IMPACT: International Journal of Research in Engineering & Technology (IMPACT: IJRET)
ISSN(E): 2321-8843; ISSN(P): 2347-4599
Vol. 3, Issue 11, Nov 2015, 1-10

PREPARATION OF ECO-FRIENDLY SUSTAINABLE PLASTIC COMPOSITE FROM AGRICULTURAL WASTE

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ABSTRACT

Properties of agricultural waste plastic composites largely depend on mass ratio and chemical composition of individual components, as well as of the mixing methods and mixing sequence of the components. Significantly higher values of the properties of polypropylene – agricultural waste (PP-Aw) composites indicated that two-step procedure of the composite preparation is more favorable. Maleic anhydride (MA) in the form of maleated polypropylene (MAPP) was frequently used as a coupling agent for production of PP-Aw composites. It was found, that MA reliably improves adhesion at the waste - polypropylene interface, thus creating composites with better mechanical properties. The achievement of effective coupling action already at 1.7 % - 2% of MA addition, together with its favorable accessibility and relatively low price, recommend it for this purpose. However, the addition of MA, at the same time reduced impact resistance of the resulting composites. This study was conducted to examine the influence of MA addition to tensile strength, elongation, modulus of elasticity of PP-Aw composites made with MAPP coupling agent as per the application.

KEYWORDS: Agricultural Waste Plastic Composites, Polypropylene Matrix, Coupling Agents, Properties

INTRODUCTION

Utilization of wood biomass has rapidly increased during past decade. Especially sugarcane wastes were used as replacements for glass fibers to reinforce thermoplastic composites. This trend relies on some advantages of the wood material over inorganic fillers, such as: low price, biodegradability, recyclability, low density, and high modulus (Hwang at al., 2008; Takatani at al., 2000; Sanady at al., 1995).

Wood products and plastic polymer composites (WPC) have shown good potential to improve the water resistance of wood based composites, because thermoplastic polymers are highly hydrophobic (Wang and Morrell, 2005; Sanady at al., 1995; Mahlberg at al., 2001). On the other hand, using wood flour (WF) to reinforce polyolefins like polypropylene reduce impact and tensile strength of resulting WPC. Such influence of wood flour presents one of its major disadvantages (Kazayawoko at al., 1999; Djiporovic at al., 1997a). It is due to poor adhesion between the hydrophilic wood filler and hydrophobic thermoplastic.

This problem can be overcome by the modification of filler/matrix interface with coating suitable coupling agents on the surface of wood particles, polymer or both by compounding, blending, soaking, spraying, or other methods (Lu and McNabb, 2000). A number of investigations on isocyanates, silanes, anhydrides (maleic – MA, phtalic – PHA, succinic - SA) and anhydride-modified polymers such as maleated polypropylene (MAPP) as coupling agents (Milkovic at al., 2000;

Djiporovic at al., 1996; Maldas and Kokta, 1990,1991) were performed. The results indicated that MAPP, as known commercial agent, successfully improved the filler/matrix interface. However, the MA addition, at the same time reduced elongation, modulus and impact resistance of the resulting PPWF composites.

The limited impact resistance of PP-WF composites made with MAPP may prevent their use in some applications. On the other hand, the use of MAPP in the composite preparation is quite simple and very economical in regard to other commercial agents.

The plastic based composites, the polymers, either thermoplastics, act as a matrix and flour of wood or other natural flour are reinforcement. The reinforcing flour is the main load-carrying component in the composites. It provides high strength and stiffness as well as resistance to bending and breaking under the applied stress. Interface bonding between the fillers and the matrix is the key to transfer the stress from the matrix into the fillers across the interface. The interface adhesion between the polymer matrix and wood fillers can be improved using coupling agents. The coupling agents will form a bond between the wood flour (reinforcement) and the thermo-plastic (matrix) through the improved compatibility and developing a mechanical or chemical bonding.

The studies regarding the influence of MAPP on thermal stability of wood particles during processing are very scarce (Myers and Shahyadi, 1993). Our previous work (Djiporovic at al., 2003) revealed the presence of a large number of voids in PP-WF composites, perhaps because of the rate of thermal decomposition of lignocelluloses. Han et al. reported that the use of MgO as a processing stabilizer for wood flour-filled PP can reduce the influence of degradation on the composite properties (Han at al., 1989).

