J. Mater. Environ. Sci. 3 (5) (2012) 907-916
ISSN : 2028-2508
CODEN: JMESCN

Mechanical and physical characterization of agricultural waste reinforced polymer composites

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Received 19 March 2012, Revised 27 June 2012, Accepted 27 June 2012
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Abstract
Increasing concern about global warming, primarily due to deforestation has led development of new materials substitute to wood, which enhances optimal utilization of natural resources. Natural fibers such as jute, flax, sisal, etc., belong to this category and are locally available in abundance. All these natural fibers have excellent physical and mechanical properties and can be utilized more effectively in the development of composite materials for various applications. This paper investigates the properties of groundnut shell particles reinforced polymer composite (GSPC). Composite samples were prepared with different weight percentages of particles in polymer matrix. These samples were tested for some physical and mechanical properties. From the results of the experiments, it has been observed that the sample A (with 20 wt% of reinforcement) has maximum MOR of 40.57MPa and sample E (60 wt% of reinforcement) has maximum MOE of 8.204 GPa. The tensile test shows sample C (40 wt %) has maximum tensile strength and young's modulus of 28.09 MPa and 8204MPa respectively. The impact test results show a steady increase in impact strength upto 50 wt % of filler addition. Moisture content of GSPC varies from 1.92 to 4.96% and water absorption was only 1.51–8.82% for 15 days.

Key Words: Groundnut shell particles, Vinyl ester, Physical and Mechanical properties.

Introduction
Most of the developing countries are very rich in agricultural fiber and a large part of agricultural waste is being used as a fuel. India alone produces more than 400 million tones of agricultural waste annually. It has got a very large percentage of total world production of rice husk, jute, stalk, baggase, groundnut shell and coconut fiber, etc. In the composites industry, natural fibers refer to wood fiber and agro based bast, leaf, seed, and stem fibers. These fibers often contribute greatly to the structural performance of the plant and when used in plastic composites, can provide significant reinforcement. Natural fibers are complex and three-dimensional polymer composites, which are made up of cellulose, pectin, hemicellulose and lignin. Recent advances in the use of natural fibers in composites have been reviewed by several authors [1-4]. Currently natural fibres form an alternative for glass fiber, the most widely applied fiber in the composite technology. The advantage of the natural fibers over synthetic fibers like aramid, carbon or glass fiber are low densities, non abrasive, non-toxic, high filling levels possible resulting in high stiffness and specific properties, biodegradable, low cost, good

thermal and acoustic properties, good calorific value and enhanced energy recovery [5-6]. The environmental impact is smaller since the natural fiber can be thermally recycled and fibers come from a renewable resource. The natural fibres also offer a possibility in developing countries to use their own natural resources in their composite processing industries. Extensive studies on the preparation and properties of thermosetting and thermoplastic composite filled with kenaf [7-8], jute [9-11], sisal [12-13], bagasse [14], bamboo [15-16] and pineapple [17] were carried out. Nor Azowa Ibrahim, et.al [18] prepared the composite material using kenaf fiber and Ecoflex using different fiber loadings and the fiber was treated with different concentrations of NaOH. The results showed that the alkaline treatment of fiber gave the better tensile strength and flexural strength of the composite when compared to untreated fiber. 40% of fiber loading improved the tensile strength properties and WSK fiber treated with 4% NaOH was found to enhance tensile and flexural properties. Shih et.al.[19] prepared composites using disposable chopsticks and polylactic acid polymer.. The results on mechanical tests indicated that the tensile strength of the composites increased with fiber content, reaching 115MPa for 40 % fiber. Further, this type of reinforced PLA is more environmental friendly and could effectively reuse the waste of disposable chopsticks.

The mechanical properties of groundnut shell reinforced urea formaldehyde composites were investigated by Aji [20]. Various samples were prepared based on varying proportion of shell and resin with the groundnut shell volume fraction in the range from 6 to 14 %. Tensile and compressive tests were carried out for; yield strength of the samples was found in the range 29.92- 49.08 MPa and compressive strength 59.48-94.370 MPa. It was observed that the prepared samples exhibit lower tensile strength than the compressive strength due to brittleness of the composites. It was also found that increased volume of shell up to 12% increases the strength and beyond this value, the strength decreases. Also, as the volume of urea formaldehyde increases, the better is the strength of the composite. An established shell volume of 12% and 79 gm of urea formaldehyde in the sample gives the optimum composite material for application as a particle board. Utilization of peanut husk to produce fiberboards for general purpose use was studied by Mehmet Akgul [21]. For panel production, peanut husk was added at various percentages to the wood fiber. The results indicated that the panels could be produced utilizing up to 30% peanut husk without affecting the usability of the panels. However, the panels did not meet the minimum IB strength requirements as per standards when peanut husk was added to the mixture. Also, higher additions of peanut husk resulted in panels having lower MOR and MOE than the minimum requirements according to EN standards.

