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Synergistic Behavior of Hybrid Polymer Composites Reinforced Using Raw and Chemically Treated Agricultural Residues and Poultry Leftovers

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Abstract: The main motive of this study was to find an auxiliary application of the discarded agricultural remnants and poultry waste. Rice straw and chicken feathers are disposed off as landfills or incinerated causing pollution and environmental threats after their primary consumption. In this study epoxy composites were made using varying proportions of these raw and alkali treated materials. Flexural strength of the composites decreased till 35% fiber loading, followed by an increase. Chicken feather composites showed increased impact strength with fiber addition. Alkali treatment improved the mechanical properties of rice straw composites. Alkali treated chicken feather composites showed better impact strength but no significant change in flexural strength. Hybrid composites explicated enhanced properties both before and after alkali treatment corroborating noteworthy interfacial adhesion and synergistic effect of these fibers as ascertained from SEM images. The study evinced a better option for averting environmental problems by recycling these disposed materials.

Keywords: rice straw; chicken feather; mercerization; hybrid polymer composites; mechanical properties; fractography

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1. Introduction

Natural fibers play a predominant role in the development of sustainable composites and in the movement towards sustainable development goals. Abundant availability with cheap or no cost, less density, less energy requirements for processing are some of the propitious points considered in the selection of natural materials against conventional materials[1- 3]. Biodegradability is a major phenomenon that adds merit to the naturally available materials. The agricultural by-products like wheat straw, rice straw, corn husks, soya bean straw, oat husks and leaves, sugarcane bagasse have been studied as potential fiber sources similar to coir, kenaf, jute, hemp and sisal [4, 5]. Many research groups are meticulously searching for new fiber sources to meet the increasing demand for natural products and to reduce the usage of synthetic fibers produced from petroleum resources. On the other hand, reducing the wastages produced after primary consumption and or exploring an alternative usage for discarded agricultural residues is also on the rise [6]. Of course, this is now important so that any future demand can be easily met.

Stepping towards sustainable goals is not always related to find new materials but lies in judicious use of available materials, even waste or discarded ones through primary or secondary applications or by recycling them [7]. The process of recycling from waste starts with identification of waste, collection, separation, cleaning and using them as per requirements. The present work too focuses on utilizing such a waste in the fabrication of usable fiber reinforced polymer composites.

India's arable land area is approximately 159.7 million hectares (394.6 million acres). This does not include the unaccounted land used for self and local consumption. Indian Council of Agricultural Research (ICAR), India reported that the country generates around 350 million tonnes of agro waste every year. The major agricultural residues include rice straw, paddy straw, husk, leaves, pods, pseudo-stems and sugar bagasse. These wastes are simply dumped and or incinerated causing ecological problems. Agricultural and Processed Food Products Development Authority (APEDA) says that poultry products exports rose to USD 137 million in 2022-23 from USD 71 million compared to previous fiscal. Egg production in India increased to 126.53 billion during 2021-22 according to an official release. This shows that India is rich in livestock and has vast resources of poultry. It was reported that the poultry industry produces 8.5 Billion tons of poultry waste worldwide and India generates poultry waste of 3.3 million tons annually which is valued as USD 28.13 Billion in 2023 and is expected to reach USD 44.97 Billion by 2032 due to booming livestock sector [8]. Environmental Assessment reports that India ranks fourth in the Mismanaged Waste Index (MWI) with 98.55 per cent of generated waste being mismanaged. This shows the pervasive nature of the problem and the huge potential left for exploration. Based on this scenario, the discarded wastes namely rice straw and chicken feather are considered as the subject of this present study.

Oriza sativa L. commonly called as Rice is one of the primary foods for Asians and in particular Indian subcontinent, the second largest producer of rice globally. Harvesting of rice produces residue called rice husk and rice straw which are used as cattle feed, making domestic shelters, fuel etc. Other uses include pulp and papermaking, production of bio-fuels and activated carbon [9]. Fabrication of chip boards, furniture and medium density boards are some of the other commercial applications of straw fibers [10]. As per a report, about 45 - 60% of rice straw is incinerated causing pollution and the remaining is used for the above mentioned applications [9]. The applications of straw now expand and since they do not cause any harm to the environment during and after use, they may be considered as sustainable materials. Previous studies show that fibers can be extracted from rice straw. Rice straw contains cellulose (30- 36%), hemicellulose (19 – 32%), lignin (28 – 30) and Silicon (5.5%) [11]. Many studies have reported the use of these fibers in the manufacture of fiber reinforced composites [8-10].

