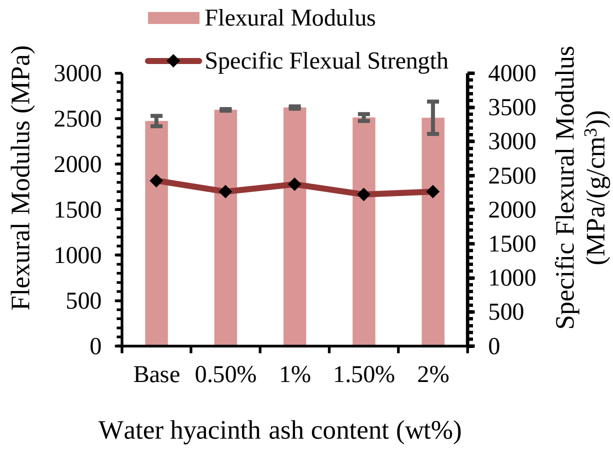

Fig.9: Effect of filler weight percentage on Flexural Modulus and Specific Flexural Modulus

The energy absorption and specific energy absorption during bending are shown in Fig.10. The highest energy absorption is seen at 1.5 wt% of WHA content, with a 31.73% improvement from the baseline. Overall, the flexural properties were improved due to the addition of WHA in the jute fiber mat-reinforced epoxy composite and optimum is found at a WHA content of 0.5wt.%. This moderate WHA loadings are like micro-reinforcements, which inhibit bending deformation of the matrix, enhancing stiffness. However, the flexural properties are consistently detrimental at a filler content of 2wt.% indicating that higher WHA content in the composite would not be beneficial in terms of flexural properties. In this case, particle clustering interrupts the continuity of the epoxy phase and introduces internal stress concentrations, which explain the observed drop in flexural strength and energy absorption. Therefore, a small amount of waste and abundantly available WHA is found to be effective in improving the flexural properties of the jute fiber mat-reinforced epoxy composite.

Table 2. Comparison of mechanical properties of natural fiber epoxy composites

Composite system	Filler type	Tensile strength (MPa)	Flexural strength (MPa)	Reference
Jute/epoxy + custard apple seed powder	Custard apple seed	60.82	145.51	[8]
Jute/epoxy + neem & groundnut shell	Dual bio-fillers	43.28	46.08	[9]
Jute/epoxy + Portunus sanguinolentus	Crab shell powder	48.73	5.45	[10]
Jute/PLA + pistachio shell	Pistachio shell powder	57.38	114.67	[11]
Jute/epoxy + pomegranate peel	Pomegranate peel powder	74.6	207.1	[13]
Jute/epoxy + Azadirachta indica seed &	Azadirachta indica seed	33.11	5.4	[15]
Jute/epoxy + brown algae particles	Algae filler	34.39	73.16	[16]
Jute/banana/epoxy + eggshell	Eggshell powder	95.27	117.47	[17]
Jute/epoxy + clam shell	Marine shell filler	23.56	39.80	[19]
Jute/epoxy + rice husk flour	Rice husk flour	38	57	[21]
Jute/epoxy + fruit-waste (Citrullus	Watermelon peel powder	68.2	149.84	[22]
Jute/epoxy + WHA (present study)	**Water Hyacinth Ash (0.5 wt %)**	**44.16**	**73.41**	–

3.4 Short Beam Shear Strength

The short beam shear (SBS) strength is plotted in Fig.11 for various WHA content in the composite. It is observed that the short beam shear strength is maximum at a WHA content of 0.5wt.% similar to the observation in the case of tension and flexural properties. The maximum SBS strength of the composite with 0.5wt.% WHA is approximately 12.07 % greater than the base composite. However, further addition of WHA in the composite decreased the SBS strength. The SBS strength remained approximately similar to the base composite up to a WHA content of 1.5wt.% and at 2wt.%, the SBS strength decreased significantly. The specific SBS strength has consistently decreased with the addition of WHA ash in the composite. The better SBSS at 0.5 wt% indicates that the existence of fine dispersed ash particles provides interfaces bonding between the fiber mat and the matrix and thus prevents delamination. A higher content of filler saturates interfaces, leading to localization of stress and interlaminar debonding, shear strength reduces.

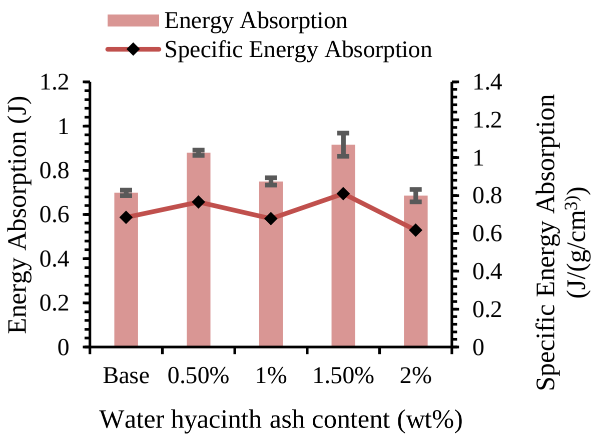

Fig.10: Effect of filler weight percentage on Energy Absorption and Specific Energy Absorption

