Review Article

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Rice husk as a fibre in composites: A review

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Abstract: In the last decade due to ever growing environmental concerns, use of natural fibres as fibre materials has gained momentum and acceptance. Natural fibres provide advantage of being economical and environment friendly at the same time. Rice husk, an agricultural waste is being utilized as a natural fibre for development of biocomposites. Present paper attempts to understand the applicability of rice husk as a fibre with various polymers based on the recent research works. It also throws light on various modification techniques that can further enhance the associated mechanical properties by altering the chemical and physical properties of husk. The paper may assist in understanding the phenomenon associated in manufacture of rice husk based bio-composite and provide a critical insight to the future applications of rice husk.

Keywords: rice husk, polymers, treatment

1 Introduction

At the advent of the industrial revolution, there were very few materials that we as humans were using but as the science and technology developed our need for newer and better materials increased, the quest for which has even not stopped today. The scientific community developed artificial materials called composites. To make them cost-effective the scientific community started to look for materials hitherto considered as waste. Rice husk an abundant agricultural waste fulfils all the above mentioned criteria and as such has been thoroughly used to develop bio-composites.

Rice is the staple crop of India and is produced in copious amount, and the husk produced is mostly used for burning which adds to the already beleaguered state of environmental pollution. It produces rice husk ash which is of graver concern as its disposal is difficult. It is estimated that the production of rice husk worldwide is approximately 759.6 million tons in 2017 [1], of this 22% of this is husk [2] (167.10 million tonnes) which give an enormous amount of virtually free of cost raw material if it can be brought to a good scientific use.

Typically, rice husk can be used in the form of husk itself or the silica derived from it can also be used giving different sets of physical, mechanical properties. Different methods have been proposed by various researchers to produce rice husk ash which would give us different quality of ash which would have different properties.

2 Chemical constituent, structure and properties of rice husk

The chemical constituents are found to vary due to the different geographical conditions, type, weather conditions, chemistry of the soil and manures used in the paddy growth [3–5].

Naturally RH is tough, water insoluble, woody and has abrasive resistance behaviour and silica-cellulose structure. The exterior is mostly silica coated with a thick cuticle and surface hairs, while small amount of silica is present in the mid region and inner epidermis. The various constituents of rice husk are given in the Table 1.

Table 1: Composition of rice husk [6]

| Constituent       | Percentage |
|-------------------|------------|
| Cellulose         | 35         |
| Hemicelluloses    | 25         |
| Lignin            | 20         |
| Crude protein     | 3          |
| Ash               | 17         |

The chemical composition of RH from different regions was analysed and found to have an average composition of 80% organic matter and 20% ash. The chemical analyses of the inorganic part revealed that the main component is amorphous silica and traces of some alkali
oxides, earth metals, aluminium and iron. The last mentioned compounds vary significantly among samples, due different chemical fertilizers being used and also due to the difference in the soil chemistry [6].

3 Utilization of rice husk as filler in composites

The advantages of naturally occurring fibres like their availability, cost, biodegradability, low density, high specific strength have motivated scientific community to try to develop newer materials using these naturally occurring fibres, which also solves the problem of the disposal of the wastes like RH.

Use of polymers in the industries and household activities has been done previously but using RH as filler can improve certain mechanical, thermal, physical properties and at the same time can prove to be economically beneficial. The addition of the fillers can radically change the properties of the polymer and consequentially of the composite.

The properties of the final composite obtained in this way would depend upon several factors that are crucial to the properties of the composite thus developed like particle size, percentage composition, co-efficient of distribution in a matrix, the matrix used [7]. So a particular attention has to be focused on these factors before developing a composite material because using the same matrix and the same filler can result in giving different sets of properties if the conditions mentioned above are varied.

The use of RH as the filler material has been pursued from 1970’s and a lot of work using different type of matrix materials has been done and a lot of literature in this respect is available, below we have tried to arrange the various matrix materials that have been used as matrix with RH and have tried to study the effects of the filler material on the various properties which can be of any use to humans.

The focus of most of the studies has been the mechanical and physical characterization of the composites obtained so as to justify their probable use in future as an alternative material. Various researchers have used different type of matrix materials to obtain composites like polypropylene, polyethylene, resins, natural rubber etc. Besides this efforts have been made to further enhance the properties of these composites by treatment of RH fibres with different techniques (physical as well as chemical) and the results have been quite encouraging, besides this, a number of studies related to the development of hybrid

composites with RH as one of the components have been made, keeping in view this enthusiasm evoked by the scientific community a review has been done on the potential use of RH as a reinforcing agent in different matrices.

4 Mechanical properties

4.1 Tensile properties

The tensile properties which are an important aspect of any composite material mainly depend upon the filler type, matrix material, concentration, size, and dispersion, adhesion between the filler and the matrix material and orientation. Various studies have been conducted on the variation of tensile properties with different filler loadings using a different type of matrix materials from polymer matrices to concrete and tire.