In addition to the plants, animals too remain as a source of fiber. Wool and silk are some traditionally used fiber materials obtained from animals. Chicken, ducks, guinea fowls and geese are some sources of avian fibers [11, 12]. Chicken feather were found to contain 92% keratin, 7% water and 1% lipid. Keratin is a complex protein structure with rachis, and quill [13, 14]. Chicken feathers possess very low density as compared to synthetic and other natural fibers. Also, they are non-abrasive, hydrophobic with high thermal and sound insulating capacity [15]. The morphological structure of the chicken feather fibers shows that it consists of many voids resembling the lumen or lacuna present in the plant fibers [15]. Chicken feathers are the wastes produced in poultry farm and according to a study 10% weight of a chicken is occupied by its feathers [11, 12]. They are to be disposed off without any damage to the environment. Typically, they are burnt or thrown off as garbage in some dilapidated areas causing pollution and environmental damage affecting mankind and other living things [16, 17]. At this juncture, it would be imperative in transforming these wastes into some useful products. It would not only tackle the environmental issue to a certain extent, but also will be a source of income for villagers.

A proper mechanism need to be devised so that these enormous wastes do not cause any problem to the environment, if not they would affect both the underground water and land. Effective utilization of these resources can surely improve the socio-economic conditions of peasants and rural masses. From the view point of engineers, materials need to be replaced and refined to suit a variety of applications. The search for new materials is never ending and novel applications of prevalent materials are being found and tested. The use of fiber reinforced polymer composites are increasing and natural fibers reinforced composites are gaining momentum due to their positive aspects like light weight, bio-degradability and cost-effective nature. Keeping this scope and the available resources in hand, this study was conducted.

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The objective of this present study was to disclose an auxiliary application of waste agricultural remnants and poultry litter by converting them into value added materials. Polymer composites were made using epoxy resin and varying vol% (5, 15, 25, 35 and 45%) of rice straw fibers and chicken feather fibers. The influence of these fibers on the flexural and impact strength of the composites and the effect of hybridization of these materials was studied. In addition, the effect of mercerization of these fibers and their implication on the flexural and impact strength of the composites was also studied.

2. Materials and Methods

2.1. Materials

Rice straws were collected from the rice producing region in the outskirts of Madurai city, India. They are the agricultural remains that are generally regarded as waste and left off after harvest. Fibers were taken from them. Chicken feather fibers were collected from a waste disposal site in a rural area near Madurai city, India. These chicken feather fibers contain rachis, barbs and after feathers. They were found in different colors and belong to different chicken of different age group. Rice straw fibers and chicken feather fibers were initially washed with tap water to remove dirt and other impurities and were left to dry at room temperature for 48 hours. Then these raw fibers were used for the composite preparation. In order to find the influence of alkali treatment, the fibers were soaked in NaOH of 6% concentration for 1 hour at room temperature. Later, the fibers were thoroughly washed again and again multiple times with tap water followed by distilled water and then dried at room temperature. Chemical treatment was done to enhance the interfacial adhesion between reinforcements and the resin in the composite system [18]. Epoxy resin (LY556) along with a hardener (HY 951) was used for the fabrication of the composites using varying proportion of the fibers collected. All the chemicals were obtained from GVR Enterprises (India), Madurai and used as specified without any modifications. Figure 1 shows the sample of rice straw and the chicken feather collected, washed and dried for this study.

Figure 1. Rice straw and chicken feather samples.