4. Discussion

It is seen that the tension, flexural and short beam shear properties were improved with the addition of WHA in the jute fiber mat-reinforced epoxy composite. The optimum WHA content is found to be 0.5wt.% for tensile strength, flexural strength and short beam shear strength which indicates that a small amount of WHA filler improves the interfacial adhesion between epoxy and filler. However, at a higher WHA loading there may be particle agglomeration creating weak spot for ineffective stress transfer and path for crack initiation and propagation. The insignificant change in modulus confirms that the modulus of the composite is mostly dependent on the jute mat and modification of matrix has little effect on the modulus of jute fiber mat-reinforced composite. This enhancement suggests that at this optimal concentration, the WHA particles improve the interfacial adhesion between the matrix and reinforcement, leading to better stress transfer and resistance to interlaminar shear.

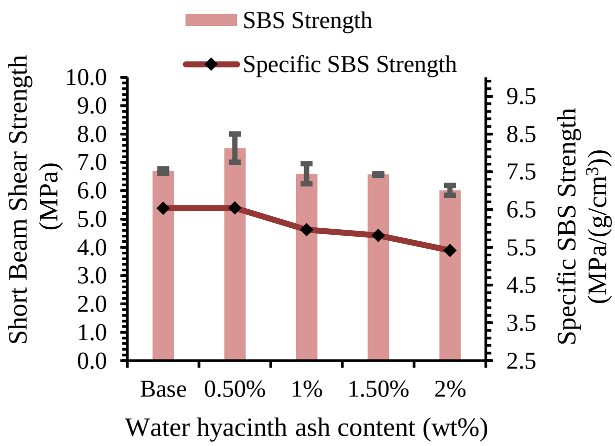

Fig.11: Effect of filler weight percentage on SBS strength and Specific SBS Strengthh

Although, the 0.5wt.% of WHA filler showed the maximum strength and energy absorption, the composites with WHA filler content up to 1.5 wt.% were effective in improving the mechanical properties of the jute fiber mat-reinforced epoxy composite. The addition of filler in the composite also reduces the epoxy content in the composite.

4.1 Comparison with Some Natural Fiber Composites

Table 2 offers a comparison and summary of the current findings with some literature on natural-fiber epoxy composites. It underlines that the best formulation (0.5 wt% WHA) has similar or better mechanical performance yet is sustainable due to the use of waste.

5. Conclusion

The incorporation of water hyacinth ash (WHA) as a natural filler in jute fiber mat-reinforced epoxy composites demonstrates significant potential for sustainable material development. The overall findings indicate that:

1. Filler loading effect exhibited a fine optimum between 0.5-1.0 wt%.
2. A 0.5 wt.% WHA addition yields optimal improvements in tensile (18%), flexural (12%), and short beam shear (12%) strengths, enhancing interfacial bonding and energy absorption.
3. Excess filler (>1.0 wt%) resulted in particle agglomeration and micro-voids which resulted in strength-degradation.

The findings suggest that small amounts of WHA can effectively enhance mechanical behavior while reducing epoxy usage, contributing to cost efficiency, waste utilization, and environmental sustainability in composite manufacturing. Thus, it favors the production of lightweight, sustainable composites to be used in engineering with less carbon footprint and promotes the use of biodegradable alternatives to non-biodegradable synthetics generally used as fillers in composites.

6. References

[1] M. Ramesh, "Kenaf (Hibiscus cannabinus L.) fibre based bio-materials: A review on processing and properties," Jun. 01, 2016, *Elsevier Ltd*.

[2] S. Prashanth, K. M. Subbaya, K. Nithin, and S. Sachhidananda, "Fiber Reinforced Composites - A Review," *Journal of Material Science & Engineering*, vol. 06, no. 03, 2017.

[3] M. Pervaiz and M. M. Sain, "Carbon storage potential in natural fiber composites," *Resour Conserv Recycl*, vol. 39, no. 4, pp. 325–340, Nov. 2003.

[4] M. Ramesh and S. Nijanthan, "Mechanical property analysis of kenaf-glass fibre reinforced polymer composites using finite element analysis," 2016.

[5] O. A. Khondker, U. S. Ishiaku, A. Nakai, and H. Hamada, "Fabrication mechanical properties of unidirectional jute/PP composites using jute yarns by film stacking method," *J Polym Environ*, vol. 13, no. 2, pp. 115–126, Apr. 2005.

[6] M. George, P. G. Mussone, K. Alemaskin, M. Chae, J. Wolodko, and D. C. Bressler, "Enzymatically treated natural fibres as reinforcing agents for biocomposite material: mechanical, thermal, and moisture absorption characterization," *J Mater Sci*, vol. 51, no. 5, pp. 2677–2686, Mar. 2016.

[7] G. Raghavendra, S. Ojha, S. K. Acharya, and S. K. Pal, "Jute fiber reinforced epoxy composites and comparison with the glass and neat epoxy composites," *J Compos Mater*, vol. 48, no. 20, pp. 2537–2547, 2014..

