Study of Hardness and Impact Behaviour of Phenol Formaldehyde Based Wood Plastic Composite

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Abstract— **This study investigates the effect of coconut shell powder on the mechanical characteristics of wood plastic composites(WPC).The two main objectives of this work are to prepare a lightweight wood plastic composite and to use locally available materials and wood wastes. The coconut shell powder appreciably increases the mechanical strength of the studied composites.**

Keywords - Wood plastic composite (WPC); hardness; impact strength; wood flour.

I. INTRODUCTION

The interest in using natural fibres such as different plant fibres and wood fibres as reinforcement in plastics has increased dramatically during last few years. The present day trend is to go in for light weight constructions for easy handling and reduced space, reduction of as many parts in an assembly, aesthetic appearance and high resistance to weathering attack. These factors have propelled modern designers to develop newer composite materials for large scale production with exacting requirements. The overall objective of this study is to develop and investigate the performance of WPCs product made of polymer resin and sawdust with focus on stability and durability with various composite formulations.

N Rocha et al studied the influence of the nature and composition on the performance properties of wood flour composites. The inclusion of wood flour into PVC leads to poorer tensile properties. This effect is related to the lack of association between the wood flour and the PVC [1]. The wood and plastics – combination of these two offers potential for the provision of high-value wood–plastic composites (WPC). Compared to wood, WPC can have a longer service life with less need for maintenance, less water absorption, better dimensional stability and less biodeterioration [2].WPC can be used as a substitute for wood in a variety of applications, including decking, benches, marina boardwalks, and window and door profiles [1].

The dimensional stability of these materials tends to be greater than that of traditional wood products because of the incorporated plastic. This renders them suitable for application in end uses where dimensional stability is a prerequisite [3]. The effects of wood species on water absorption, biodegradation, and metal corrosion as well as color change of outside exposure WPC were recently studied by Kim et al. [4]. Unfortunately, the study did not consider the influence of the intrinsic chemical composition of wood species used. (Harper and Wolcott,)[5].

Faruk and Matuana suggested that melt blending technique was the best approach for incorporating nanoclay into wood/high-density polyethylene (HDPE) to enhance the mechanical properties. The approach of melt blending technique was also well-applicable in the case of wood/PVC composites using carbon nanotube (CNT) [6].

Pei-Yu Kuo et al studied the effects of material compositions (including different plastic matrices, wood flours, and coupling agents) on the mechanical properties of WPCs manufactured by injection molding. The results of their work provide information for estimating optimal material compositions in the manufacture of WPCs [7].The finite element method (FEM) has been successfully used for the analysis and design of composite materials and composite structures [8].

II MATERIAL SELECTION

A. Wood Flour

The wood is a renewable natural material and the waste wood is an important biomass resource. Many research groups are looking for ways to its utilization including new polymer composites development. The principal purchaser of the sawmill by-products is obviously the wood-based panels industry, which also receives materials through the trade. The wood used in WPCs is most often in particulate form (e.g., wood flour) or very short fibers, rather than longer individual wood fibers. The relatively high bulk density and free-flowing nature of wood flour compared with wood fibers or other longer natural fibers, as well as its low cost, familiarity, and availability, is attractive to WPC manufacturers and users.

Common species used include mahogany, teak, and maple. Typical particle sizes are 10 to 80 meshes.

B. Coconut shell powder

Coconut shell powder is made from coconut shells and is used as filler. Availability of adequate quantity of coconut shells is the most critical aspect. Mesh size of 80-100 is suitable for thermoset molding powder whereas for synthetic resin glues the size has to be around 230-240 mesh. Product provides substantial value-addition as normally shells are either thrown away or used as a fuel. The preferred locations are Karnataka, Kerala, Goa and Maharashtra. Coconut shells are cleaned and broken manually into small pieces and then fed into pulveriser. Powder obtained from pulveriser is fed into rotor lift, coiled and passed through dresser to have required mesh size. Rejects from the dresser are recycled. Efficient pulverizing and screening are critical aspects. Recovery is around 90%. Coconut shell particles are used as reinforcing material for investigation. Shell particles of size between 200-800µm are prepared in grinding machine. Coconut shell filler are potential candidates for the development of new composites because of their high strength and modulus properties. An approximate value of coconut shell density is 1.60 g/cm^3.

Fig.1. Coconut shell particle

C.Phenolic resin

Phenolic resins continue to be an important bonding agent for a diversity of uses encompassing the joining of metals, glasses, wood, paper, rubber to other substrates with favorable cost–performance characteristics that surpass most other polymeric resins. The Composites market is arguably the most challenging and profitable market for phenolic resins aside from electronics. The quality that all phenolic composites offer is the capability to provide a fire safe, light weight composition at a relatively low material cost. Phenolic composites are commonly used in high temperature environments and wherever they can be applied to protect human life from fire.