2.2. Composites Preparation

Dried rice straw fibers and chicken feather fibers were used for the preparation o composite samples. The rice straw fibers were longer than the chicken feather fibers. They were made uniform after cutting them manually to a size of about 15-25 mm length. Short fibers were used without cutting. Required quantity of matrix, fibers and hardener were taken and the samples were prepared using hand layup technique as found in literature deploying a wooden mould of 150 x 150 x 3mm size [18]. Composite samples were prepared separately with rice straw feathers and chicken feather fibers. Fiber loadings were kept as 5%, 15%, 25%, 35% and 45% by volume proportion to matrix. The chicken feathers were too soft and torturous, unlike rice straw fibers making them quite difficult to place in mould. Hence the fibers were impregnated in the matrix and fabrication was done. This led to improved dispersion and averted formation of weak bonding. Equal volume proportion of rice

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straw fibers and chicken feather fibers in respective quantities were taken for preparing hybrid composites. The constituents of the composite system were thoroughly mixed to avoid agglomeration. Samples were fabricated and cured. The samples were carefully taken from the mould post curing. The samples were cut into required sizes for conducting the mechanical tests. Likewise, the alkali treated fiber reinforced composites samples too were fabricated.

2.3. Flexural Test

Flexural test was done on the samples as per ASTM D790 standards using three point bending method at a temperature of 25±°C and an average relative humidity of 50% at a cross head speed of 5mm/min. The test was continued until the specimen fractured and broke. In each case, five samples were tested and the average is reported for consistency.

2.4. Impact Test

Impact testing of the samples was done as per ASTM D256 standards. Samples were first loaded in the machine and test was conducted until the pendulum hit and broke the specimen. The energy required to break the specimen was measured. Five un-notched specimens were tested for each combination and the average is reported.

2.5. Morphological Analysis

Morphological analysis of the fractured composite samples was done using Scanning Electron Microscope (VEGA 3 TESCAN) with 30kV electron beam. The reason for the failure of the samples, the fiber compatibility with matrix and the fiber-fiber compatibility were observed. The fractured samples were sputtered with gold before observation.

3. Results and Discussion

The flexural and impact strength of the composites reinforced using varying volume proportions of the rice straw and chicken feather fibers is discussed here.

3.1. Rice Straw Composites

3.1.1. Flexural Strength

The flexural strength of 5% raw rice straw fibers loaded composites showed a flexural strength of 39.8 MPa. The flexural strength of the resin without any fibers (neat resin) was found as 40MPa. This shows a slight decrease in the flexural strength of the rice straw composites. When the fiber loading was increased to 15l%, the flexural strength was 36.7MPa which was again lower than the neat composite. This is concomitant to the flexural strength of the fiber reinforced polyester composite reported by Zhu et al. [19]. Increase in fiber to fiber interaction and dispersion problems may be the cause for decreasing flexural strength at high fiber loading. Further fiber loading resulted gradual decrease in the flexural strength of the composites and a minimum flexural strength of 32.2 MPa was obtained for 35% fiber loading. Thus, it is obvious from the results obtained, that the flexural strength decreases with increase in rice straw fibers in the composite system. This behaviour is similar to the previously published reports using coir fibers [20]. Similar kind of report was published with respect to the tensile property of the hybrid composites [21].This initial lowering of flexural strength than that of resin is in accordance with the rule of mixtures, i.e. when the volume fraction of the reinforcing fibers is lower than the critical quantity, the fibers act as flaws in the matrix [22]. Generally, the addition of fibers was reported to produce an increase in flexural strength and was attributed to the increase in the bending strength provided by the cellulose content in the fibers as reported by many researchers [16, 22-24]. But in this case, the fibers with their ends act as stress concentrating regions and are susceptible to failure quiet easily than the control composites. Hence, addition of more fibers produced more flaws and they failed at low loads. However, the trend was seen to reverse, as the flexural strength increased to 45.4MPa for 45% fiber loading. This shows that

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atleast 35% rice straw fibers is needed to reinforce and enhance the flexural strength of the composites. At this fiber loading, the stress transfer was relatively more effective as compared to less fiber loadings.

Fibers treated with NaOH too exemplified the same flexural behaviour of untreated rice straw reinforced composites. Albeit, the surface treatment of the fibers improved the flexural properties of the composites and maximum flexural strength of 51.6MPa was obtained with 45% of mercerized rice straw fibers. When compared to the flexural strength obtained by control composite this is 29% more and also it is 44% more than the untreated rice straw fiber reinforced composites. The treatment reduced the tendency of forming weak hydrogen bonds [25]. Also, untreated rice straw fibers contain a thin waxy layer on their surface and the increase in flexural strength may be related to the removal of this waxy layer resulting in a rough surface. This rough surface would have assisted in maintaining an inextricable bonding with the matrix for effective stress transfer [26]. Figure 2 shows the flexural strength of the rice straw composites with and without mercerization.

