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Effect of Barium Sulphate on Mechanical Properties of Woven Aloe Vera/Flax Reinforced Epoxy Composites

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Abstract

Natural fiber-reinforced composites are becoming popular because of their lightweight, eco-friendly, and sustainable nature. Nevertheless, single-fiber composites tend to exhibit poor mechanical performance. This research paper has created a hybrid composite bonded with woven Aloe vera and flax reinforced with an epoxy bond. Barium sulphate ($BaSO_4$) filler was added to further improve the properties. The fibers were subjected to sodium hydroxide (NaOH) to enhance bonding with the matrix and the composites were made through the hand lay-up process. Mechanical properties studied include tensile, flexural, compressive strength, impact energy and hardness. Its findings indicate that tensile, flexural and compressive strength enhance effectively with the addition of $BaSO_4$ filler because of the improved transfer of stress and minimized voids. Impact energy and hardness however had minor variations. Analysis of Scanning Electron Microscopy (SEM) established better bonding of fibers with the matrix and fewer defects in filled composites than unfilled composites. the developed Aloe vera/flax hybrid composite with filler of $BaSO_4$ is shown to have a stronger mechanical performance and has possible applications in lightweight and sustainable engineering sectors like automotive and construction.

Keywords; Aloe vera**,** flax, hybrid composites, barium sulphate, mechanical properties

INTRODUCTION

The composites made using natural fibers have received a lot of interest in the materials science community because of their eco-friendly properties, light weight, and biodegradability. These are composite materials, where renewable resources, including jute, flax, and aloe vera, are used as reinforcement fibers, an appealing alternative to synthetic fiber composites, in large part due to their lower environmental impact relative to traditional composite materials, which require petroleum-based resins and fibers. The natural fiber reinforced polymer composites have been known to have good mechanical characteristics, which include good tensile strength and rigidity thus they can be applied in various applications, which include automotive, construction and consumer products [1, 2]. Also, the low density and price of these materials are added to their structural benefits, which makes them more appealing to various industrial segments. Although natural fiber composites provide a wide range of benefits, single fiber systems have serious disadvantages, particularly in the sector of. mechanical performance. The natural properties of the particular fibers tend to cause composites that would not be maximizing the potential of the raw materials; so, they were proven to be. demonstrate a low mechanical performance

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compared to their synthetic counterparts [3–5]. In addition, natural fibers are more prone to external forces such as moisture absorption, which can be very disastrous. damage their mechanical characteristics. As such, reliance on a single fiber will limit the options. of maximization of performance of composite under different loading conditions and environments. To about these bottlenecks, fiber hybridization has been used to offer a working solution to the enhancement. of the mechanical and physical properties of the composite materials. Especially, Aloe Vera and Flax fibres. hybrid system is able to take advantage of the specific features of every one of these types of fibers; Aloe Vera fibers can be. to add flexibility, but to add tensile strength, Flax fibers can be employed. This type of synergistic strategy improves the general mechanical performance, there are also prospects to. moisture intake-moisture intake has been identified as one of the most critical features of natural durability and life cycle. fibers composites [6–9].

This is where the fact that the combinations of fibers will have to be selected in opposition to each other either mechanically or chemically can be mentioned. Other than fibre hybridization, addition of fillers such as Barium Sulphate ($BaSO_4$) is also a widely explored option to enhance properties of the natural fibre reinforced composites even more [10–15]. BaSO4 addition gives mechanical reinforcement, improved impact strength, and improved thermal stability which could be a good direction towards improving the performance of composite materials. They can also be made more adhesive by adding fillers and in this case, more stress is transferred during mechanical loading [16–22]. They also mitigate high moisture absorption rates of natural fibers and this leads to increased durability of the composites. It is this twofold process of fiber hybridization along with the filler integration, which is also a good methodology of developing high-performance composite materials, which can be exploited in the arduous work of the automotive industry, among others. Despite the slight advancement in terms of the mechanics of the natural fiber composites, there are few gaps in the literature, particularly on the studies on the Aloe Vera/ Flax composites reinforced with BaSO4 [23–25]. Their certain impacts on mechanical properties and failure study especially in automobiles which are highly dependent on load resistance and the durability of their goods should be better researched. Therefore, the primary objective of the research is to analyze mechanical properties and failure of Aloe Vera/Flax hybrid materials as control groups (BaSOx filler) and experiments (BaSOx filler). In this gap, it is desirable that the paper illuminates the ways in which these formulations can be utilized to further the performance and applicability of natural fiber composites within the industry, which is increasingly being oriented towards sustainability and eco-friendliness [26–28]. The novelty of the current work is the synergistic nature of woven Aloe vera and flax fibers and the inorganic filler reinforcement with $BaSO_4$ in the epoxy matrix which has not been widely documented in the literature. As opposed to the traditional research on individual natural fibers, or on hybrid systems that do not contain fillers, this study combines two-fiber hybridization with particulate filler modification to attain better mechanical performance and retain eco-friendly properties.