The team from Korea [8] have done extensive studies on RH based polypropylene composites and have published their findings in a series of research papers. It was seen that the higher filler loading levels of RHF had a negative impact on the tensile strength of the composite which was optimum for 10% RH composite (decreased by about 15% for 40% RH, decrease was substantially high compared to pure polypropylene) which occurs due to the interfacial bonding decreasing between filler which is hydrophilic and matrix polymer being hydrophobic. The material became brittle as the filler loading increased since fraction of polymer (thermoplastic) decreased. The result

![Figure 1: Tensile strength of different wt. Compositions of RH](image-url)
of tensile test for different compositions of RH is shown in Figure 1 accompanied by stress strain curve in Figure 2.

In another study comparison was made between PP filled RH and talc composites [9] and the same results were obtained that with increasing content of RH the tensile strength (yield strength) decreased and the brittleness increase with increasing filler loading.

In a different study [10] the same composition of filler and matrix was used and the same results have been obtained and the tensile strength has reduced by around 50% for 40% RH.

A different number of studies concerning the same compositions [11–15] have conclusively proven that the increase in filler loading is detrimental to the tensile strength of the composite obtained.

As far as the Young’s Modulus is concerned there is seen to be an increase in the modulus in all the findings published, this always occurs when rigid fillers are filled in softer polymer matrices. Natural lignocellulosic fillers have elastic modulus higher than PP [16], consequently the rigidity of the resulting composites tends to strongly enhance with addition of fillers. Increase in composites rigidity can also be attributed to the reduction of mobility of polymer chains due to fillers [17]. The change in the Young’s Modulus with RH is shown in Figure 3.

Another polymer used as a matrix for composite manufacturing is polyethylene that has been much used as matrix along with RH as filler material

Some other researchers have also utilised this combination of filler and matrix [18–21].

Two different type of matrix namely recycled low density polyethylene (RPE) and virgin polyethylene (MPE) were observed [22]. They observed that the tensile strength increased first up to 10% RH but thereafter it decreased which can be attributed to the fact that the matrix being hydrophobic cannot adhere well with the hydrophilic fibre (RH in this case), however this effect is not pronounced up to 10% but thereafter its effect is considerable and hence the decrease in tensile strength. The tensile modulus increased with increasing filler content and is significantly improved for 40% RH and becomes almost double. Moreover the performance of MPE was much better as a matrix material the increase in Young’s Modulus can be attributed to the decrease in chain mobility.

Effects of chemical treatment were studied and it was shown that the tensile strength decreases with the increase in filler loading, the decrease was significant for 40% RH [20]. The Young’s Modulus increases with the increase in filler loading. The results of all the papers described above are also the same as has been shown by [17, 19] except for the one study [21] who have also studied the size effect of fillers besides studying the effect of coupling agents. RH particles of 75, 180, 250, 355 and 500 µm were used. They observed that the tensile strength was better for smaller filler size and it decreased with increasing size of the filler material because smaller particles have larger surface area thus providing enhanced load transfer from the PE matrix to the RH phase, but the tensile strength in their study was seen to be increasing with increasing filler loading which is described by the author that rigid silica rich RH particles into the tough PE made the composite stiffer.

Besides these polymer matrices a number of different matrices have been used by various other scientists [22–28] who have used various other matrices ranging from concrete to natural rubber.

Resin derived from Cashew nut shell with RH as filler was studied [29]. They have used different sizes of RH in their study and observed an increase in the tensile strength with decreasing filler size (Figure 4) and also that the increasing filler content increased the tensile strength fur-
The nature of the Young’s Modulus is also exactly same as that for tensile strength (Figure 6). The brittleness of the composite increased with increasing fibre size and the material changed towards being more ductile at higher fibre content (Figure 5).

Unsaturated polyester resin has also been used as the matrix [26] using RH as filler material. It was seen that the tensile strength decreased first up to 20% fibre loading after which it increased which is believed is due to the fillers used where it acted as a flaw at higher filler mass fraction since there were lack of resin which could wet the filler, which also resulted in an inefficient stress transfer, leading to increase in tensile strength followed by slight increase with increasing filler loading. The Young’s Modulus first increased up to 15% and thereafter it decreased.

RH as a filler with concrete was also used [22] and the results have been encouraging the compressive strength, rupture modulus, Young’s modulus and shear strength are seen to be greater than that of conventional concrete and further they increase with increasing RH content however the study has been done for up to 1.5% RH.

In an interesting work [25] composite based on RH-waste tire rubber mixtures was developed. It is concluded in their study that the increasing filler content has the same effect on Young’s Modulus as almost other studies that is it increases, while for the ultimate tensile strength it decreases. It is also to be noted that the composite becomes more and more brittle as the filler loading increases.