It was also observed that the properties of wood plastic composites largely depend on chemical composition of individual components, as well as on the settings parameters of the mixing methods and mixing sequence of the components. It was found that higher temperature of mixing, sousing degradation both matrix and filler at greater degree. In addition, a longer mixing time as well as a faster rotation speed of mixing decreasing the aspect ratio of particles causing reduce the mechanical properties of composites (Kokta at al., 1986; Raj at al., 1992; Sapieha at al., 1986; Stark, at al., 2003; Maldas and Kokta, 1991; Djiporovic at al., 1997b).

The mentioned reasons induced the investigations presented in this study. The influences of various ways of composite preparation on properties of PP composites were studied. All composites were prepared with equal amounts of PP matrix vs. waste flour (Aw) as filler (1:1) and with 1.7% of maleic anhydride (MA).

MATERIALS AND METHODOLOGY

Agricultural Waste

Sugarcane production waste (bagasse) is used as a reinforcing material in this study which is collected from the local Jaipur sugarcane juice producer G.T.Road The fresh bagasse of sugarcane received is dried at 103°C for 24 h to a moisture content of about 2-3% and then grounded to finer flour by using a sieve analysis. The sieve analysis found that most of the particles remained in the 35-45 mesh sizes with corresponding particle diameter ranging between 0.2 and 0.5 mm (200um<D<500um).

Figure 1: Finely Sized Sugarcane Bagasse

Thermoplastic Polymer

Both virgin and recycled post-consumer thermoplastics of PP are used in this study. Polypropylene purchased from the reliance industries limited (RIL) which is manufacturing at Hazier manufacturing division Surat, village Mora. It is homo polymer and it is full recyclable and reusable. The grade is H10 MA. After arriving at the laboratory, the plastic granules are dried at 65°C for 12 hr before mixing and compounding with sugarcane bagasse in a twin-screw extruder.

Figure 2: Polypropylene Homopolymer Granules

Coupling Agent

The coupling agent used is maleated polypropylene (MAPP). This was collected from Kaizen chemicals Ahmedabad.

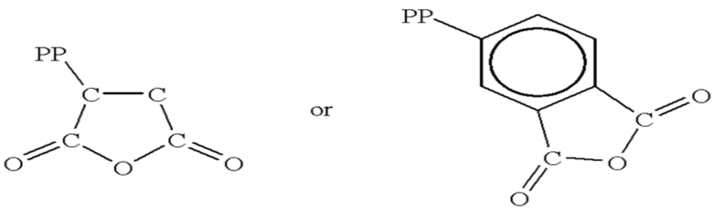

Figure 3: MAPP Chemical Structure

COMPOSITES PREPARATION

Mixing and Compounding

The sugarcane bagasse is compounded, respectively, with the recycled and the virgin plastic granules (PP) using the co-rotating twin-screw extruder at an operating condition, speed of the screw 80 rpm, cycle time 3 min temperature 186 to 190 °C.

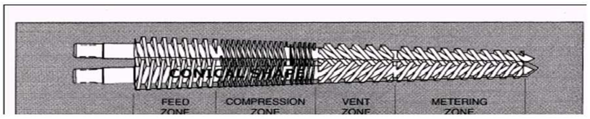

Figure 4: Conical Twin Screw Extruder

The operation conditions of the co-rotating twin-screw extruder compounding including extruder barrel temperature at different extruding zones, melt pressure, and screw speed employed for the compounding of both sugarcane bagasse and plastics (PP). The bagasse and the plastic are fed through feeders at the extruder. The plastic pellets are firstly fed from the main feeding hopper at the end of the extruder, and then the bagasse is fed through a feeder. The extruded strand coming out from the die head is then passed through a water bath and subsequently palletized. The composite formulations are designed as per the mass proportion in percentage. The plastic composition was varied from 50-100 wt. % while the wood flour varied from 0- 50 wt. % in the composites. In some formulations, coupling agent (MAPP) is added at the proportion of 3 or 5 wt. %. In the text of this paper V, R, Aw and M will be used to represent virgin, recycled, bagasse and coupling agent and the composition is given by the percentage values (% wt.) in the formulations. In the formulations where the MAPP is added, the plastics mass is reduced correspondingly thus, the total proportion of the plastics and the agent is either 50% (RPPAwM1) and (RPPAwM2).