Moreover, a comparison of composites containing and without $BaSO_4$ filler is conducted in a systematic way in order to explicitly show how the filler improves tensile, flexural, and compressive properties. Moreover, micro-structural confirmation through SEM analysis is used, in order to tie mechanical performance to interfacial bonding, reduction of void and behavior of crack propagation. This integrated solution offers a well-defined structure-property relationship and offers a viable alternative to traditional synthetic composite in lightweight engineering. The formulated composite materials have high possibilities of use in the transportation and auto field. Findings have indicated that barium sulphate filler improves tensile, flexural and compressive strengths over composites that lack fillers whilst retaining high levels of hardness and impact resistance. Improvements of this type suggest the potential to substitute traditional glass fiber composites with hybrid natural fiber composites in vehicle interior parts, non-structural covers, and other lightweight parts. In addition to automobiles, such composites can be used in green building materials, packaging, and sporting gear because of their lightness and ability to be recycled and biodegraded, thus, making the environment sustainable and eco-friendly.

MATERIALS AND METHODS

Aloe vera and flax natural woven fibers which were obtained in Go Green Natural Fiber, Chennai, India, were used as reinforcements. The LY556 grade of epoxy resin and hardener HY951 were chosen as the system of the matrix in 10:1 ratio. The composite performance was improved by the filler material, barium sulphate (BaSO4). The fabric used was plain weave type, which is very dimensionally stable and fabric-integrity providing. To enhance bonding between the fiber and the matrix, the natural fibers were exposed to alkaline treatment with sodium hydroxide (NaOH) to aid in eliminating the substances and raising the surface roughness to enhance bonding. The composites were fabricated by hand layup process, which is cheap and easy to perform. When fabricating it, layers of woven Aloe vera and flax mats were put in a mold 300 × 300 mm, with every layer being impregnated with a mixture of epoxy resin and hardener. This was replying up until the desired thickness of about 3.2 mm was acquired. Rollers were placed between the layers to get consistent distribution of the resin and to remove air that was trapped between the layers.

The laminates were then pressed and left to dry in room temperature condition and left to dry within 24 hours. Aloe vera-flax hybrid composites were made in two forms that were Aloe vera-flax hybrid composite without filler and Aloe vera-flax hybrid composite with BaSO4 filler. The laminates were cured and then cut into test specimens according to ASTM standards of various mechanical characterizations. Tensile test specimens were made as per ASTM D638, flexural test specimens as

Per ASTM D790, impact test specimens as per ASTM D256, compression test specimens as per ASTM D695 and hardness test specimens as per ASTM D2240-05. All the tests were performed at Delta Inspection and Analytical Lab, Chennai, on universal testing machine (UTM) and Izod impact tester. Besides, surface and failure morphology of tested specimens were also analyzed under Scanning Electron Microscopy (SEM, Carl Zeiss SUPRA 55 FESEM), which provided the understanding of the fiber pull-out, the cracking of the matrix, the formation of the voids, and the overall fiber-matrix interaction. Woven Aloe vera and flax were the natural fibers employed in this investigation as indicated in Figure 1.

Aloe vera fiber is characterized by being lightweight and biodegradable, whereas flax fiber has significant tensile strength, stiffness, and damping vibration absorbing ability. The hybrid form of these fibers was chosen to provide an optimal balance in the combination of strength and environmental sustainability. The mats being woven had dimensional stability and fabric integrity and could therefore be fabricated into composite. The cured laminates were then fabricated and then cut into mechanical characterization specimens. The specimens were cut using a saw cutter and their edges were smoothed using a file and emery paper to remove flaws.