Guler [22] studied the physical and mechanical properties of the peanut hull reinforced urea formaldehyde particle boards. Various samples were prepared based on varying density of the panels in the range from 0.5 to 0.8 gm/cm^3. It was observed that MOR values of the samples were in the range 2.90-12.14 MPa, MOE values of 571.2- 1718.8 MPa and internal bond strength of 0.16-0.41 N/mm^2. The water absorption of peanut hull reinforced urea formaldehyde particle boards for 24 hours was found to be 67.85- 94.88 % and thickness swelling of 12.34-25.71 %. The results indicated that panels having 0.8 gm/cm^3 density and 9- 11% adhesive ratio met the general requirement of the panels for general purpose applications as per the standard EN 312. The mechanical properties of groundnut shell particles - epoxy composites were studied by Raju and Kumarappa [23]. The study investigated the feasibility of using high filler loading of groundnut shell particles in polymer for the manufacture of composite panel. Composite samples were fabricated by randomly distributed groundnut shell particles of different sizes and epoxy resin with volume percentages of 70:30, 65:35, and 60:40. From the study it was found that, MOR of the samples was in the range of 8.183–22.612MPa, MOE of 1075.45–2509.83 Mpa and tensile strength in the range 3.6842–9.6842 Mpa. Also, Moisture absorption values of the composites vary from 12.18% to 25.62% for 24 h and from 20.89% to 36.92% for 10 days. The result showed that a useful composite with moderate strength could be successfully developed using groundnut shell particles as a reinforcing agent in the epoxy matrix.

The primary drawback of the use of natural fiber is the lower processing temperature due to the possibility of lignocellulosic degradation, lack of good interfacial adhesion, poor resistance to moisture absorption. Chittaranjan Deo et.al [24] studied effect of moisture absorption on mechanical properties. To

improve the properties of the composites, the natural reinforcing fibers can be modified by chemical treatment. The coupling agent contains chemical groups, which can react with the fiber and the polymer. The bonds formed are covalent and hydrogen bonds which improve the interfacial adhesion [25-27]. The use of compatibilizers [27], surface modification techniques such as treatments, acetylation [28], graft co-polymerisation [29] or the use of maleic-anhydride–polypropylene copolymer has been reported to overcome the incompatible surface polarities between the natural fiber and polymer matrix. The influence of surface treatments of natural fibers on the interfacial characteristics was also studied and reviewed by Mohanty et al. [30]. The scope of this paper is to study the perspectives of using lignocellulosic plant residue as filler of thermoset polymer. These plant residues are low-cost by-product, environmental friendly and practically sustainable raw materials.

Experimental Details

Vinyl Ester Resin

Vinyl ester resin utilizes a polyester resin type of cross-linking molecules in the bonding process and is tougher and more resilient than polyesters. The ester groups in vinyl ester molecule are susceptible to water degradation by hydrolysis, which means that vinyl esters exhibit better resistance to water and many other chemicals. A vinyl ester resin has excellent physical and mechanical properties and is well known for its versatility as a composite matrix. With the development of a promising room temperature molding technology, the processability of vinyl ester resins at low temperatures has attracted considerable attention from the composite industry.

Groundnut

Groundnut botanically known as Arachis hypogeae belongs to Leguminosae family. India is the second largest producer of groundnut after China. In India, groundnut is the largest oilseed in terms of production and accounted for about 7.5 million tons during 2009-10. A complete seed of Groundnut is called as pod and outer layer of Groundnut is called shell. Brian George et.al. [31] investigated the groundnut shell fiber characterization. Average length of the groundnut shell fibers was found to be 38mm and 0.25mm diameter. Average tenacity of groundnut shell fiber is of 1.06 g/den. Also, average strain of the fibers was 7.45 % and average modulus 25.3 g/den. The selected groundnut shells are used in the present study. Clean and dried groundnut shells are initially washed with water to remove the sand and other impurities. The washed shells are then chemically treated with 10 % NaoH solution for 1 hour and later washed with distilled water. Subsequently, the shells were dried at room temperature for 24 hours. The dried shells were ground and particles were sieved through 600µm BS sieve. The similar procedure was followed by the authors [20, 22] for the preparation of material.

Chemical Composition of Groundnut Shell

Lignocellulosic fibers are constituted by three main components: hemicellulose, cellulose and lignin, which are known to present very complex structure. Cellulose, which is the main fraction of the fibers, is a semi crystalline polysaccharide made up of D-glucosidic bonds. A large amount of hydroxyl groups in cellulose gives hydrophilic properties to the natural fibers. Hemicellulose is strongly bound to the cellulose fibrils, presumably by hydrogen bonds. It consists of polysaccharides of comparatively low molecular weight built up from hexoses, pentoses and uronic acid residues. Lignin acts as the cementing agent in fiber, binding the cellulose fibers together [32]. Chemical composition of groundnut shell is compared with the composition of selected species. The hemi cellulose content of the fiber was found to be 18.7%, cellulose 35.7%, lignin 30.2% and Ash content 5.9% [23]. Table 1 compares the chemical compositions of groundnut shell with some other important natural fibers. The hemi cellulose content of groundnut shell is greater than Sisal. The lignin content of groundnut shell fiber is much greater than that of coconut coir, bamboo, hemp, kenaf and sisal fibers.