Injection Moulding of Pellets

Injection molding (British English: moulding) is a manufacturing process for producing parts from both thermoplastic and thermo set plastic materials. Agricultural waste (bagasse) pellets material is fed into a heated barrel, mixed, and forced into a mold cavity where it cools and hardens to the configuration of the mold cavity. Operating condition of the injection moulding temperature of the cylinder is about 200 0C, temperature of the mould 50 0C and holding pressure up to 10 sec is 500 bars.

Table 1: Composite Formulation for PP Series (% by Weight)

Composite Code	Plastic Type	Plastic(Pp)	Bagasse	Coupling Agent
VPP1	Virgin	100	0	0
RPP1	Recycled	100	0	0
VPPAw1	Virgin	60	40	0
RPPAw1	Recycled	60	40	0
VPPAw2	Virgin	50	50	0
RPPAw2	Recycled	50	50	0
RPPAwM1	Recycled	47	50	3
RPPAwM2	Recycled	45	50	5

EXPERIMENTS/RESULTS AND DISCUSSIONS

Water Absorption Properties

Dimensional stability of the composites is investigated for both VPP and RPP with and without addition of the MAPP coupling agent. From the experimental results illustrated in table 2. It is found that the water absorption is increased with increasing wood content in the composites that is true both for 2 h and for 24 h water immersion. It is also found that the water absorption for 2h immersion varied from 0.02 to 1.3%, and after 24 h water immersion, the water absorption increased from 0.04 to 4.1% depending on the composite formulations.

Table 2: Experimental Result

Composite sample code	Water absorption (%)	
	2h	24h
VPP1	0.03	0.05
RPP1	0.02	0.04
VPPAw1	1.28	2.67
RPPAw1	0.94	2.15
VPPAw2	2.1	4.1
RPPAw2	1.3	3.6
RPPAwM1	0.58	1.3
RPPAwM2	0.49	1.11

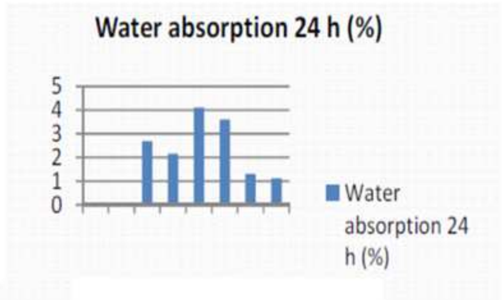

Figure 5: Water Absorption Graph

The composites made of RPP have lower water absorption compared to those made of VPP given the same bagasse to PP ratio. It is also noted that the coupling agent (MAPP) can significantly reduced the water absorption. As the RPP may have experienced chain scission beforehand a part of OH- of polymer already consumed by the bagasse thus having lesser water resident sites Additionally the bagasse dispersion is poor in case of VPP matrix composites. When coupling agent is added, the influence of the plastic to bagasse ratio is no longer as important as in the composite without the coupling agent. With 3-5 wt. % MAPP, the water absorption is reduced at 2h and 24h immersions are in the RPPAw2 composite formulation.

With the increase in bagasse content, there are more water-residence sites thus more water is absorbed. On the other hand, the composites made with higher plastic content have less water-residence sites and thus lower water absorption. The water absorption of the entirely RPP or entirely RPP was only 0.02-0.03% after 2 h and 0.04-0.05% after

24 h water immersion

Thickness Swelling Properties

Thickness swelling of the bagasse-PP composites has a similar trend as the water absorption and composites with high water absorption also showed higher thickness swelling. The thickness swelling values for the 2 h immersion varied from 0.01 to 0.32%, and these values are increased after 24 h immersion, varying from 0.02 to 1.21% depending on the composite formulation.