The mechanical properties of lignocellulosic fillers along with polypropylene and polyethylene as matrix was studied [26]. The mechanical behaviour was studied and it was observed that the tensile strength reduced with the addition of RH filler for both high and low density polyethylene it being higher for high density polyethylene. The same results were obtained for polypropylene as well.

In yet other interesting study [30] the mechanical properties with respect of using raw, ground and expanded rice husk with polyethylene as a matrix material was investigated. The size of the raw rice husk was 6 mm, that of ground rice husk was 250 µm and that of expanded rice husk (prepared by a proprietary technique) was 35 µm. The expanded rice husk was found to be the most effective in terms of tensile strength followed by ground and raw rice husk, properties for which were comparable. With the increase of filler loading the tensile strength is seen to be increasing but in the meanwhile they were found to be lower than the pure polyethylene. The reason for this trend is that initially the small amount of particulates acted as fillers [31], which instead of reinforcing the polymer by providing proper stress transfer between the polymer and the particles became defects or the stress risers within the
materials, i.e. weakening the composites. As the particle loading increased, the particles were distributed more uniformly within the composites to ensure better stress transfer. In this way the particles started acting as reinforcement rather than just fillers. The better performance of expanded rice husk could be due to smaller particle size of ERH, as the smaller-size particles give a larger total surface area per volume which is beneficial for interfacial bond between the polymer and reinforcing particulates [32].

The Young’s Modulus was better for raw rice husk which is due to the fact that its aspect ratio was much less than those of expanded and ground rice husk [33]. With increasing filler loading the Modulus increased as has been shown in all other studies.

RH with polyurethane (polypropylene glycol) was used to study the effect of percentage of OH hydroxyl groups on the mechanical properties [34]. The OH content is determined by reacting phthalic anhydride with RH in pyridine and is followed by titration with sodium hydroxide. It was seen that as OH group increased tensile strength increased reached maximum at about 60% and thereafter decreased, same was the case for tensile modulus.

Rubber which we have been using now for quite a long time for various purposes has also been used for developing composite with rice husks to enhance its properties. Some of the work with this type of matrix has been published [35, 36].

Two types of rubber namely standard Malaysian natural rubber Grade L (SMR L) and epoxidized natural rubber (ENR 50) was used [36]. Tensile strength was seen to be decreasing with increasing filler loading, decreasing by about 30% for 40% filler loading for both SMR L and ENR 50. This observation may be mainly attributed to the RHP geometry. The irregularly shaped fillers are unable to support stress transferred from the polymer matrix [36] and hence tensile strength decreased. The RHP is hydrophilic, while the rubber is hydrophobic, which also causes the deterioration of the tensile strength with the increment of filler.

The Young’s Modulus increased with increasing filler loading as has been the case with all the other matrix materials whether polypropylene, polyethylene, resins among others. It was found that the elongation at break decreased gradually with an increase in RHP content. The increase in the cross-link density with increasing RHP loading reduces the mobility of the rubber chains, increases the stiffness and brittleness, and subsequently leads to lower resistance to break. The increment in filler content results in the deterioration of deformability of rigid interface between the filler and the rubber matrix [38]. So, it can be seen that the results of modulus also agree well with the elongation at break.

The effect of RH addition on the mechanical properties of epoxy resin was studied for RH particle size of 120 microns [39]. It was observed that the properties improved up to 20% filler level, beyond which there was reduction in mechanical strength due to the tendency of RH agglomerating as is evidenced by SEM images [39].

The effect on the mechanical properties of RH fiber based composite with the fiber concentration and fiber size was also studied [40]. In their investigation, they recorded that better tensile strength was obtained in small size RH fiber based reinforced polyester composites when compared with the categories of medium and larger fiber size.

RH/ epoxy for mechanical properties characterization and performance of machining was studied using three different epoxy/ RH composites were used as husk’s particulate form, hybrid (mixing particulate with equal proportion with full RH), and RH used [41]. Results showed that particulate RH reinforced composites have higher ultimate tensile strength. Young’s modulus is higher for particulate RH reinforced and decreased with an increase in the weight % of RH. Results showed that when RH weight % was increased brittleness of fabrication increased with the reduction in % of elongation.