Table 1: Chemical composition of some natural resources

Species	**Cellulose, wt%**	**Hemicellulose, wt%**	**Lignin, wt%**	**Ash, wt%**	**Reference**
Coconut coir	47.7	25.9	17.8	0.8	[33]
Sisal	63-64	12.0	10-14	-	[33]
Groundnut shell	35.7	18.7	30.2	5.9	[23]
Rice husk	31.3	24.3	14.3	23.5	[34]
Bagasse	40-46	24.5-29	12.5-20	1.5-2.4	[35]
Hemp	70.2-74.4	17.9-22.4	3.7-5.7	-	[36]
Kenaf	31-39	21.5	15-19	-	[36]

Composite Board Preparation

The desired amount of dried groundnut shell particles were mixed with the vinyl ester resin in a plastic container and stirred to obtain a homogonous mixture. After adding the hardener, the mixture was again stirred for 10 minutes. The mould containing the composite was kept until the curing process was completed. To investigate the mechanical and physical properties of vinyl ester-based composites, the samples with various groundnut shell particle loadings were prepared. Subsequently, the specimens were fabricated based on different experimental purposes. In the current study, the composites containing 20%, 30%, 40%, 50% and 60% loadings (by weight) of groundnut shell particles were prepared and the samples were designated as A, B, C, D and E respectively.

Flexural Test

The flexural tests were performed according to ASTM D790 using Universal Testing Machine at a constant rate of 2mm/min. Five test specimens were cut to 191mm × 13 mm and 10 mm depth. The support span was 150mm. The flexural strength and flexural modulus were calculated using the following equations.

$$\text{MOR (Flexural strength)} = \frac{3PL}{2b\,h^2} \text{ (MPa)} \quad (1)$$

$$\text{MOE (Flexural modulus)} = \frac{m\,L^3}{4b\,h^3} \text{ (MPa)} \quad (2)$$

where , P = maximum load applied on test specimen (N)
L = support span (mm)
b = width of specimen tested (mm)
d = thickness of specimen tested (mm)
m = slope of tangent to the initial straight line portion of load deflection curve (N/mm)

Tensile Test

The tensile tests were performed according to ASTM D638 standard using Universal Testing Machine at a crosshead speed of 5 mm/min. Five specimens for each sample were tested and the tensile strength and tensile modulus were expressed as:.

$$\text{Tensile strength (MPa)} = \frac{P}{b\,h} \quad (3)$$

$$\text{Tensile modulus (MPa)} = \frac{\sigma}{\varepsilon} \quad (4)$$

where, P = Pulling force (N)
b =Specimen width (m),
h = Specimen thickness (m)
σ =Stress (N/m^2),
ε = Strain

Impact Test
The impact tests were performed according to ASTM D256 standard using Impact testing machine. The test method determines the Izod impact strength of groundnut shell particle reinforced polymer composites. An Izod type test in which specimen is held as a cantilever beam (usually vertical) and is broken by a blow delivered at a fixed distance from the edge of the specimen clamp. Five specimens for each sample having size 63.5 mm × 10 mm and 10 mm thickness were prepared and tested. The V notch was made at a distance of 31.75 mm from the top at a depth of 2.5mm. Impact strength was calculated by:

Impact strength = $\frac{J}{A}$ (KJ/m^2) (5)

where**,** J**=**Energy absorbed (KJ)
A= Area of cross section of the specimen below the notch (m^2).

Drop Weight Impact Test
Drop weight impact test was performed according to IS 2380 (Part X) standard. This test method determines the drop weight impact strength of groundnut shell particle reinforced polymer composite (GSPC) specimens. Each specimen was prepared as specified in the standard having dimensions 350 mm × 350 mm and 10 mm thickness. The test specimen was clamped firmly between two frames such that the internal area of the specimen was 250 × 250 mm^2. A block having mass 1.2 kg with a mild steel hemispherical end of radius 25 mm was arranged to fall freely on the center of the specimen. Initially, the block was allowed to fall from a height of 25 mm measured from the upper surface of the specimen and subsequently from successive heights rising in increments of 25 mm until final failure of the specimen occurs. The height of the drop causing the initial and final failure in the composite specimen was recorded. The energy absorbed by the composite board was determined using the following equation:
Potential Energy absorbed = h × W (J) (6)
where, h = height of drop (m)
W= weight of the dropping weight (N).