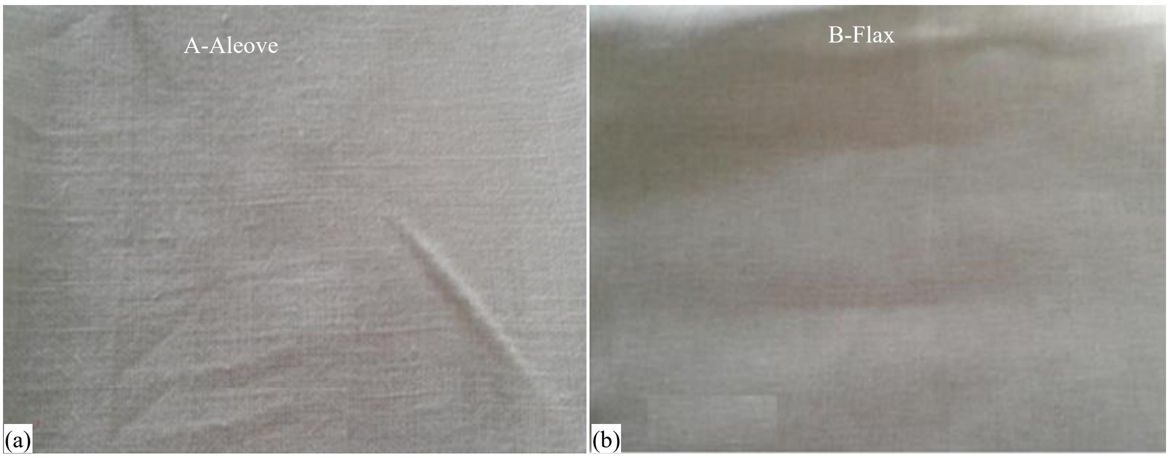

Figure 1. Aloe vera and flax material for composite preparation.

The preparations were done with care to ensure that the dimensions were uniform and that there is no destruction of surfaces. Several specimens were taken on each laminate to generate uniformity of results. Figure 2 illustrates the exemplary Aloe vera/flax hybrid composite test samples prior to and following mechanical tests, tensile, flexural, impact, compressive, and hardness samples. The before-testing images demonstrate the consistency of the specimen preparation, and the after-testing images demonstrate the fracture patterns and deformation modes, which were further correlated with SEM analysis.