A high-fiber green composite from the rHPDE / rPET blend matrix and RH as a filler (40 wt% to 80 wt%) was prepared with the help of a co-rotating twin-screw extruder and compression moulding [42]. 16% increment for the tensile strength and 121% increment for the young’s modulus was achieved at 70 wt% of RH filler. The tensile strength of composites increased gradually by increasing RH loading to a maximum value of 22.2 MPa which was obtained at 70 wt%. This is because of enough adhesion, and also better wettability among hydrophilic fiber and non-polar polymer matrix having enough polarized hydrophilic fibers in aid of incorporating coupling agent. In this case, MAPE is promoting an effective distribution of stresses among one another. When the RH was further increased to 80 wt%, the matrix at 20 wt% is not sufficient for wetting the fiber and thus causing fiber agglomerations causing restriction of transfer of stresses. For the high- fiber loading case, the coupling agent lacks to offer an adequate amount of fiber-matrix adhesion and reinforcing effect in the composite of RH fibers. Thus, the tensile strength of the composite is reduced when fiber loading is exceeded by more than 70 wt%.

rHDPE as a matrix and RH was used as a filler material with a mesh size of 212 μm [43] and the morphological examination were done showing that 50 weight % filler
content results in an efficient dissipation of cell having the smallest size of the cell and highest density. Rice Husk has also been used with resin derived from corn starch and the results show an improvement in the tensile strength of bio-composite due to the addition of RH [44].

Poly Lactic acid derived from corn starch has also been a part of study [45]. It was however observed that addition of RH resulted in deterioration of tensile strength which can however be improved by addition of compatibilizing agent like Maleic Anhydride Polyethylene and Maleic Anhydride Ploypropylene [45]. The reason for this decrease in tensile strength with increase in fibre content is due to the decrease of matrix material and increase in irregularities within the matrix [46].

Recycled high density polyethylene was used by [47] and tested for their mechanical properties. A remarkably high level, 70% of filler loading showed optimum tensile strength. Compatibilization further increased the tensile strength.

Slazar and Salinas [48] studied the prospect of using Columbian Rice Husk with Polypropylene and notice a significant increase of 63% compared to pure polypropylene. Extrusion and injection moulding techniques were used for sample preparation.

In an interesting study recycled Rice Husk was utilized for the development of bio composite based on Poly Lactic Acid [49]. PLA treated with Acrylic acid and Rice Husk treated with a coupling agent were used and a remarkable improvement in properties was observed. This can be attributed to even dispersion of treated rice husk in poly lactic acid due to the ester reaction.

Recycled high density polyethylene with rice husk was used to develop composites. It was observed that recycled polymer based bio-composite reveal better mechanical properties which, however can also be attributed to additives that were added during recycling process. The results however reveal that recycled polymers have a promising prospect in the development of bio-composites [50].

Used polyethylene was utilized with acetalized rice husk to prepare bio composites [51]. There was a significant improvement in the tensile properties compared to unmodified polyethylene. The Izod strength was greatly enhanced by 35%. SEM studies revealed better adhesion between acetalized RH and polyethylene.

Recycled high density polyethylene and recycled PET were used with RH as fibre. Compatibilizers were also added to improve adhesion. It was observed that compatibilized composites had significantly higher mechanical properties. These clearly indicate to improved adhesion between fibre and matrix [52].

4.2 Flexural and impact properties

The flexural properties are other important mechanical properties, knowledge of which is important before using the composite for any purpose. In this section the analysis of the flexural properties of various RH based composites have been done.

In a study the flexural modulus is seen to be increasing with the increasing filler loading with polypropylene as the matrix material increasing by about 25% for 60% RH reinforcement [53]. The impact strength is seen to be decreasing with increasing filler loading, when a crack is generated [54] due to an impact it propagates towards a poor interfacial region. Therefore the impact strength decreases as the filler content increases. On the other hand the strong filler matrix adhesion restricts the mobility of the matrix molecules, this also results in reduction in impact strength.

Chopped RH with polypropylene observed was used and it was observed that the flexural strength and modulus increased with fibre loading whereas the impact strength decreases as the filler loading increases. Flexural strength increased by 12.5%, while modulus increased phenomenally by 100%. The energy at break dropped significantly for 40% loading [9].

With increasing filler loading the flexural strength decreased by about 19.6 and 39.1% for 20 and 30% filler loading respectively while modulus increased by 24 and 34 % for 20 and 30% loading. The impact strength was also seen to be decreasing with increasing fibre content however for 20% it was better than pure polypropylene [13].

The Izod impact strength of the composites decreased as the filler content increased [54]. Micro cracks occur between the filler and the matrix polymer at the point of impact due to poor interfacial bonding, which cause the cracks to propagate easily in the composite.

In another study it was seen that the impact strength decreases with increasing filler loading and also the behaviour of impact strength with temperature was studied and the impact strength is seen to be decreasing with increasing temperature [8].

RH with polyethylene was used to prepare composites [20] and it was seen that the flexural strength enhanced with filler loading up to 35% where after it dropped rapidly, while the modulus continuously increased with the increasing reinforcement. For the impact strength the results were the same as flexural strength i.e. it increased in the starting up to 35% loading due to the strengthening mechanism of the fibre after which it dropped because the effect of fibre becomes less significant due to the higher ratio of fibre to the matrix.
In a study using RH and epoxy as constituent materials [39] the flexural strength and impact strength were seen to be decreasing with respect to pure epoxy that can be attributed to poor interfacial adhesion between fibre and matrix at higher filler loading and to the tendency of RH to agglomerate.