D. Cenosphere

Cenospheres are unique free flowing powders composed of hard shelled, hollow, minute spheres. A small proportion of the pulverized fuel ash (PFA) produced from the combustion of coal in power stations is formed as Cenospheres. Cenospheres are made up of silica, iron and alumina. Cenospheres have a size range from 1 to 500 micron meters with an average compressive strength of 3000+ pounds per square inch.

E. Additives

Natural fibers are generally hydrophilic and do not bond well with the hydrophobic matrix polymer. Ways to promote adhesion between the two phases include introducing additives such as compatibilizers to the polymer/fiber mix during processing or chemical modification of the fiber prior to composite manufacture. Ragi Straw is an agricultural by-product. It is the stalk of cereal plants after the grain and chaff have been removed.

F. Red millet fibers

Millets are a group of highly small-seeded grasses, widely grown around the world as cereal crops or grains for both human food and fodder. They do not form a taxonomic group, but rather a functional or agronomic one. Millet are important crops in the semi-arid tropics of Asia and Africa. The crop is favoured due to its productivity and short growing season under dry, high temperature conditions. It is cut to 0.5 cm to 1cm length.

Fig.2. Red millet straws

G. Groundnut stem fibers

The peanut, or groundnut (Arachishypogaea), is a species in the legume or bean family (Fabaceae). It is an annual herbaceous plant growing 30 to 50 cm tall. The leaves are opposite, pinnate with four leaflets (two opposite pairs; no terminal leaflet); each leaflet is 1 to 7 cm long and 1 to 3 cm across. The ground stem cut to about 0.5 cm to 1 cm length.

Fig. 3. Ground nut straws

III. FABRICATION AND EXPERIMENTAL PROCEDURE

A. Preliminary test for reinforcement

The preliminary test such as density and grain test conducted to know the density and grain size particles to be used for the fabrication of WPC. Table 1 shows these values.

Table. 1. Density and grain size of reinforcement materials

Sl. No.	Filler material	Density(kg/m^3)	Grain size
1.	Mahogany wood flour	1350	47
2.	Coconut shell powder	650	31

B. Hot pressing

Hot pressing is a high-pressure, low-strain-rate powder metallurgy process for forming of a powder or powder compact at a temperature high enough to induce sintering and creep processes. This is achieved by the simultaneous application of heat and pressure. The composites prepared using hot press machine.

Fig. 4. Hot press machine

C. WPC Sample preparation

The selected materials of required volume and composition (shown in table 2) is thoroughly mixed and uniformly compacted in the 12X12X 1 cubic inch designed mould. The mould is then placed in the hot press and it is allowed for curing at the temperature of 150°C and curing time of 15 minutes. The mould is taken out from the hot press after 15 minutes and allowed for cooling. The specimen is cut by cutting machine as per ASTM standards. (For Impact test specimen ASTM B256).

Table. 2. Designation of composites

Sl No	Composite	Composition in %
1	C1	40 (PR) + 60 (25CSP + 20WF + 5CS + 10 additives)
2	C2	50 (PR) + 50 (20 CSP + 15 WF + 5 CS + 10 additives)
3	C3	60 (PR) + 40 (15 CSP + 10 WF + 5 CS + 10 additives)

(PR-Phenolic Resin, CSP-Coconut Shell Powder, CS-Cenosphere,WF-Wood flour)

Fig. 5. Mixing of all materials

Fig. 6. Compacting in a mould before keeping into hot press.

D. Hardness test

Hardness is not an intrinsic property of any material; it is rather a characteristic deriving from the composition and essentially from the structure of the specimen involved. The samples used for the tests were of square shape, minimum 50 mm long and with the normative thickness, made of mahogany wood. The tests were carried out by both Brinell and Rockwell method. Brinell hardness number is obtained using a perfectly spherical hardened steel ball of 10 mm pressed against the test surface using a static force of 3000 kilograms for at least 10 seconds and measuring the diameters of the indentation left on the surface by means of a graduated low power microscope. Brinell hardness is evaluated by taking the mean diameter of the indentation (two readings at right angles to each other) and calculating the Brinell hardness number (HB) by dividing the applied load by the surface area of the indentation. In Rockwell hardness testing a minor load of 3 kilograms, and a major load of 45 kilograms were applied. The indenter used was steel ball.