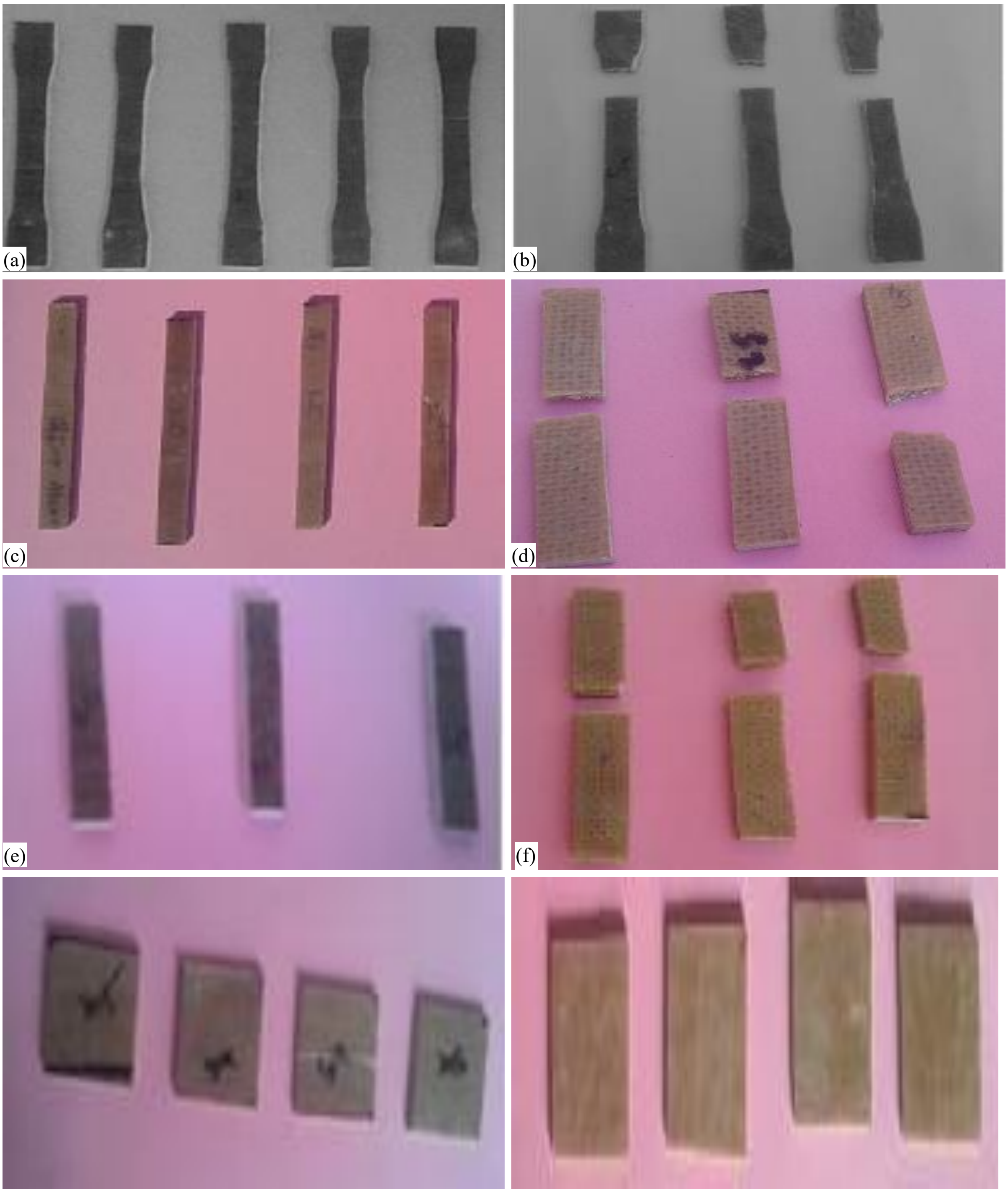

Figure 2. Aloe vera/flax hybrid composite test specimens: (a, c, e, g) before testing and (b, d, f, h) after testing for tensile, flexural, impact, and compression.

RESULT AND DISCUSSION

Tensile Strength

Figure 3 shows the tensile behavior stress of Aloe vera/flax hybrid composite with and without the presence of the filler ($baSO_4$). The findings are that when the filler is added to the composites in the form of $BaSO_4$, tensile strength is greatly enhanced compared to composites of similar composites without a filler. The hybrid composite of Aloe vera/flax with $BaSO_4$ gave an average tensile strength of approximately 40 N/mm^2 which is greater compared to the non-filled composites whose tensile strength was reported as 29-31 N/mm^2. This improvement would be explained by the fact that the stress transfer between the fibers and matrix is better due to the introduction of $BaSO_4$ filler particles that limit crack propagation and give extra stiffness. Regarding the yield stress, Samples 2 and 3 had the highest yield stress of approximately 10 N/mm2, indicating resistance to plastic deformation and Sample 1 had the highest breaking stress of approximately 9.5 N/mm^2. These results support the fact that the hybridization of Aloe vera, flax fibers along with fillers enhance the strength and fracture protection of the composite material. The research side of things confirms that BaSO4 is an effective reinforcing filler to natural fiber composites. The observed improvement can be associated with the previous literature where it was stated that tensile properties of hybrid natural fiber composites could be improved by incorporation of filler [29]. Nevertheless, the differences in performance between the samples also indicate the dependency of processing parameters, i.e. distribution of resin and void formation, on the ultimate mechanical properties of hand lay-up composites.

Impact Energy

Figure 4 presents the effect of the energy values of the Aloe vera/flax hybrid composites in the presence and absence of $BaSO_4$ filler.