Other similar studies by various other researchers have observed that the poor adhesion between the hydrophobic matrix and hydrophilic fibre mostly results in decrease in flexural strengths as well as impact strength, however for flexural modulus it is seen to be increasing.

4.3 Water absorption

All the polymers absorb water in a moist atmosphere. The amount of water absorbed in bio-composites containing filler mainly depends on the nature of the fillers. Natural fibres have an undesirable affinity towards water because of their hydrophilic nature. The moisture absorption by composites containing natural fibres has an adverse impact on their properties, thus affecting their long term performance that is why knowledge of water absorption characteristic is of much importance.

Many of the studies listed above have also focused on this aspect and the results of these studies are summarized below:

While studying the water absorption characteristic of chopped RH it was seen that increase in CRH content increased the rate of water absorption since RH is hydrophilic in nature [12]. However, the equilibrium inside the composites is rapidly achieved and it remains constant, independent of time, it was also seen that the diffusion coefficient increased linearly with CRH content of the composites.

It was also seen that water absorption increased as the filler loading increased and comparatively the use of raw rice husk was better than ground rice husk and the worst was expanded rice husk. So we can also say that the smaller the particle size the higher is the water absorption [30].

Figures 9 and 10 show the result of water absorption for composites with 42% and 57% RH respectively [32]. Obviously the water absorption increases as the immersion time increases. RH is lignocellulosic material, possesses hygroscopic OH thereby attracting water through the formation of hydrogen bonds. This phenomenon is intensified as the amount of RH is increased. The larger sized fibre material show higher water absorption rate. This happens since smaller size filler have more OH groups to interact with the matrix. This blocks the OH groups of the filler to be reachable to water. It can also be seen from the figure that the increase in RH content increases the water absorption rate.
In another study it was seen that the effect of OH groups on the water absorption is negative and it increases as the fibre content is increased and at 100% RH it becomes very high [34]. They also the effect of varying particle size and the lower particle size was seen to be less water absorbing also seen in the above work.

Most of the other studies concerned with this aspect of composite manufacturing have conclusively proven that the increase in fibre loading results in an increase in the water absorption rate, the reason behind which is the presence of hydroxyl groups.

4.4 Tribological behaviour

Tribology encompasses the study and application of the principles of friction, lubrication and wear. The tribological interactions of a solid with interfacing materials and environment results in loss of material, this process is known as wear. Estimated direct and consequential annual loss to industries in the USA due to wear is approximately 1-2% of GDP [55]. So taking into account the losses that are accrued due to wear the study of this aspect becomes very important.

Abrasive wear measurements were done under multi pass condition on a single pin-on-disc machine was conducted [56] on composites prepared by RH and polyvinyl chloride. Three different abrasive papers of different grit size were used in the study. The disc was rotated with a rotational speed of 200 rpm. The cylindrical pins were held normal to the abrasive counter face and abraded at 10 N applied load for 10, 20, 30, 40 and 50 s. With the increase in the grit size of abrasive paper, wear rate increased drastically. It was also seen that with increasing sliding distance, the specific wear rate (K0) decreased gradually and reached an almost steady state.

It was seen that as the sliding distance increases the specific wear rate decreases. It was also observed that with increasing reinforcement the specific wear rate also increases the reason behind which is the improper adhesion between the filler and the matrix material PVC in this case. The wear rate of reinforced polymer was even higher than pure polymer for all percentage of reinforcement.

In another work the tribological behaviour of composites produced from rice husk and chopped carbon fibre was investigated [57]. The coefficient of kinetic friction and the specific wear rate were evaluated using a ball-on-disk type friction test system under dry conditions. Two samples of 10 & 20% chopped carbon fibre were considered. It was seen that with the addition of CF the wear resistance increased compared to pure RH and later it decreased.

The tribological behaviour of RH composite against various materials viz. stainless steel, alumina, silicon carbide, and silicon nitride under dry conditions was investigated [58]. The coefficients of friction for RH ceramics sliding against each type rapidly decreased during the initial stage. RH ceramics sliding against SiC balls displayed stable friction coefficients (approximately 0.15). Friction coefficients for RH ceramics sliding against the stainless steel and Si$_3$N$_4$ balls showed a decrease. In contrast, the friction coefficients for RH ceramics sliding against Al$_2$O$_3$ balls increased gradually. It was observed that the tribological properties worsened with addition of fillers against harder materials and improved when rubbed against softer material, this is due to the RH being a softer material.

The tribological behaviour of RH filled epoxy composites was studied [59]. The composites composed of RH and epoxy was tested under load of 10N and RPM 300. It was observed that with increasing sliding distance the wear...
rate decreased. The effect of increasing the reinforcement was that the wear rate first decreased with increasing fibre content compared to pure epoxy for up to 10% RH loading. Thereafter it started increasing with further increase in filler loading (Figure 11).