Samples made with lower content of bagasse have the lowest thickness swelling as for the water absorption. However, MAPP coupled composites showed less thickness swell than composite samples without the coupling agent at the same wood content. In general, the composite made of virgin and recycled PP has similar dimensional stability properties without adding the coupling agent. However, the stability properties of these composites are improved by adding 3-5 wt. % MAPP coupling agent. As cellulose fiber is the main component in the bagasse, the absorbed water mostly resides in the regions such as the flour lumens, the cell wall, and the gaps at the interface between the bagasse and the polymer matrix.

Table 3: Experimental Result

Composite sample code	Thickness swelling 24h (%)	
	2h	24h
VPP1	0.01	0.03
RPP1	0.01	0.02
VPPAw1	0.21	0.71
RPPAw1	0.18	0.59
VPPAw2	0.32	1.21
RPPAw2	0.28	1.09
RPPAwM1	0.16	0.55
RPPAwM2	0.11	0.43

Microstructure Characterization

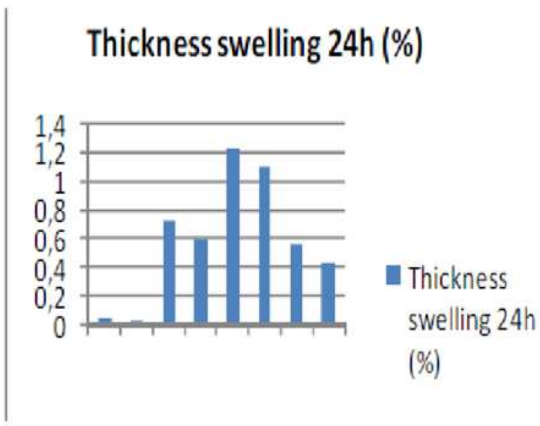

Figure 6: Swelling Graph

Microstructure of the fractured surface of specimens tested in tensile is examined using SEM. SEM images of the sugarcane bagasse-PP composites at filler loading of 50 wt. % for VPP and RPP matrices are shown in Fig.7(a) and (b), in 1000× magnification. From these images, it is clearly observed that there are distinct cluster and gaps between polymer matrix and bagasse. The patterns from bagasse that are so weakly bonded to the matrix have been released from the matrix during fracture. The failure surface is undulated with clear bagasse surfaces with visible trachaids and lumen, indicating the path of weaker part through the wood-wood interface and weakest polymer matrix. This suggests that the interface between the bagasse and PP matrix is weaker due to the poor dispersion and compatibility.

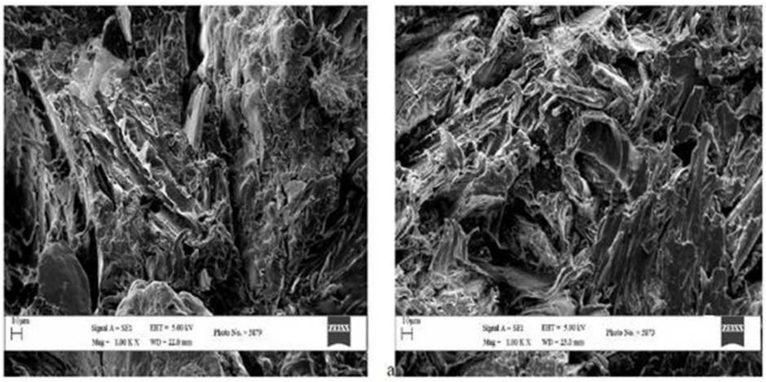

Figure 7: SEM Images(X1000) of Fractured Surface of A) Vppaw2,B)Rppaw2

The dispersion of the bagasse in the RPP matrix (Figure 8(b)) is uniform as compared to VPP matrix (Figure 7(a)).

This may be due to the different grade of plastic and other impurities in the RPP. In some cases, the part of the wood lumen is filled with plastic that could increase the strength of the composites because of mechanical interlocking. When bagasse content is increased, the polymer matrix is no longer continuously distributed and many bagasse are in direct contact with one another, resulting in poor bonding at adhesion at the interface.