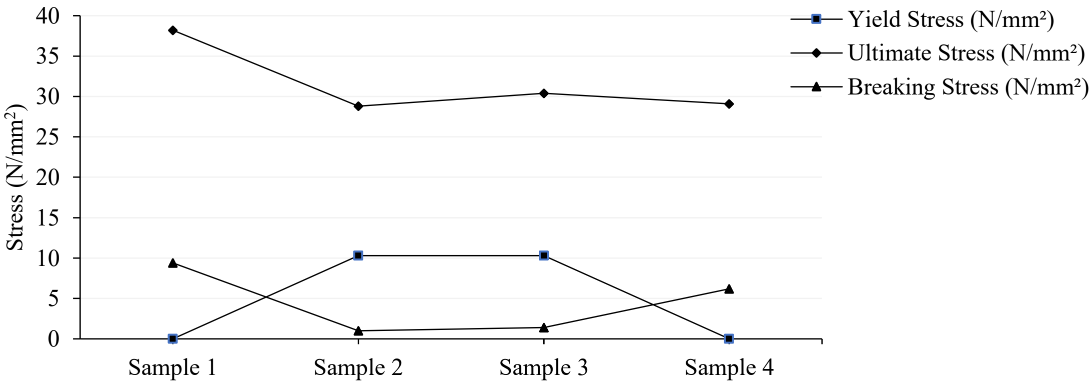

Figure 3. Tensile stress comparison of Aloe vera/flax hybrid composites.

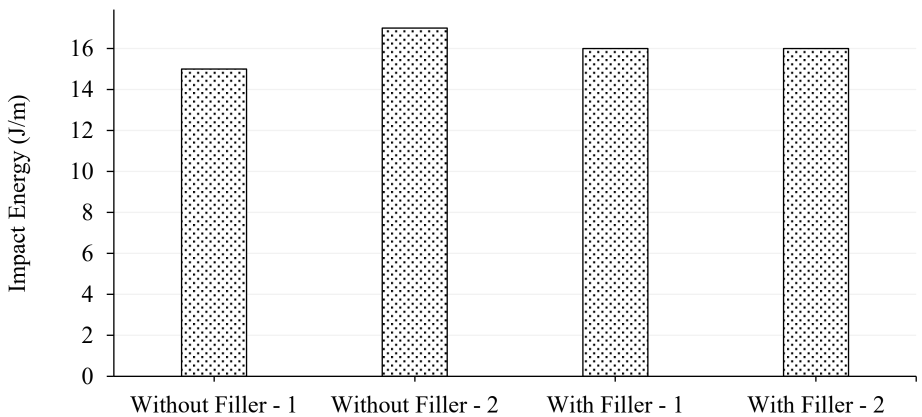

Figure 4. Impact energy of Aloe vera/flax hybrid composites with and without $BaSO_4$ filler.

The findings show that the composites have similar impact strength of 15–17 J/m with slight variations noticed between the filler and non-filler samples. In research terms this implies that the incorporation of $BaSO_4$ has no real effect on the energy absorption capabilities of the composites. In natural fiber composites, the effect strength is usually controlled by fiber pull-out, matrix cracking and interfacial bonding as opposed to filler content. Thus, filler improves static strength properties, but strongly reduces impact resistance, as previous research on hybrid natural fiber composites has indicated.

Flexural Strength

The flexural strength outcomes, as shown in Figure 5, indicate an evident enhancement with the introduction of filler, i.e. $BaSO_4$. The Aloe vera/flax filler composite composite yielded up to 130.67 N/mm^2, which is in contrast to 93.24 N/mm^2 of the non-filled composite. This improvement is credited to the fact that the filler provides greater stiffness contributing to resistance to bending stresses. In terms of research, this finding justifies the presence of fillers to strengthen the matrix and enhance load transfer among fiber and resin. It also notes the possibility of Aloe vera/flax hybrid composites with filler as green alternative to glass fiber composites in applications where flexural rigidity is important such as automotive interior panels and lightweight structural parts.

Compressive Strength

The compressive strength of the hybrid composites is presented in Figure 6. With addition of $BaSO_4$ filler, there observed is a significant improvement with the value reaching around 338-343 N/mm^2 (without filler) and then 369–392 N/mm^2 (with filler). This means that the filler particles contribute greatly to the prevention of the localized deformation and prior buckling of compressive loads. In terms of research, the compressive strength gain is an indication that $BaSO_4$ is reinforcing the epoxy matrix and thus the filled composites are better suited to compressive stresses. This type of performance enhancement is especially applicable to the automotive and construction sectors where compressive loading conditions are common to composites.