[8] P. K. Ramadoss, M. Mayakrishnan, and F. S. Arockiasamy, "Discarded custard apple seed powder waste-based polymer composites: an experimental study on mechanical, acoustic, thermal and moisture properties," *Iranian Polymer Journal (English Edition)*, vol. 33, no. 4, pp. 461–479, Apr. 2024.

[9] R. D. S. Kumar, P. Gurusamy, and D. Dinesh, "Hybrid effect of neem seed and groundnut shell bio-fillers on the mechanical, water absorption and thermal properties of jute fiber reinforced epoxy composites," *International Journal of Materials Research*, vol. 115, no. 7, pp. 517–528, Jul. 2024.

[10] P. Kumaran *et al.*, "Investigation on thermo-mechanical characteristics of treated/untreated Portunus sanguinolentus shell powder-based jute fabrics reinforced epoxy composites," *Journal of Industrial Textiles*, vol. 50, no. 4, pp. 427–459, Oct. 2020.

[11] K. Karunanidhi, M. Manoharan, and G. Sivanantham, "Valorization of agricultural waste in jute–PLA biocomposites: performance analysis of pistachio shell, tea leaf, and quail eggshell fillers," *J Mater Cycles Waste Manag*, 2025.

[12] P. Dhiman and H. Sharma, "Effect of walnut shell filler on mechanical properties of jute-basalt hybrid epoxy composites," in *Materials Today: Proceedings*, Elsevier Ltd, 2020, pp. 4537–4541.

[13] R. V. S. Reddy, L. R. Jeeru, P. V. Reddy, and K. Swamy, "Mechanical Properties Evaluation of Pomegranate Peel Powder Filled Jute Fiber Reinforced Epoxy Composites," *Mater Today Proc*, vol. 62, no. P13, pp. 6923–6926, Jan. 2022.

[14] S. Balakrishnan, C. Krishnaraj, and C. R. Raajeshkrishna, "Mechanical characterization of pineapple, watermelon peel nanoparticles reinforced carbon, jute fabric, and its hybrid epoxy composites," *Mater Res Express*, vol. 6, no. 10, Sep. 2019.

[15] R. Vijay, A. Vinod, R. Kathiravan, S. Siengchin, and D. L. Singaravelu, "Evaluation of Azadirachta indica seed/spent Camellia sinensis bio-filler based jute fabrics–epoxy composites: Experimental and numerical studies," *Journal of Industrial Textiles*, vol. 49, no. 9, pp. 1252–1277, Apr. 2020.

[16] R. Karthikeyan and S. Madhu, "Impact of brown algae particles on the mechanical properties of jute-reinforced polymeric composites for sustainable development," *Results in Engineering*, vol. 25, Mar. 2025.

[17] B. Dev, M. A. Rahman, A. N. Khan, A. B. Siddique, M. R. Alam, and M. Z. Rahman, "Eggshell bio-filler integration in jute/banana fiber-reinforced epoxy hybrid composites: Fabrication and characterization.," *Applied Polymer*, vol. 141, no. 44, Aug. 2024.

[18] A. Çetin, "Utilizing almond shell filler to improve strength and sustainability of jute fiber composites," *Polym Compos*, vol. 46, no. 1, pp. 450–470, Sep. 2024.

[19] H. Jena, A. Panigrahi, and M. Jena, "Mechanical property of jute fibre reinforced polymer composite filled with clam shell filler: a marine waste," *Advances in Materials and Processing Technologies*, vol. 9, no. 1, pp. 75–91, 2023.

[20] V. Matějka *et al.*, "Jute fibers and powderized hazelnut shells as natural fillers in non-asbestos organic non-metallic friction composites," *Mater Des*, vol. 51, pp. 847–853, 2013.

[21] N. Bisht and C. Gope, "Mechanical properties of rice husk flour reinforced epoxy bio-composite," *International Journal of Engineering Research and Applications*, Vol. 5, Issue 6 (June 2015), pp 123-128.

[22] S. Balakrishnan, C. Krishnaraj, C. R. Raajeshkrishna, P. Sivapandi, and M. Natrayan, "Investigation of mechanical properties of jute epoxy composite with fruit waste (Citrullus vulgaris peel) filler for automotive applications," *Polymers and Polymer Composites*, vol. 29, no. 9, pp. 1430–1441, Nov. 2021.

[23] A. Ajithram, J. T. Winowlin Jappes, I. Siva, M. A. Khan, and N. C. Brintha, “Investigation of water, chemical absorption and mechanical properties of water hyacinth (Eichhornia Crassipes) aquatic plant powder, ash composites for commercial applications,” *Mater Today Proc*, vol. 60, pp. 1339–1346, Jan. 2022.

[24] V. Murugesh, S. K. Devi, P. M. Unni, S. Hemalatha, and V. Venugopalan, “Chemical properties of water hyacinth plant ash,” Journal of Advanced Zoology, 2024.