Moisture Absorption Test
Moisture absorption tests were performed according to IS: 2380(PART XVI) standard. Test specimen of 75 mm × 50mm and thickness 10mm were prepared for the moisture test. This test covers the method of determination of water absorption of boards from lignocellulosic materials. Most of the Natural fibers absorb excessive moisture when compared to synthetic fibers. The effect of this absorbed moisture is to degrade the tensile strength property. The specimens were immersed in water for a period of 15 days. The moisture absorption in the composite was measured by the weight gain of the material in regular intervals. The percent moisture absorption is expressed as the ratio of increase in mass of the specimen to the initial mass.

Moisture Content Test
The moisture content tests were performed according to IS:2380 (PARTIII) standard. The test specimen of 75 mm × 50 mm and 10 mm thickness were prepared for moisture content test. Initially, each specimen was weighed and then the specimen was dried in ventilated oven at a temperature of 103^o C until the mass became

constant to ±0.2 percent between two successive weighing made at an interval of 1 hour. The percent moisture content was calculated as the ratio of decrease in mass of the specimen to the initial mass and is given by:

$$\% \text{ moisture content} = \frac{m_o - m_f}{m_o} \times 100 \quad (7)$$

Where m_o = Initial mass
m_f = Final mass.

Results and Discussion

The experimental results of mechanical tests are illustrated in Figures 1-5. These figures depict the mechanical properties in relationship with the filler content (weight %). The mechanical properties were obtained by conducting test on five different specimens for each composition and the average values are presented in Figures 1-5. Based on EN standard 312-2 and 312-3, 11.5 N/mm^2 and 1600N/mm^2 are the minimum requirements for MOR and MOE of panels for general purpose and interior fitments respectively [37, 38]. The computed values of MOR and MOE of the proposed groundnut shell particles reinforced polymer composite (GSPC) specimens are shown in Figures 1 and 2.

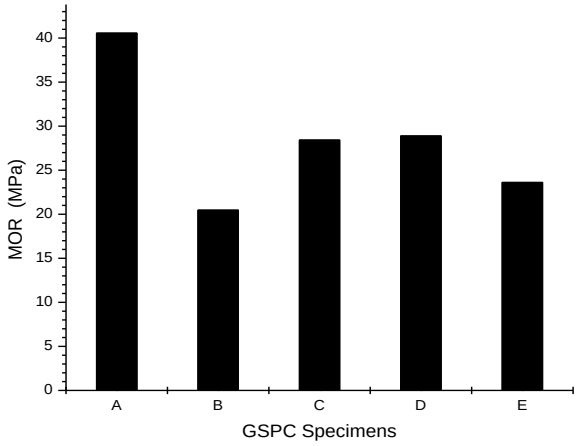

Figure 1: Modulus of Rupture of GSPC Samples

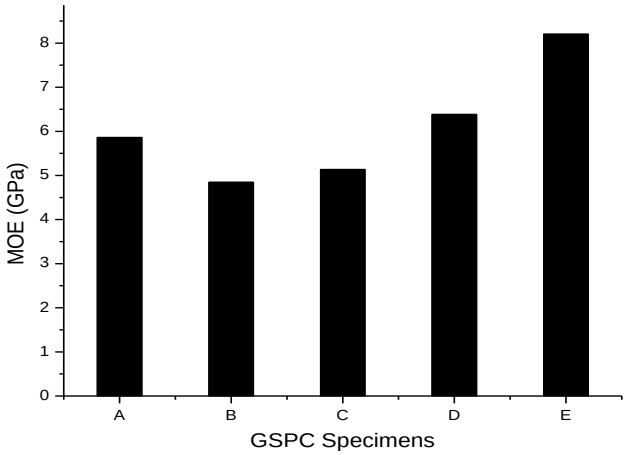

Figure 2: Modulus of Elasticity GSPC Samples

As can be seen from these figures, all GSPC boards have much higher MOE and MOR than the general purpose requirements. The chemical treatment had a positive effect on the MOR and MOE of the composite samples. The higher mechanical properties of the samples due to chemical modification were an indication of improved interaction and stress transfer between the particles. From the results of the investigations shown in Figures 1 and 2, MOR of GSPC is in the range of 20.48-40.57 MPa, indicating the highest value of 40.57MPa for the sample A (20 weight % of groundnut shell particle reinforcement). By further increasing the filler content up to 30%, MOR value decreases due to weak filler-matrix adhesion. Thereafter, MOR increases up to 50% of filler loading and decreases for further loading. This may be due to insufficient wetting of resin to the fillers for higher filler content. Similar results have been reported by other researchers that the flexural strength decreased after 40 wt% of filler loading [39-40]. However, opposite trend was exhibited by the GSPC composite samples for MOE property. MOE of samples increased with increase in filler loading and is due to enhancement in stiffness of the composite specimens with the addition of reinforcement filler. It is due to the reason that reinforcing particles have higher stiffness than the weak resin matrix. Similar results were also reported by several authors [21, 41]. MOE of GSPC is in the range of 4.848-8.204 GPa and the sample E (60 wt %) has the maximum of MOE of 8.204 GPa.