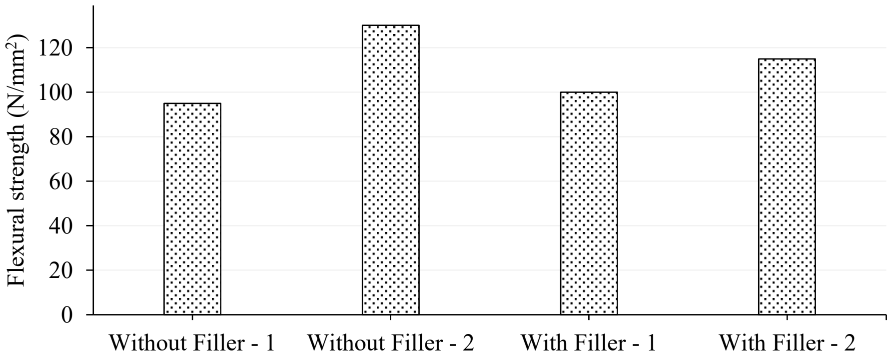

Figure 5. Flexural strength of Aloe vera/flax hybrid composites with and without $BaSO_4$ filler.

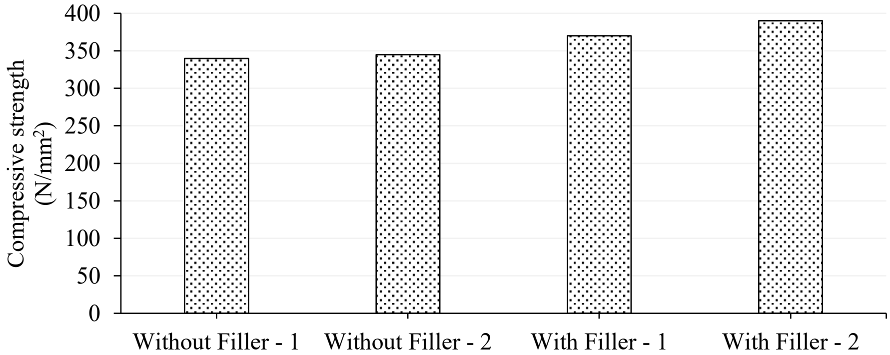

Figure 6. Compressive strength of Aloe vera/flax hybrid composites with and without $BaSO_4$ filler.

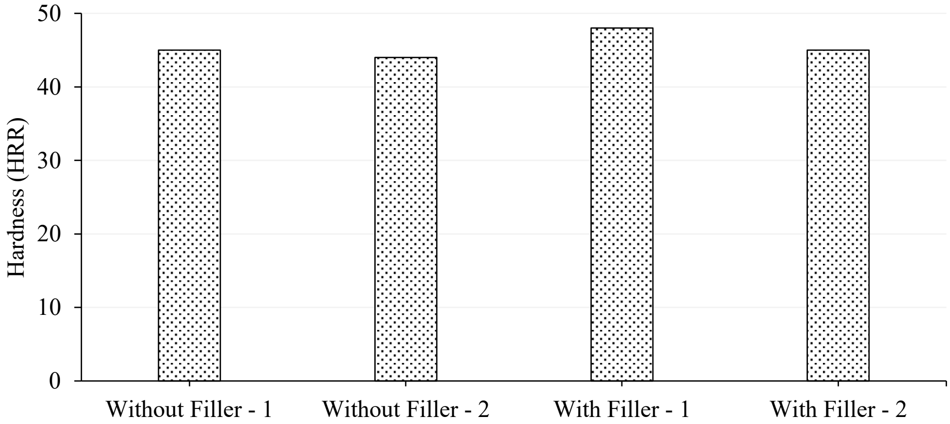

Figure 7. Hardness of Aloe vera/flax hybrid composites with and without $BaSO_4$ filler.