E. Impact test

An impact test measures energy absorbed when an object fractures or breaks under a high speed collision. Izod and Charpy tests characterize the dynamic impact resistance behaviour of various percentages of WPC.The experimental values and material properties used for the analysis are obtained from the previous work [9].

IV. RESULTS AND DISCUSSION

A. Brinell hardness

The measured hardness values of all the three composites are shown in table. 3. It can be seen from the fig. 7. that the hardness value of the composition C2 wood composite is more as compared C1 and C3wood composite.

Table. 3. BHN for WPC samples

Sl No	Composite	BHN
1	C1	70
2	C2	99.37
3	C3	59.75

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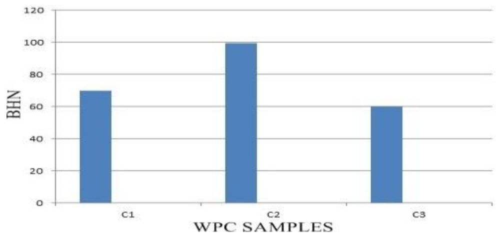


Fig. 7. BHN versus WPC samples

B. Rockwell Hardness

Table. 4. RHN for WPC samples

Sl No	Composite	RHN
1	C1	66.5
2	C2	111.25
3	C3	57.875

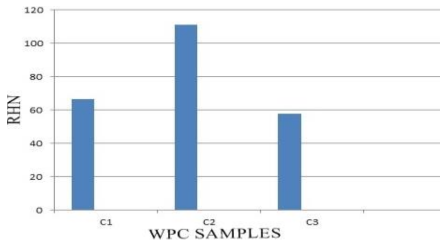


Fig. 8. RHN versus WPC samples

The measured hardness values of all the three composites are shown in table.4. It can be seen from the fig. 8. that the hardness value of the composition C2 wood composite is more as compared C1 and C3wood composite.

C. Izod and charpy impact analysis using Ansys

ANSYS is a general-purpose finite element-modeling package for numerically solving a wide variety of mechanical problems. ANSYS LS-DYNA combines the LS-DYNA explicit finite element program with the powerful pre- and post-processing capabilities of the ANSYS program. The explicit method of solution used by LS-DYNA provides fast solutions for short-time, large deformation dynamics, quasi-static problems with large deformations and multiple nonlinearities, and complex contact/impact problems. Transfer geometry and results information between ANSYS and ANSYS LS-DYNA to perform sequential implicit-explicit / explicit-implicit analyses, such as those required for drop test, spring back and other applications.The procedure for an explicit dynamics analysis consists of three main steps, build the model, apply loads and obtain the solution, review the results.

D. Material properties

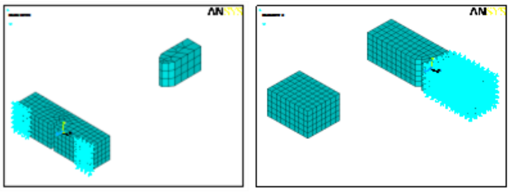
Material properties used for the analysis are obtained from the previous work and shown in the table 5.

Table. 5. Material properties

Sl no	Composite	Density Kg/m^3	Young's Modulus MPa	Initial velocity m/s	
				Charpy test	Izod test
1	C1	1350	1450	6	4
2	C2	1300	725	6	4
3	C3	1280	580	6	4

E. Model generation

The geometric model is created in ANSYS LS DYNA. The finite element model is built using SOLID164 elements as shown in fig. 9.



(a) Charpy Impact Test (b) Izod Impact Test

Fig. 9. Finite element model

F. Charpy impact test results by Ansys

The finite element model is built using SOLID164 element. Charpy and Izod impact analysis was carried out and result of the analysis is listed in table. 6 and 7 respectively.

Table. 6. Charpy impact test values using ANSYS

Sl. No.	Composite	Stress N/mm^2	Strain	Deflection m	Impact Strength J/mm^2
1	C1	0.656e7	0.0058	0.476e-2	0.91
2	C2	0.396e7	0.0072	0.692e-2	0.99
3	C3	0.288e7	0.0112	0.694e-2	1.12

Table. 7. Izod impact test values using ANSYS

Sl. No.	Composite	Stress N/mm^2	Strain	Deflection m	Impact Strength J/mm^2
1	C1	0.254e8	0.0233	0.341e-3	1.009
2	C2	0.193e8	0.0354	0.351e-3	1.2
3	C3	0.156e8	0.0358	0.465e-3	1.34

Deflections and the stress values obtained through the Charpy impact analysis of composites C1, C1, C3 are as shown in fig 10 to 12.