The computed tensile strength and Youngs modulus values of GSPC specimens are shown in Figures 3 and 4. The experimental results observed in this work attributed that the fillers had created some reinforcing effect and had been responsible for the increase in tensile strength. However, at some point of further increment in the filler content, a decrease in the tensile strength was witnessed. During tensile loading partially separated microspaces are created that obstructs stress propagation between the fiber and the matrix [42]. As the fiber loading increases, the degree of obstruction increases, which in turn decreases the strength of the specimens. It was observed by many researchers that the Young's modulus increases with an increase in filler loading [25, 43]. This behaviour may possibly lead to the conclusion that tensile modulus perhaps depend on the on the filler content rather than particle–matrix interface. Furthermore, increase in tensile modulus for higher filler content is due to the higher stiffness of the reinforcing particles than the matrix material. Owing to this, overall stiffness of the composite specimens increased and thus tensile modulus enhanced. Tensile strength of GSPC is in the range of 21.58-28.09 MPa which is more than other agro based composites and particle boards. From the results of the experiments depicted in Figures 3 and 4, the tensile test shows a steady increase in strength with increased filler content indicating the maximum tensile strength of 28.09 MPa for the sample C (40 weight % of groundnut shell particle reinforcement), bears load of 5886 N at an elongation of 4%. It has been observed that GSPC of sample C (40 wt %) has maximum tensile modulus of 1872.65 MPa.

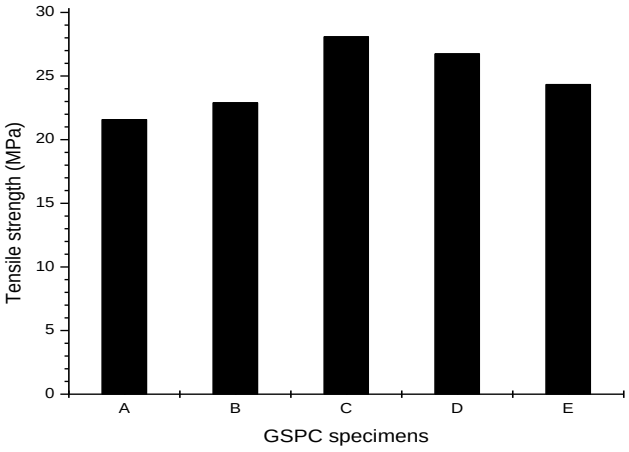

Figure 3: Tensile Strength of GSPC Samples

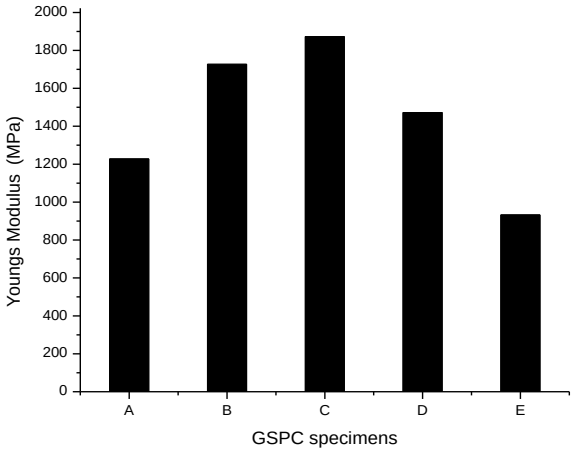

Figure 4: Young's Modulus of GSPC Samples

The experimental results of impact strength of GSPC specimens are displayed in Figure 5. The graph shows a steady increase in impact strength with increase in filler content, indicating 42.91 KJ/m^2 with 50 wt % of filler addition. However, there is a decrease in impact strength for further increase in filler content (60 wt %). This may be attributed to the weak interfacial interaction between the filler and matrix material for higher filler content that is beyond 50 wt %. Similar behaviour of the composite specimens was also observed by Haque [25] and Joseph [43] that is impact strength decreases for higher filler loading. In the drop weight impact test, the GSPC board absorbs the potential energy. From the results shown in Figure 6, it can be stated that in the drop weight impact test, the energy absorbed increases with the increase in weight percentage of filler loading that is groundnut shell particles. It almost shows a linear incremental behavior up to 50 wt% filler loading, indicating the maximum energy absorbed 12.0663 J for the sample E (with 50 wt % filler loading). This is possibly attributed to the fact that the reinforcing particles being cellulose absorb more potential energy as its content increases in the matrix material. Conversely on further filler loading to 60 wt %, drop weight impact strength decreases. This may be due to the weak interfacial interaction between the filler material and matrix for higher filler content that is beyond 50 wt %.