Hardness

The obtained hardness data is shown in Figure 7, and the overall trend is that the values are quite constant in all the samples with a range of 45–48 HRR. The composites with filler (48 HRR) showed a slight improvement, but the differences were minimal in general. This implies that the hardness is less affected by addition of the filler of $BaSO_4$ and more affected by the resin-fiber interface and the surface density of the composite. As a research perspective, it means that fillers can increase tensile, flexural, and compressive strength but not the hardness of the surface. Yet, steady values of hardness and enhanced other mechanical characteristics prove that the addition of fillers does not affect the surface performance negatively, which is advantageous in practice-based engineering solutions.The increase in mechanical properties of the Aloe vera/flax hybrid composites that are augmented with $BaSO_4$ filler can be described by a higher stress transfer and better interfacial interactions. In fiber-reinforced composites, a good transfer of load between the matrix and the reinforcement fibers is important in enhancing enhanced strength. The filler particles of $BaSO_4$ enhance the rigidity of the epoxy matrix and enhance the distribution of loads on the fiber-matrix interface. The particles fill micro-voids in the matrix and serve as bridging components and, thus, minimize stress concentration locations and avoid early crack initiation. In addition, the filler also improves the fiber-matrix bonding through mechanical interlocking and enhancing the bond at the interface. The alkali-treated fibers offer a rough surface and also addition of $BaSO_4$ also helps to strengthen the interface by enhancing resin packing and interfacial gaps. Consequently, fiber pull-out is reduced, and an enhanced stress transfer is achieved under tensile and flexural loads. In compressive loading, the filler particles become rigid and inhibit localized deformation and postpones buckling or failure of the matrix. This adds to the compressive strength increase that is seen. Also, the presence of $BaSO_4$ particles prevents crack propagation by breaking the paths of the cracks and absorbing energy, thus increasing the overall structural integrity of the composite.

SEM Analysis

SEM micrographs of Aloe vera/flax composite without filler $BaSO_4$ (Figure 8a &8b) show that the composite had significant fiber pull-out and voids, as well as low adhesion between the fiber and the matrix. Figure A shows discrete spaces between the resin and the fiber, which means that the interfacial bonds are not very strong. These flaws serve as points of concentration of stress as micro-cracks get initiated which spread readily under loading. Figure B emphasises matrix cracking and partial fibre pull out that indicates that fibers were not wet enough in the hand layup process. It is these structural weaknesses, which are the major cause of the comparatively lower tensile, flexural and compressive strength values obtained in the non-filled composites. As a research observation, such observations confirm the fact that low interfacial bonding minimizes the transfer of stress and therefore limits the overall performance of the hybrid material.

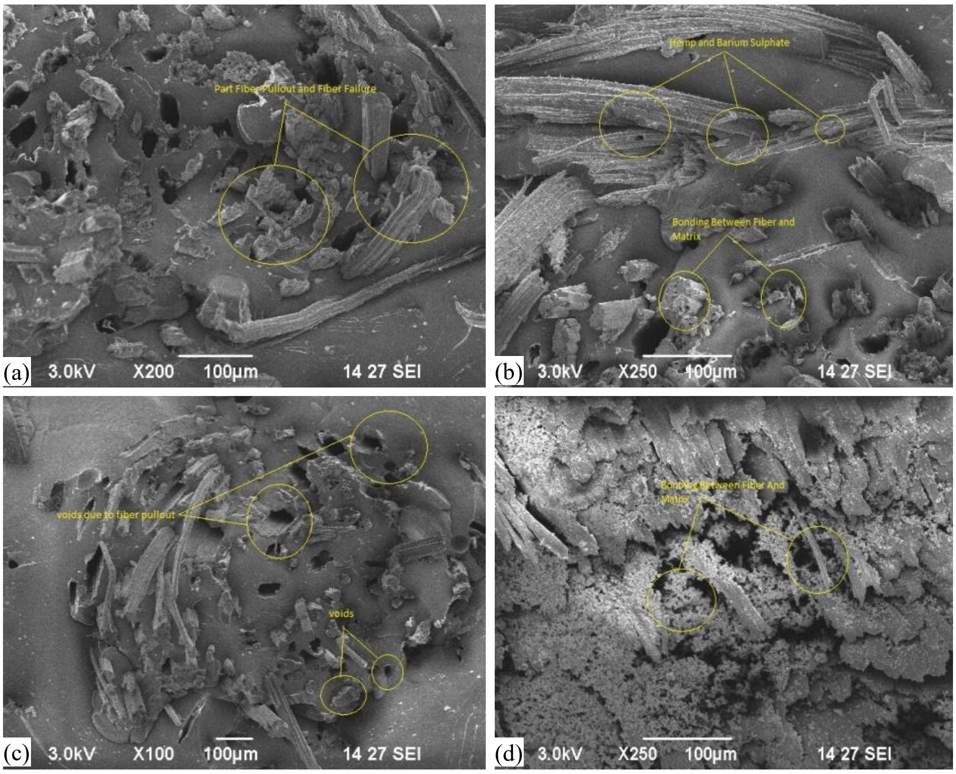

Figure 8. SEM micrographs of Aloe vera/flax composites: (a), (b) without $BaSO_4$ filler showing fiber pull-out, voids, and matrix cracking; (c),(d) with $BaSO_4$ filler showing reduced voids and improved fiber-matrix bonding.