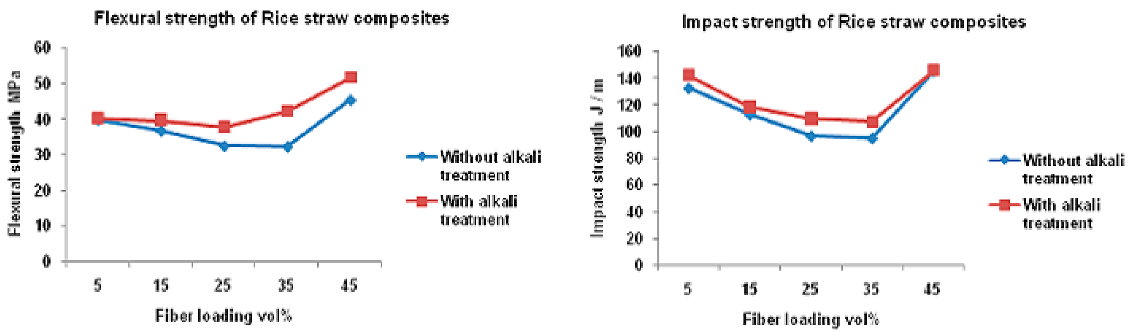

Figure 2. Flexural and Impact strength of rice straw reinforced composites.

3.1.2. Impact Strength

As seen in the Figure 2, the impact behaviour of the rice straw fiber composites showed a decreasing trend on fiber loading in accordance with previous study [27]. The impact strength of the 5% rice straw fibers reinforced composites was 132.4 J/m, while the impact strength of 15% rice straw fiber reinforced composite was 112.6 J/m. This decreasing trend continued till 35% fiber loading for an impact strength value of 94.8MPa, after which the value abruptly increased to 145.2 J/m for 45% fiber loading. The hydroxyl groups in the surface of rice straw along with their propensity to form hydrogen bonds with hydrophilic fibers show less compatibility with matrices. This is the limitation of rice straw fibers resulting in less impact strength [28, 29]. The increase in impact strength at higher fiber loading may be due to the effective stress transfer assisted by fibers. The fibers would have absorbed more energy during the impact.

The impact strength of the alkali treated rice straw composites was 142.4 J/m for 5% fiber loading. This value is slightly higher than the raw fibers and is because of the removal of the waxy layer present in the rice straw surface. The impact strength values declined on further fiber loading to produce minimum impact strength of 107.4 J/m for 35% fiber loading. This is similar to the impact strength of untreated fibers composites reported in this study and as found in literature [30]. Maximum impact strength of 145.8 J/m was obtained for 45% fibers loaded composites. However, no significant improvement in impact strength was noticed, since the impact strength of composites before and after treatment was more or less same. The properties of rice straw do not vary significantly and hence no change in the trend was observed after mercerization.

3.2. Chicken Feather Composites

3.2.1. Flexural Strength

In case of chicken feather fibers too, the flexural strength values decreased with fiber loading.

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This is in accordance with the results reported by Uzan et al. on the flexural strength of chicken feather fiber reinforced composites [31] On the other hand, this is contrary to the flexural strength of propylene based ground chicken quill filled composites which was reported to increase with increasing chicken quill [32]. In this study, maximum flexural strength of 34.6MPa was obtained for 5% fiber loading and minimum flexural strength obtained was 28.6.8MPa for 35% fiber loading. Finally, the flexural strength value increased to 36.2MPa for 45% fiber loading. This improvement in the flexural strength at 45% fiber loading is in agreement with the previously published literature [31]. This shows that a minimum amount of fiber is essential to buttress the matrix. This may be called as threshold limit and in this study, the minimum amount of fiber required to strengthen the matrix lies between 35% and 45%. When the fiber volume is inadequate, large stresses will be developed and the stress distribution will not be uniform. When the amount of fiber attains the threshold value, the stress distribution becomes uniform resulting in better bending strength. In case of chicken feathers, it is interesting to note that differences exist between the distal region and proximal region of the feathers and as a result, differences exist in the physical properties of same feathers. This is reflected in the flexural strength of the composites. [33].