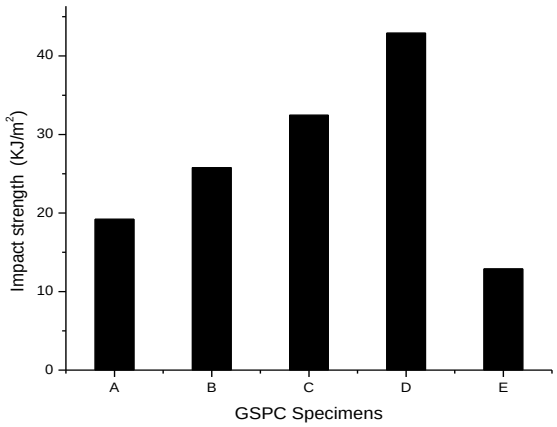

Figure 5: Impact Strength of GSPC Samples

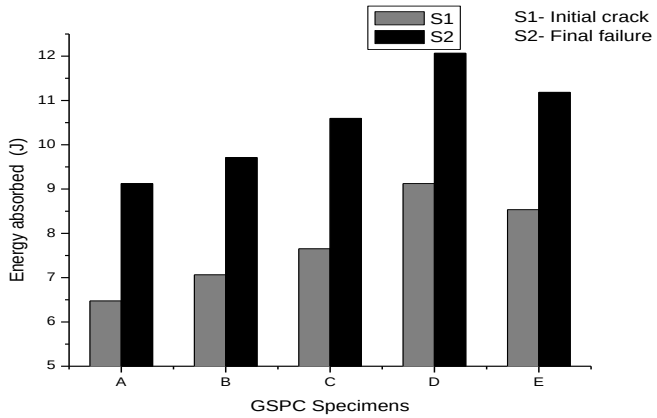

Figure 6: Drop weight impact energy absorbed by GSPC Samples

The physical properties obtained from the tests are shown in Figures 7 - 9. From the moisture content test shown in Figure 8, it was observed that moisture content increases with increase in filler content ranging from 1.92 to 4.96%. The moisture content and water absorption in case of GSPC are minimum compared to other agro based composite materials [44-45]. Khimp plant stem with phenol formaldehyde and urea formaldehyde resin was used by Bhaduri [43] to prepare the composite boards. The water absorption values for the specimens for 24 hours were found to be 34-61% depending on the different percent of resin. Mehmet Akgul [45] used corn stalk agricultural residue mixed with oak wood fiber with urea formaldehyde matrix for the preparation of the boards. The water absorption values for the boards for 24 hours were found to be 48-62% depending on the density 0.7 to 0.8 g $cm^{-3}$of the boards. The densities of GSPC are in the range of 1100 to 1320 Kg/m^3 as shown in Figure 7.

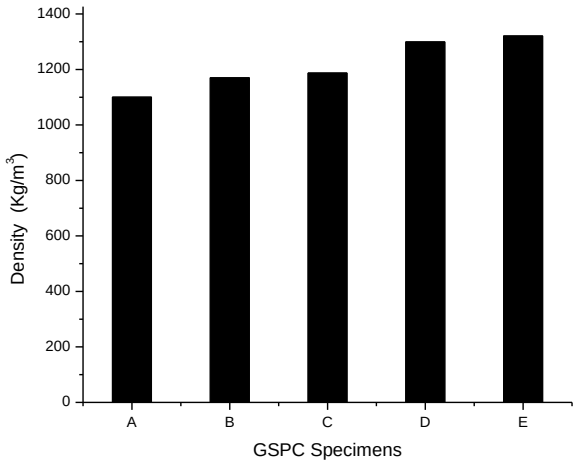

Figure 7: Density of GSPC Samples

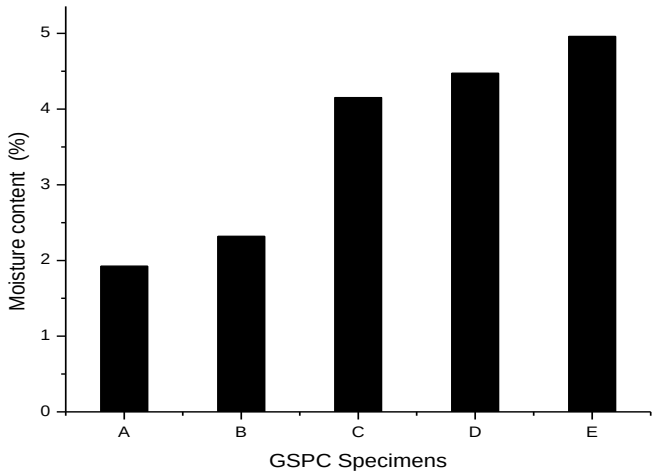

Figure 8: Moisture Content of GSPC Samples

The water absorption, which is an important property to select appropriate material for doors in building, is only 1.51–8.82% for 15 days and 0.656-3.28% for 24 hours in the case of GSPC as depicted in Figure 9. This may

due to lower void space in composite arising at better bonding between particles and resin. Due to this property, it has better outdoor applications. Water absorption increases with increase in groundnut shell particles as shown in Figure 10.