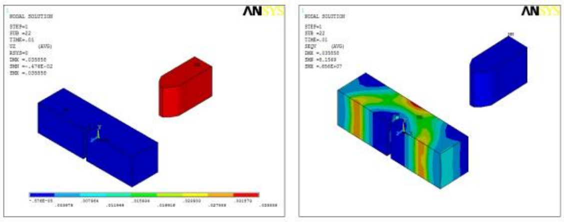


Fig. 10. Deflection and stress of the specimen C1

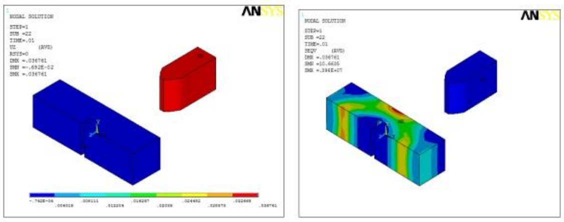


Fig. 11. Deflection and stress of the specimen C2

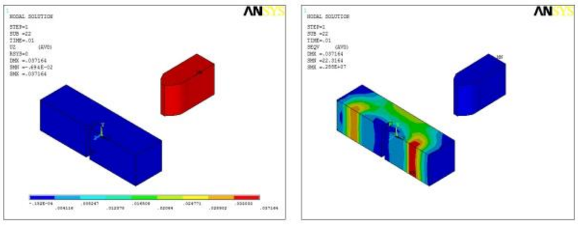


Fig. 12. Deflection and stress of the specimen C3

Deflections and the stress values obtained through the Izod impact analysis of composites C1, C1, C3 are as shown in fig 13 to 15.

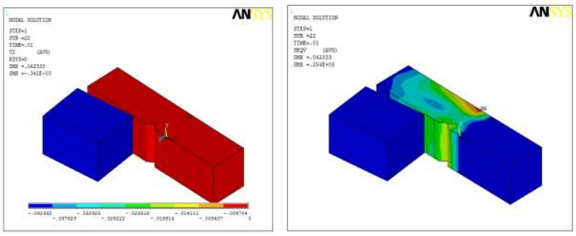


Fig. 13. Deflection and stress of the specimen C1

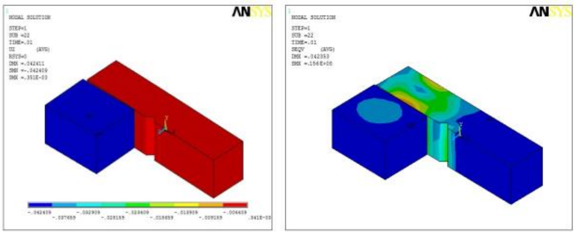


Fig. 14. Deflection and stress of the specimen C2

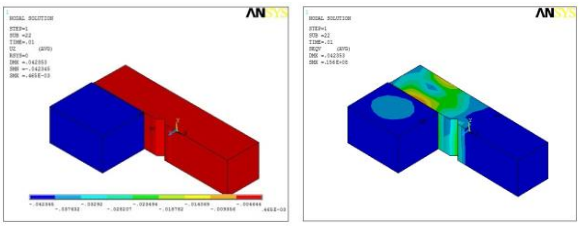


Fig. 15. Deflection and stress of the specimen C3

The table 8 and 9 shows comparison for both Izod and charpy values of experimental and FEM analysis.

Table.8 Comparison of Izod experimental and FEM values

Sl. No.	**Composite Specimen**	**Experimental Impact Strength J/mm^2**	**ANSYS Impact Strength J/mm^2**	**% Deviation**
1	C1	0.8909	0.91	**02.1**
2	C2	0.9272	0.99	**06.3**
3	C3	1	1.12	**10.7**

Table.9 Comparison of charpy experimental and FEM values

Sl. No	**Composite Specimen**	**Experimental Impact Strength J/mm^2**	**ANSYS Impact Strength J/mm^2**	**% Deviation**
1	C1	0.9545	1.009	**05.4**
2	C2	1.0909	1.2	**09.1**
3	C3	1.1818	1.34	**11.8**

V. CONCLUSION

The study focus on the effect of coconut shell powder on the mechanical properties hardness and impact of phenolic formaldehyde based wood composite. The adding of coconut shell powder improves the mechanical property of WPC. The hardness test signifies the influence of shell powder. It was observed that the hardness value of 50:50 (phenol formaldehyde resin: materials) specimen was more compared to 60:40 and 40:60 specimens. The results obtained by experimental and analytical methods agree with each other with a deviation of about 2.1%–10.7% for Charpy impact test. The results obtained by experimental and analytical methods agree with each other with a deviation of about 5.4% – 11.8% for Izod impact test. There is a good correlation between experimental and FEM values of the impact analysis.

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