The surface treatment on the chicken feather fibers showed no significant changes on the flexural strength of the composites. The flexural strength of 5% alkali treated chicken feather fiber reinforced composites exhibited 36.7MPa as compared to raw fibers reinforced composites which was 34.6MPa. The bending strength value slightly declined to 36.2MPa for 15% alkali treated composites and on further fiber loading (25 - 45%) the values ranged between 37.1MPa and 37.5MPa with no considerable change in the flexural behaviour. This showed that alkali treatment was not that much effective in improving the flexural behaviour of the chicken feathers reinforced composites. It may be due to the following reasons. The fibers have not been restrained by the matrix to allow sufficient stress transfer and also the physical properties of the feathers collected from different feather tracts of same species too differ due to the disparity between proximal and distal ends due to the fiber architecture [34]. Moreover, presence of voids might have also affected the performance of the composites and the distribution of the fibers in the composite system controls the strength of the composites [35]. Figure 3 shows the flexural strength of untreated and treated chicken feathers reinforced composites.

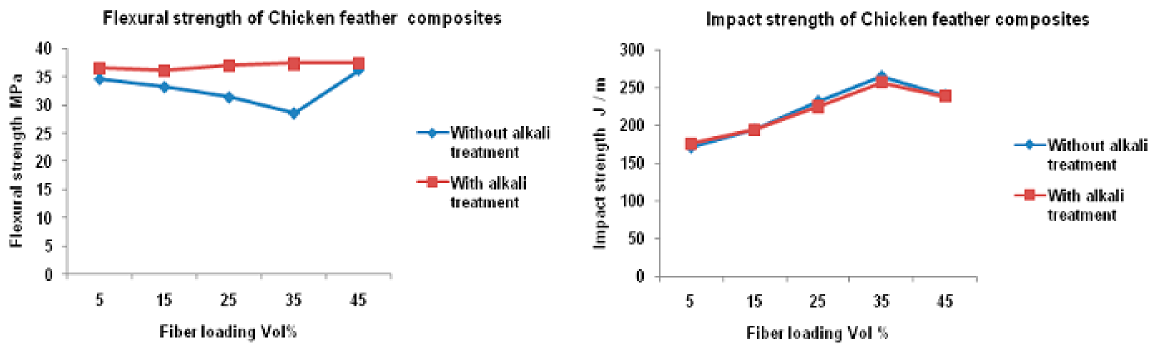

Figure 3. Flexural and impact strength of chicken feather reinforced composites.

3.2.2. Impact Strength

In case of chicken feather fiber reinforced composites, the impact strength increased from 170.8 J/m for 5% fiber loading to 232.4 J/m for 25% fiber loading exemplifying that impact strength is in linear relationship with fiber loading. The composites exhibited a maximum value of 265.4 J/m at 35% fiber loading which is 55% more than 5% fiber loading. However, the impact strength reduced to 240.3 J/m for 45% fiber loading. It was due to the higher fiber content that caused fiber-fiber interaction with less matrix content to restrain them. Increase in fiber loading may cause local fiber agglomeration. Agglomeration mitigates the adhesion and coupling mechanism between the matrix and the reinforcements, capitulating less impact strength [36]. This shows that 45% increase in fibers

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produce 41% improvement in the impact strength. This shows that chicken feather fibers constitute to high impact strength.

The impact strength of the alkali treated chicken feather fibers reinforced composites produced increase in impact strength with increasing fiber content [37]. The increasing trend continued till 35% fiber loading to produce impact strength of 256.4 J/m. The impact strength values are more or less quite similar to the raw fiber reinforced composites exemplifying that alkali treatment is not much effective to produce increased mechanical strength to the fibers and composites. This is similar to the results obtained for flexural strength. Figure 3 portrays the impact strength of chicken feather composites.