Conversely, micrographs of SEM of the Aloe vera/flax filler composites with $BaSO_4$ filler Figure 8(c) and 8(d) indicate significant enhancement of the microstructural integrity. Figure C shows a reduced number of voids whereby filler particles have successfully occupied micro-gaps in the matrix thus limiting areas of crack initiation. The existence of the filler also makes fiber pull-out less dominant as more mechanical interlocking of the fiber and the matrix occurs. Figure D also shows the results of better bonding at the interface of the fiber and the matrix, where the filler increases the resin packing and suppresses crack propagation. These characteristics justify the increased tensile strength (approximately 40 N/mm^2), flexural strength (approximately 130 N/mm^2) and compressive strength (approximately 392 N/mm^2) in the filled composites. In research perspective, the findings confirm the use of $BaSO_4$ as a good reinforcement agent which increases interfacial bonding, fiber debonding and mechanical performance.

CONCLUSION

- The hand lay-up method was used to successfully fabricate woven Aloe vera and flax fiber-reinforced epoxy composites with and without the barium sulphate ($BaSO_4$) filler. NaOH alkali treatment enhanced surface properties of fibers and interfacial bonding between fiber and matrix.
- The tensile strength of the composites was greatly enhanced by the addition of $BaSO_4$ filler. This can be attributed to the fact that it has enhanced stress transfer between fiber and matrix, decrease in the void content and enhanced distribution of loads.
- A definite increase in flexural strength was accompanied by addition of filler. This means that the $BaSO_4$ will increase the stiffness and resistance to the bending load and the composite will be more applicable in the applications of structure.
- Filler reinforced composites experienced a significant improvement in compressive strength. The filler particles are used to prevent the localized deformation and slow down failure of compressive loading, consequently enhancing structural stability.

- There was minimal change in impact strength with the addition of filler ($BaSO_4$). This implies that fiber properties and fiber-matrix interaction as opposed to filler content are the key determinants of impact behavior.
- The values of hardness did not show any significant difference among all samples, and only slight improvement was observed in filler-added composites. This implies that the surface hardness does not vary much with the addition of fillers but rather varies with the composition of the matrix and the distribution of fibers.
- SEM analysis showed that there were considerable microstructural enhancements in filler-reinforced composites. The inclusion of $BaSO_4$ minimized the voids, enhanced the fiber-matrix bonding and reduced fiber pull-out as compared to unfilled composites.
- The composites that were not filled had defects like cracking of the matrix, interfacial adhesion and formation of voids that led to poor mechanical performance.
- Improvement in the mechanical properties is largely credited to the better filler-matrix interaction, interfacial bonding, and the stress transfer. $BaSO_4$ particles serve also as crack propagation inhibitors thus enhancing durability.
- The relative analysis shows clearly that the tensile, flexural, and compressive property of $BaSO_4$ filled composites are superior to unfilled composites.
- The new Aloe vera/flax hybrid composites filler with $BaSO_4$ have a good potential in being a sustainable and environmentally friendly substitute to the traditional synthetic composites.
- The Composites are applicable in the automotive interior parts, in light structural parts of the automobile industry as well as in construction materials requiring strength, structural durability, and environmental friendliness.

Future Scope

It is possible to conduct further research to determine the best percentage of filler that is to be used of $BaSO_4$ in order to determine the best performance. Even more can be added by other fillers such as SiC, Al_2O_3 or nano-additives. There can be crossbreeding with other natural or manmade fibers which could lead to multifunctional composites. Research on long-term bases under environmental conditions like moisture and UV conditions and their durability would be of huge importance. Finally, application-oriented studies can verify the usefulness of these sustainable composites in a more experimental manner especially in the automotive and construction sectors.

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