5 Surface modifications

The incorporation of natural lignocellulosic materials into polymers resulted in the lack of good interfacial adhesion between the two components resulting in poor properties of the resulting composite [60]. The polar hydroxyl groups on the surface of the lignocellulosic materials cannot form a well bonded interface with a non-polar matrix, due to the hydrogen bonds tending to prevent the wetting of the filler surfaces. Furthermore, the lignocellulosic materials have a tendency of agglomeration. This incompatibility results in poor mechanical properties and high water absorption if the matrix is hydrophilic.

Thus to improve properties the interface between the matrix and the lignocellulosic material has to be improved. There are various methods for promoting interfacial adhesion in systems where lingo-cellulosic is present, treatment with silicon compounds, graft co-polymerization, use of compatibilizers, plasma treatment, and other chemicals. These methods are usually based on the use of certain catalysts, containing functional groups capable of bonding to the hydroxyl groups of the lignocellulosic material, and at the same time maintaining good compatibility with the matrix.

Presently industry relies on the addition of small amounts of another component which, by its chemical characteristics, may promote adhesion promoter between polymer matrix and cellulosic fillers, by forming chemical bonds (either covalent, or Van der Waals kind) [61].

Some of the above mentioned methods have also been applied to RH like use of compatibilizer [8, 10, 13, 14, 64], chemical treatment [62–65, 67–71], electron beam irradiation [66], plasma treatment [62].

5.1 Effect of compatibilizer

The effect of maleated PP on the tensile properties was observed [10]. The addition of the coupling agent increased the tensile properties drastically. The tensile strength increased by about 18%, while Young’s Modulus increased by about 40%. This behaviour can be attributed to the reaction of the hydrophilic –OH groups from the filler and the acid anhydride groups from MAPP.

Petchwattana et al. [64] used maleic anhydride grafted polyethylene as a compatibilizer. It was seen that the tensile strength increased with increase in compatibilizer. Similarly the flexural strength and impact strength also increased.

Another useful method for artificially enhancing the adhesion between fillers and matrix is the use of compatibilizing agent. Similar study was done [14] in which they have used two different compatibilizers namely Epolene E-43 and Epolene G-3003. These agents have dual characteristic having both the hydrophilic and hydrophobic properties necessary to adhere well with the lignocellulosic filler and matrix polymer. It was observed that the addition of compatibilizing agents enhanced appreciably the value of tensile strength up to the level of pure RH. The effect of the compatibilizing agents on the impact strength was also the same i.e. it improved with the addition of the compatibilizers, the mechanism behind, which is shown in Figure 12.

Figure 12: Proposed model of PPMAH compatibilization in PP/NBR/RH composites [14]

In another study the effect of using a compatibilizer in this case maleic anhydride polypropylene (MAPP) was observed [10]. It was seen that the addition of MAPP decreased the water absorption rate significantly due to the reduction of number of hydrophilic groups present on the RH surface.

5.2 Chemical and plasma treatment

The effect of chemical treatment on RH reinforced polyethylene composites was done [20]. In the study RH was treated with benzene diazonium salt in presence of alkali, acidic and neutral media. The pH levels were maintained at 10.5, 7 and 6 for basic, neutral and acidic media respectively. The alkali media increased the tensile
strength by about 11%, while for acidic media it was 3.5% and for neutral medium there was negligible increase. The results for the Young’s Modulus also showed the same behaviour. The flexural properties were also seen to be increasing after treatment. The increase in flexural strength was similar for acidic and basic media but alkali media was better as far as flexural modulus is concerned. In case of impact strength the results were same with alkali treatment being better than acidic medium followed by neutral media and then raw RH.

The change of properties due to the change of media may be attributed to the change in cellulose unit of RH. The chemical treatment of RH reduced the hydroxyl group content of the cellulose anhydro glucose units due to coupling with diazonium salts.

Acetic anhydride was used to treat the RH fibre [61] for polypropylene/recycled Acrylonitrile Butadiene and RH composites. The effect of pre-treatment was significant for all the tensile properties, the Young’s Modulus increased by about 53%, the tensile strength also increased significantly and the composite became more ductile.

Effect of plasma and NaOH for RH/PP composites was studied [62]. It was revealed by the SEM studies that the adhesion properties improved significantly. Both the methods were very effective with tensile strength increasing by a significant amount (Figures 13-15). The effect of alkali treatment was so high since the state of material was changed from hydrophilic to hydrophobic due to removal of chemicals from the surface of RH like lignin, pectin, waxes etc.

In another study the RH was modified using Glycidyl Methacrylate [63]. The tensile strength and modulus both increased as the amount of GMA used was increased due to improved adhesion. Similar was the case with the flexural strength which increased by 60% as amount of GMA increased. The flexural modulus and other properties improved significantly.