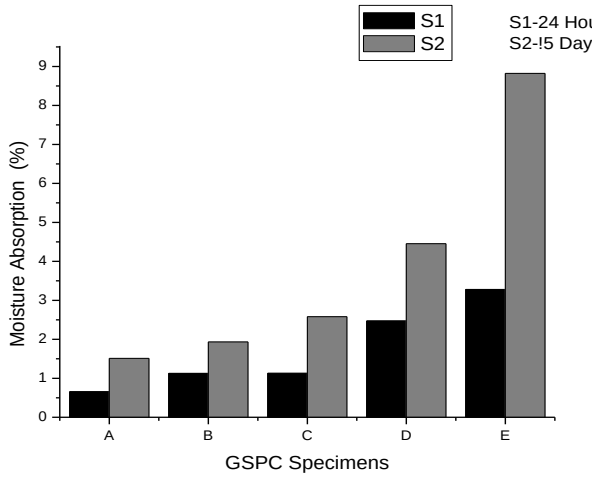

Figure 9: Moisture Absorption of GSPC Samples

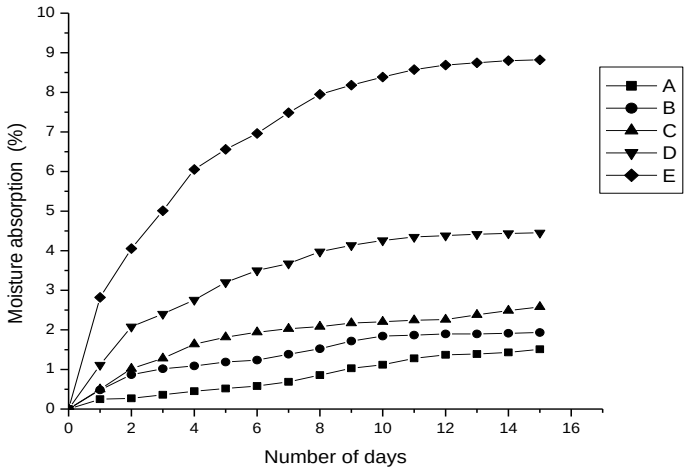

Fig. 10: Moisture Absorption of GSPC Samples

Conclusions

The present study investigates the feasibility of using groundnut shell particles in the manufacture of composite panel. The experimental results show that it is possible to produce composite panels using groundnut shell particles and vinyl ester as an adhesive. The addition of the particles improved the mechanical properties up to some weight % and further decreased with increased particle content in the samples. The sample C (40 weight % of groundnut shell particle reinforcement) has maximum tensile strength and tensile modulus. The sample D (50 weight % of groundnut shell particle reinforcement) has maximum modulus of rupture and impact strength. Depending on the applications, sample C or D could be used. An established 50 wt% particles (sample D) gives the optimum composite material for application as a particle board or roofing material. As India is one of the largest groundnut producing countries in the world, the use of its wastes such as shell for producing useful components would be very attractive for the economy. Groundnut shell reinforced composites can be further attractive by a suitable cost-effective method of composite production and may increase its application to a greater extent. The groundnut shell particles can be considered as an alternative for the wood material in the manufacture of particleboard used in indoor environment due to moderate mechanical properties, lower moisture content and water absorption.

References

1. Yang, H. S., Kim, H. J., Son, J., Park, H. J., Lee, B. J., Hwang T. S. *Composite Structure*, 63 (2004) 305.
2. O'Donnel, L, A., Dweib, M. A., Wool, R. P. *Composites Science and Technology*, 64 (2004) 1135.
3. Mohanty, A. K., Misra, M., Hinrichsen, G. *Macromolecular Materials and Engineering*. 276 (2001)1.
4. Bledzki, A. K., Gassan, J. *Progress in Polymer Science*, 24 (1999) 221.
5. Baiardo, M., Zini, E., Scandola, M. *Composites Part A: Appl. Sci. Manuf.*, 35 (2004) 703.
6. Satyanarayana, K. G. *Inter. Conf. Adv. Mat. Comp.* (ICAMC-2007) (2007).
7. Hirao, K., Inagaki, H., Nakamae, K., Kotera, M., Nishino, T. K. *Comp. Sci. Techn.*, 63 (2003) 1281.
8. Nor Azowa Ibrahim, Kamarul Arifin Hadithon, Khalina Abdan, *J. Reinf. Plast. Comp.*, 29 (2010) 2192.
9. Hinrichsen, G., Khan, M. A., Mohanty, A. K. *Composites: Part A*, 31 (2000) 143.