3.3. Hybrid Composites

3.3.1. Flexural Strength

The hybrid composites made using rice straw and chicken feather showed a linearly increasing trend of flexural values on fiber loading. The hybrid composites with 95% epoxy resin, 2.5% rice straw fibers and 2.5% chicken feather fibers exhibited a flexural strength of 12.5MPa and this value increased more than three times to 45.6MPa for hybrid composites containing 65% resin with 17.5% rice straw fibers and 17.5% chicken feathers. Increase in flexural strength values is mainly because of the reinforcing effect produced by the fibers [21, 23, 35]. Maximum flexural strength of 45.6MPa was obtained for 35% fiber loading which is similar to the results reported in literature [38]. At 45% fiber loading, the matrix was unable to wet the rice straw and chicken feather fibers and the flexural strength dropped to 44.8MPa owing to the weak interfacial adhesion and fiber-fiber interaction.

In the case of alkali treated hybrid fibers reinforced, the flexural strength rose 118% to 27.2MPa as against the untreated fibers which exhibited 12.5MPa. This enhancement may be due to the removal of non-crystalline contents and waxy layers on the rice straw after mercerization [39, 40]. The values increased with higher fiber loading and maximum flexural strength was observed for 45% fiber loading. However the difference between flexural strength values of the raw fibers and treated fibers composites at 45% fiber loading was just 12%. This shows that fiber content in also relatively more effective than surface treatments at higher proportions. Also at higher proportions, the system was packed up with adequate reinforcement for effective stress transfer and the fibers were compatible with one another. Mercerized fibers are rough with matrix particles attached to it explicating more adhesion than untreated fibers [40]. Figure 4 shows the flexural strength of hybrid composites.

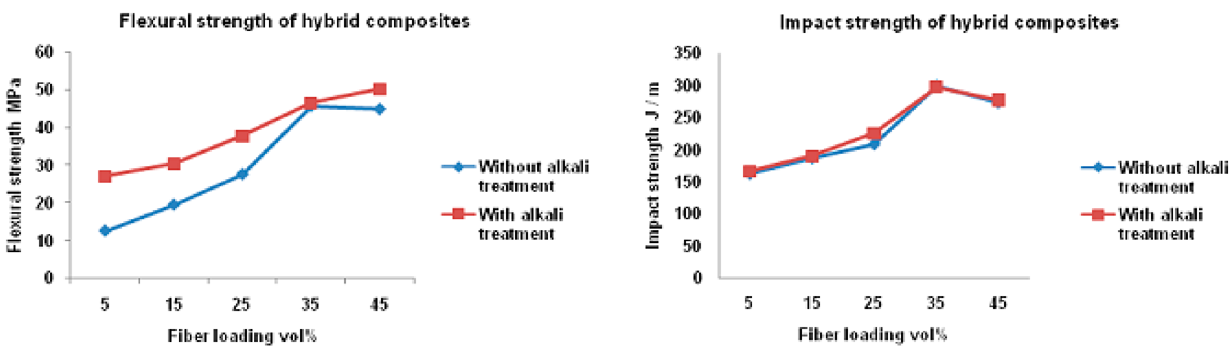

Figure 4. Flexural and impact strength of hybrid composites.

3.3.2. Impact Strength

In case of hybrid composites, increasing impact strength observed was similar to the chicken feather composites. The impact strength of 5% fibers loaded hybrid composite was 162.3 J/m with increase in impact strength for increase in rice straw and chicken feather fibers. Maximum impact strength of 298.8 J/m was obtained for 35% fiber loading followed by a slight decline in impact strength of 272.6 J/m for 45% fiber loading. Results obtained showed that hybridization of rice straw and chicken feather produced a positive effect on the impact strength. The reinforcements in the composite system obstruct dislocations and controls plastic deformation resulting in enhanced mechanical strength [41]. When fiber content was increased, there was weak interfacial adhesion between rice straw/ chicken feather fiber and matrix. In another similar research on hybridization, impact strength of 314 J/m was obtained with 40% fiber loading, agreeing with this study [41]. This shows that optimum fiber content of 35 - 45% is needed for enhanced mechanical properties of the composites.