Maleic anhydride modified polypropylene was used with polypropylene/Recycled Acrylonitrile Butadiene Rubber/Rice Husk Powder [68]. It was seen in SEM studies that the compatibilizers formed a bond with the hydrophilic RH.

Besides the mechanical properties the surface modifications can also have an effect on the water absorption characteristics of the resulting composites and this has also been studied by many authors.

In one of the studies treated RH with benzene diazonium salt in basic, acidic and neutral media and their effect on water absorption was seen [20] and here also the treatment is seen to be beneficial in terms of water absorption characteristics. The water absorption decreased for all the three treatment media compared to raw RH and the sequence of the three different media in decreasing level of water absorption is neutral, acidic and alkaline.

The NaOH treatment and plasma treatment can both be very effective techniques to decrease the water absorption rates for RH composites with plasma treatment being better than NaOH treatment the reason behind which is plasma coating which resisted water absorption [62].

In a study it was shown that with the addition of compatibilizing agents the water absorption decreases because after treatment with maleic anhydride some of the hydroxyl groups of RH reacted with it increased the compatibility of RH with matrix [65].

![Figure 13: Comparison of tensile strength of untreated and NaOH and plasma treated RH](image)

**Figure 13:** Comparison of tensile strength of untreated and NaOH and plasma treated RH [62]
5.3 Electron beam irradiation

Electron beam irradiated RH powder as reinforcing material in high density polyethylene composites was used [66]. The mechanical properties enhanced with the radiation dosage and reached an optimum dose in the range 20–30 kGy.

Treatment of fibre was done using alkali and UV treatment [43]. Results indicate that when alkali treatment was done on RH/rHDPE composite foam, tensile strength and Young’s modulus were highest among the treatment followed by UV/O₃ which shows increments when compared with non-treated composites. The better tensile strength can be achieved when used with UV/O₃ treatment rather than using an acid treatment. When compared with the untreated RH composites tensile strength increases to about 20.5%. Thus, results indicate that instead of using any acid treatment, UV/O₃ is used for better stiffness of composite by improving the interlocking of the fiber-matrix interface. Also, from the observation, it is advisable to use UV/O₃ for surface treatment for enhancing the filler-matrix adhesion composite because this method is cheap and environment-friendly.

Surface treatments also have profound effects upon the tribological behaviour as well as have been published [56, 57, 65]. In a study modified rice husk by treatment with Benzoyl chloride was used [57]. The addition of Benzoyl chloride increased the compatibility between the RH and polymer matrix and as a result the wear rate and specific wear rate both are seen to be decreasing as shown in Figure 16.

Maleic anhydride as a compatibilizer was used [65] for RH composite and it was seen that presence of the compatibilizer has the same effect it had on the tensile properties because of better bonding between the constituents. It is seen that the wear rate decreases significantly after treatment for all the compositions studied being better than pure polymer also for 10% RH composite.

In another study [71], the effect of alkali treatment on the mechanical properties of RH epoxy composites was studied. It was observed in the SEM images that there was an improved adhesion between fibre and matrix due to alkali treatment. The tendency of RH of agglomeration was also subdued. Study was also conducted on the effect of concentration of alkali media on the properties and it was observed that beyond 8% concentration of alkali media there was a reduction in properties due to surface deterioration of the RH fibres.

Treatment of the surface of the fibre without changing its structure was done by treating rice husk with hot water. Treated RH was used to develop composites with poly hydroxy butyrate as matrix material [72]. This fibre treatment was proposed by Leao [73]. Mechanical properties improved in comparison to untreated bio-composite.

**Figure 15:** Comparison of elongation at break between untreated and NaOH and plasma treated RH [62]

**Figure 16:** Variation of wear rate for treated and untreated RH with sliding distance [59]
6 Morphological analysis

The SEM studies conducted on fracture surfaces of the RH based composites have shown improper adhesion between RH and the polymers [8].

It was observed that as the filler loading increases it was seen that more filler particles are observed meaning that there was no adhesion between the fibre and the matrix. This large amount of poorly bonded area indicates towards improper adhesion and causes brittle fracture.

In some SEM images presence of voids was observed indicating poor adhesion [10]. These voids in turn act as sites of stress concentration and as the load is applied fracture at this point occurs.

Another problem with RH is agglomeration and RH instead of mixing with the matrix tends to agglomerate at certain places thereby degrading the strength.

From the SEM images of the fractured surfaces of the sample it was seen that the predominant cause of failure was fibre pull out indicating towards improper adhesion between fibre and matrix.

For the same amount of filler loading with RH treated chemically it was however observed that the presence of voids decreased [20], Figure 19.

Also, the surface was a lot smoother indicating towards proper adhesion between the fibre and the matrix. It can be said that surface modification of fibres improves the adhesion between the fibre and the matrix.