10. Alok Satapathy, Alok Kumar Jha, Sisir Mantry, Singh, S. K., Amar Patnaik, *J. Reinf. Plast. Comp.*, 29 (2010) 2869.
11. Mohanty, S., Nayak, S. K., Verma, S. K., Tripathy, S. S. *J. Reinf. Plast. Comp.*, 23(2004) 625.
12. Joseph, P. V., Kuruvilla, J., Thomas, S. *Composites Science and Technology*, 59 (1999) 1625.
13. Bakare, I.O., Okieimen, F.E., Pavithran, C., Abdul Khalil, H.P.S., Brahmakumar, M. *J. Mat. Design*, 31 (2010) 4274.
14. Dominguez, V. A., Kenny, J. M., Vazquez, A. *J. Thermopl. Comp. Mat.*, 12 (1999) 477.
15. Jain, S., Kumar, R., Jindal, U. C. *J. Mat. Sci.*, 27 (1992) 4598.
16. Smita Mohanty, Sanjay K. Nayak, *J. Reinf. Plast. Comp.*, 29 (2010) 2199.
17. Mukherjee, P. S., Satyanarayana, K. G. *J. Mat. Sci.*, 21(1986) 51.
18. Nor Azowa Ibrahim, Kamarul Arifin Hadithon, Khalina Abdan, *J. Reinf. Plast. Comp.*, 29 (2010) 2192.
19. Shih, Y.F., Chien-Chung Huang, Po-Wei Chen. *J.* Mat. *Sci. Eng. A*, 527 (2010) 1516.
20. Aji, I.S., Ngala, G.M. and Nwankwo, H. *Continental J. Engineering Sciences*, 2 (2007) 8.
21. Mehmet Akgul, Ayhan Tozluoglu. *Bioresource Technology*, 99 (2008) 5590.
22. Cengiz Guler, and Umit Buyuksari. *BioResources*, 6 (2011) 5027.
23. Raju, G.U., Kumarappa, S. *J. Reinf. Plast. Comp.*, 30 (2011) 1029.
24. Chittaranjan Deo, Acharya, S. K. *J. Reinf. Plast. Comp.*,, 29 (2010) 2513.
25. Md. Mominul Haque, Md. Saiful Islam, Md. Sakinul Islam, Md. Nazrul Islam and Md. Monimul Huque. *J. Reinf. Plast. Comp.*, 29 (2009)1734.
26. Rahman, M. R., Huque, M. M., Islam, M. N., Hasan, M. *Composite A*, 39 (2008) 1739.
27. Rana, A. K., Mandal, A., Bandyopadhyay, S. *Comp. Sci. Techn.*, 63 (2003) 801.
28. Cyras, V. P., Vallo, C., Henny, J. M., Vazquez, A. *Composite Materials*, 38 (2004)1387.
29. Mohanty, S., Nayak, S. K., Verma, S. K., Tripathy, S. S. *J. Reinf. Plast. Comp.*, 23(2004) 625.
30. Mohanty, A. K., Drzal, L.T., Misra, M. *J. Adh. Sci. Techn.*, 16 (2002) 999.
31. B. R. George, A. Bockarie, N. Bieak, A. Evazynajad, A. Kar, S. Veluswamy, H. McBride. *The Ninth Annual Conference on Recycling of Fibrous Textile and Carpet Waste*, Georgia, 2004.
32. Chanakan Asasutjarit, Sarocha Charoenvai, Jongjit Hirunlabh, Joseph Khedari. *Composites: Part B*, 40 (2009) 633.
33. Swamy, R. P., Mohan kumar, G.C. *journal reinforced plastics and composites*, 23 (2004) 1373.
34. Raveendran, K. Anuradda Ganesh, Kartic C. Khilart. *Journal of Fuel*, 74 (1995) 1812.
35. Lu, J. Z., Wu, Q.L., NegulescuII, Chen, Y. *Applied Polymer Science*, 102 (2006) 5607.
36. Mohanty, A. K., Misra, M., Hinrichsen, G. *Macromolecular Materials and Engineering*, 276 (2000)1.
37. Umit Buyuksari, Nadir Ayrilmis, Erkan Avci, Enus Koc. *Bioresource Technology*, 101(2010) 255.
38. Gokay Nemli, Aytac Aydın. *Industrial Crops and Products*, 26 (2007) 252.
39. Sultan Ozturk, Journal of Composite Materials 44(19), (2010) 2265.
40. Zampaloni, M., Pourboghrat, F., Yankovich, S.A., Rodgers, B.N., Moore, J., Drzal, L.T., Mohanty, A.K. and Misra, M. Composites: Part A, 38, (2007) 1569.
41. Lou, C. W., Lin, C. W., Lei, C. H., Su, K. H., Hsu, C. H., Liu, Z. H., *J. Mat. Proc.Techn.*, 193 (2007) 428.
42. Ismail, H., Edyhan, M. and Wirjosentono, B. Polymer Testing, 21(2), (2002) 139.
43. Joseph, S., Sreekala, M. S., Oommen, Z., Koshy, P. Thomas, S. *Comp. Sci. Techn.*, 62, (2002) 1857.
44. Bhaduri, S. K. P., Mojumdar. *Natural product Radiance*, 2 (2008)106.
45. Mehmet Akgul, Cengiz Guler, Birol Uner. *African Journal of Biotechnology*, 9 (2010) 5090.