Hybrid composites reinforced with alkali treated fibers exemplified increasing impact strength on fiber loading with the impact values more than the raw fibers reinforced hybrid composites. This is due to the breaking up of hydroxyl linkages after mercerization resulting in increased surface area for better bonding [42]. Maximum and minimum impact strength values obtained were 166.4 J/m and 296.6J/m respectively for 5% and 35% fiber addition. The impact value decreased at 45% fiber loading and it was due to the weak interfacial adhesion between reinforcement - matrix and local fiber agglomerations. At higher fiber loadings, the raw fibers were able to produce marginally higher impact strength than alkali treated composites. Comparing with the rice straw composites and chicken feather fiber composites the hybrid fibers were able to produce more flexural strength and impact strength. Improved compatibility was found between the plant and animal fibers resulting in improved mechanical strength of the composites. At higher fiber loadings, the fibers stacked within the matrix and reinforced it resulting in more strength. This is evident from the images of fractured specimens [17, 43]. This shows the synergy and the worth mentioning interfacial adhesion between rice straw and chicken feathers. Figure 4 displays the impact strength of hybrid composites.

3.4. Morphological Analysis

The SEM analysis of the fractured composite samples was performed to analyze the morphology and the distribution of the rice straw and chicken feather in the matrix. The SEM image shown in Figure 5a of the fractured sample reinforced with rice straw fibers displays that the fibers are detached from the matrix on external loading forming a valley. Hence effective stress transfer did not take place from matrix to fibers. The rice straw fibers possess a thin waxy layer on its surface which forms weak interfacial adhesion with the matrix. This is the main reason for the detachment of the fibers causing failure to the composites and is evinced from the image showing conventional mode of failure [21, 44]. In case of mercerized rice straw fibers reinforced composites, the waxy layer on the fiber surface was removed as discussed previously exposing the rough serrated surface formed due to the adhesion between matrix and fiber [33, 34]. Also, this adhesion is strong enough producing fiber breakage and is clearly visible from the image shown in Figure 5b.

Chicken feather fibers reinforced composites show that the fibers are completely restrained in matrix with very few fibers exposing their surface as shown in Figure 5c. The polymerization reaction took place by forming a dense three dimensional polymer chain with the added fibers [24]. Fiber rachis is seen on the surface of the matrix and the fibers not restrained by resin is also sparing seen. In case of alkali treated chicken feather fibers composites, the fibers and matrix produce a good interfacial adhesion between them. Alkali treated feathers exhibit a stiff nature after mercerization with their fibers losing their soft texture. Some voids are visible in the fractured surface of the composites as shown in Figure 5d [39, 40].

In the hybrid composite samples, both the rice straw fibers and the chicken feather fibers (shown within circles) are embedded in the resin as seen in Figure 5e. Compatibility between the rice straw fibers and the chicken feather fibers in the composite system is worthy resulting in effective stress transfer from the matrix to the fibers [45]. No fiber pullouts or voids could be seen in the fractured samples. The SEM image of the mercerized rice straw and chicken feather fibers reinforced composites show resin covered fiber ends evincing their noteworthy interfacial adhesion [40]. The chicken feather fibers were seen to be mingled with rice straw fibers proving their inter-compatibility. This is shown in the Figure 5f enclosed within circle. This synergistic behaviour is responsible for the effective stress transfer and enhanced mechanical strength of the hybrid composites [23, 41].