Various surface modification techniques point out to changing the polarity of RH from hydrophobic to hydrophilic. Moreover, the various waxes, lignin present on the surface of lignocellulosic fibres are removed and improve adhesion [74].

7 Application of RH based composites

High ash contents, silica content are unique physical and chemical properties of RH which can be used in various industrial and domestic processes. RH may be used as brick kilns, in the rice parboiling process, in a furnace, raw material for sodium silicate production, cleaning and polishing agent in metals, and various machine industries [75, 76].
Use of RH has been proposed for building materials like panels and boards paving the way for replacement of wood which has been used traditionally [77, 78]. Antunes et al. Developed panels using Rice Husk and earth and improved properties were observed ranging from tensile, compressive strength to moisture absorption. RH was also used for preparation of composite boards [79]. The thermal, mechanical and acoustic properties of the board were studied. The results revealed better thermal and acoustic properties with boards fabricated from RH. Waste expended polymer and rice husk were used. The results revealed high flexural strength and water resistance and as such their use in building materials is recommended [80]. Lightweight concrete blocks have been proposed using rice husk [81]. It was observed that though the compressive strength decreased at 25% filler loading no sudden brittle fracture was observed indicating high energy absorbing capacity.

Few studies that focused on comparison of RH composites with wood revealed [8, 82] that RH based bio-composites can be used as a replacement for wood. It was seen that after surface modifications addition of RH increased the flexural, tensile and impact strength and hardness of polymers and as such can be used as a replacement of wood.

Moreover, they can be blended with polymers to produce plastic toys and items of daily use. Some studies mentioned above have used recycled polymers with RH and this can help to a great extent in decreasing our carbon footprints.

The studies revealed that RH can be a replacement for plastics by improving their mechanical properties and can help in environment safeguarding. Surface modified RH also showed better properties in terms of hardness and water absorption and as such can be used in packaging industries [83].

Addition of RH has also proved to improve fire retardant properties of epoxy resin in addition to improve tensile and flexural strength [?] and as such can be used at places which have higher chances of getting burnt.

8 Future prospects

RH is an abundant raw material and so naturally has been a focus of research for developing bio-composites. Artificial resin based RH bio-composites have been developed and various surface modification techniques have been proposed to improve the adhesion between the fibre and the matrix. Still there is a lot of scope of utilizing RH with naturally occurring resins. Resins derived from natural sources can only truly help in developing environment friendly composites.

Still another less explored area has been the utilization of RH with recycled polymers. The earth has already produced enough of plastics that are eroding environment. Utilization of these already existing polymers would help the environment in a great measure.

It was seen in most of the studies that the improper adhesion between the fibre and the matrix resulted in decrease in mechanical strength at higher filler loading. This can, however, be improved by surface modification techniques. There are numerous studies regarding the surface modification techniques but still many existing techniques have not been used on RH fibres.

RH can also be used as a fibre in developing hybrid biocomposites. But very few studies have been conducted in this direction. Hybrid composites have seen to be significantly improving the properties and hence use of RH with other bio fibres can be explored.

RHA derived from RH is 92% silica and some studies have been conducted on utilizing this product of thermal degradation of RH. More studies in the future are expected to be done on this aspect of RH.

Most importantly any potential application of RH based composites would require an investigation into the ageing and weathering properties of the developed composite. Microbial, fungal action on the composites should be investigated if any commercial products are to be developed using RH based composites.
9 Conclusion

We have come a long way since the RH was first used as a fibre in composites. Almost all the ubiquitous polymers have been used with RH and contributed to reduction in use of these harmful polymers. It was mostly observed that the properties deteriorated at higher filling level. Water absorption also increased at higher filling level due to the hydrophilic nature of RH. Moreover, no study tried to take the fibre level to more than 70%. The reasons for this decrease in tensile strength with increase in fibre content were opposite nature of fibres and polymers.

Tribological properties will play an important role if future applications of these composites are considered. The studies conducted show an increase in wear rate of the composite with filler loading. This would seriously hamper the prospect of utilizing these composites in product development in the future. The reason for this increase in wear rate is also the improper adhesion between fibre and matrix.

The incompatibility between the fibre and the matrix can be improved by surface modification techniques which result in removal of waxes and lignin’s from the surface of the RH. This results in improved adhesion between the fibre and the matrix. Comprehensive studies have been taken on various surface improvement techniques out of which many have been used for RH as well. Techniques like electron beam irradiation and plasma treatment have shown remarkable improvement in adhesion.

Also there has been some studies to utilize recycled polymers with RH and the few studies conducted have shown to have yielded improvement in mechanical properties. Still considering the amount of plastic waste on the earth more studies in the future can be expected on this aspect.

RHA a product of thermal degradation of RH has also been explored and it has clearly opened the new gates for proper utilization of RH an abundant resource.

It is expected in the future that studies utilizing RH as filler for hybrid bicomposite and its use with recycled polymers and naturally occurring resins will be taken up.

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