Figure 8(a) and (b) show SEM images of fracture surface of the 3 and 5 wt. % MAPP incorporated composites filled with 50 wt. % bagasse. SEM image showed that there are no clear gap between bagasse and PP matrix, indicating the good interface bonding. The fracture surface of the composite showed a very limited amount of torn matrix, suggesting that the matrix is more brittle than those composites without MAPP.

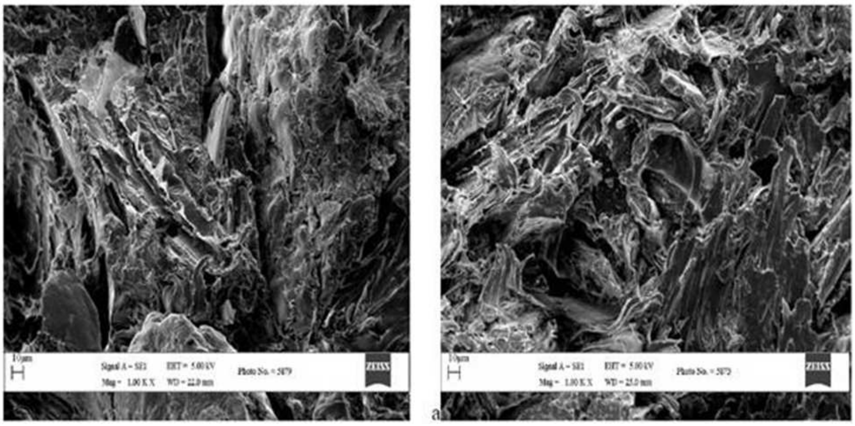

Figure 8: SEM Images(X1000) of Fractured Surface of A) Rppawm1,B)Rppawm2

It is also seen that a crack running through the bagasse, and this could be an indication of stress-transfer from the matrix to the bagasse. The interfacial bonding between the filler and the PP matrix is improved due to the esterification mechanism and the fracture occurred at the filler itself. This means that the stress is well propagated between the filler and the matrix polymer, resulting in enhanced flexural strength and modulus in response to stress. In addition, the fracture surface showed a very limited amount of torn matrix, suggesting that the composite is more brittle. In general, coupling agent is randomly distributed in composites and randomly reacted with bagasse and the matrix to form graft polymerization. Hence, grafting sites are randomly distributed on bagasse, and a network of coupling agent is formed at the interface. However, there is a limit for chemical coupling reaction and only part of coupling agent was grafted onto bagasse surface and even cross-linked at the interface. Further, the fracture surface of the composite containing 5 wt % MAPP showed a very limited amount of torn matrix, suggesting that the matrix is more brittle than those in composites containing 3 wt % MAPP. This phenomenon is mainly due to the excessive modification of the base polymer.

Comparison between Figure 7 and 8 it is observed that non-coupled composite samples had a weak interfacial region and damage mainly occurred along the loose and weak interface between the bagasse and PP matrix under loading. However, with the MAPP coupled composites, the bagasse is combined with the PP matrix through the covalent bonding or strong interfacial bonding, and interfacial fracture usually accompanied with a cross section damage of the bagasse. Hence, after the failure, the bagasse surface in the untreated composites is smooth; whereas the bagasse in the MAPP treated composites has a rough surface. It is embedded in the matrix with a chemical link.

CONCLUSIONS

SEM images of the fractured surfaces of composites confirmed that an addition of the MAPP coupling agent improved the interfacial bonding between the polymer and the bagasse filler for the RPP based composites. Stability and mechanical properties of the composites can be achieved by addition of coupling agents. SEM images of the fractured surfaces of composites confirmed that bonding strength between recycle PP and bagasse stronger then the bonding strength between virgin PP and bagasse. Dimensional stability propertied of the composites are improved with the addition of 3-5 wt. % MAPP coupling agent in the same composite formulations. Bagasse plastic composites are made using recycled polypropylene (RPP) with bagasse (sugarcane waste) as filler. Post-consumer plastics and waste from agricultural are used as raw materials. Corresponding composites are also made for some composite formulations using virgin plastics (VPP) for comparative studies. Composites sample are made through melt compounding and injection moulding based on plastic type (PP), plastic form (virgin, recycled), bagasse content and adding of MAPP coupling agent.

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