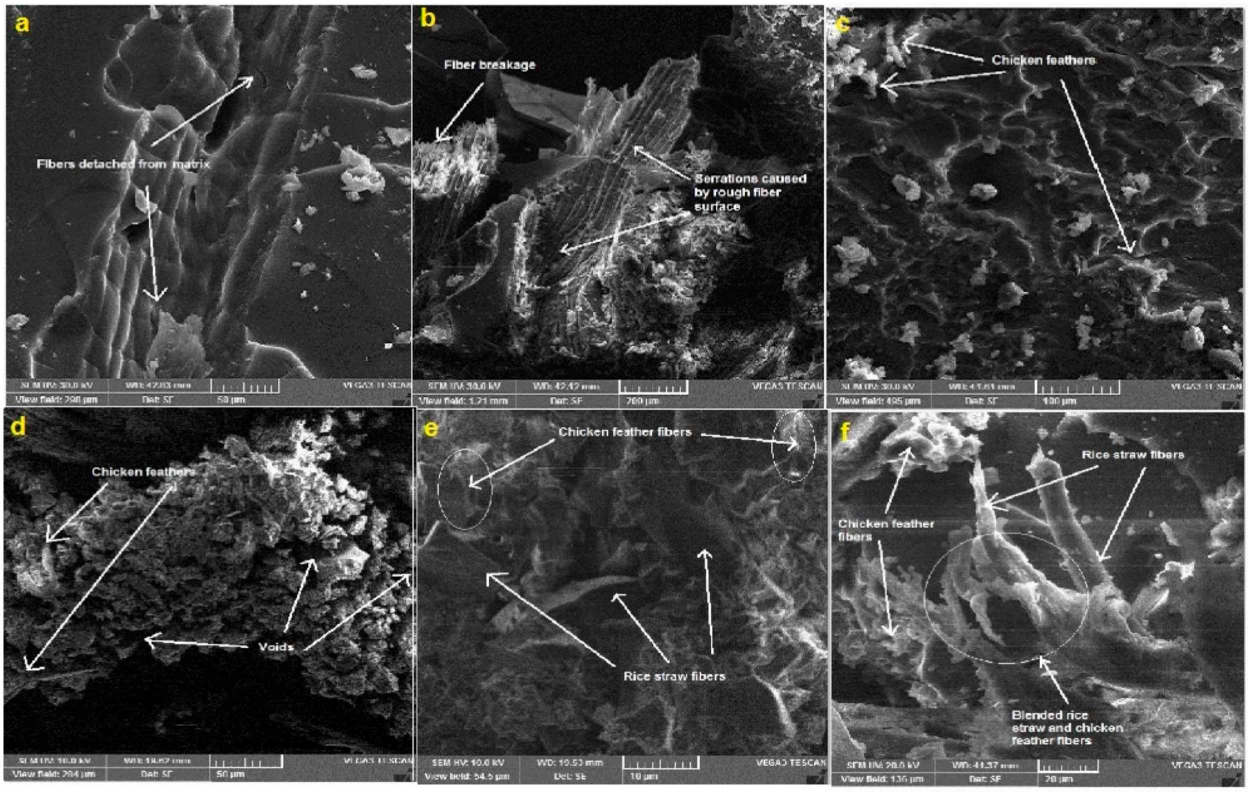

Figure 5. (a-f) SEM images of fractured composite samples.

The study thus ascertained that discarded rice straw and thrown off chicken feather can be turned into usable polymeric reinforcements for making fiber reinforced composites. They can be utilized for making automobile spare parts, boat hulls, furniture, panels, fiberboards, tubs, boxes, light weight structural components, storage tanks, ducts etc. This can reduce the MWI and can foster the socio-economic condition of rural masses and at the same time they can mitigate the ill-effects caused by dumping and blazing of these discarded materials.

4. Conclusions

In this study, naturally available waste rice straw and chicken feathers were tested for their plausibility to be turned into usable reinforcements for polymer matrices. Experimental studies confirmed the reinforcing viability of these so-called waste materials through the flexural and impact tests conducted on the composites fabricated with varying proportions of these aforementioned materials. These discarded resources can be conserved and recycled for a better use that can lead to reduced MWI.

The following conclusions were derived from the study.

1. The flexural strength of the rice straw and chicken feather fibers decreased on fiber loading till 35%, while on the contrary, the hybrid composites showed improved flexural strength with fiber loading.
2. The impact strengths of the rice straw fibers reinforced composites decreased on fiber loading, whereas the impact strength of both the chicken feather and the hybrid composites showed increase with in fiber loading exhibiting maximum impact values of 265.4 J/m and 298.8 J/m respectively.
3. Improvement in flexural strength and impact strength of the composites was noticed after surface treatment of the fibers using NaOH owing to the removal of waxy layer on the rice straw. No significant change in the flexural strength of the chicken feather composites was seen with

fiber loading where as marginal improvement in impact strength of the chicken feather composites was seen post treatment.

4. Hybrid composites pronounced enhanced flexural strength with treated fibers than raw fibers, while only a marginal increase in impact strength was found after mercerization. Hybridization of the fibers was compatible with one another resulting in synergistic effect on the mechanical properties of the composites.

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