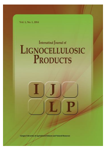

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Fiber reinforced plastic composites using recycled materials

A.R. Ashori [a,*], A. Nourbakhsh [b]

[a] Department of Chemical Technologies, Iranian Research Organization for Science and Technology (IROST), P.O. Box 15815-3538, Tehran, Iran
[b] Department of Wood and Paper Science, Research Institute of Forests and Rangelands (RIFR), Tehran Iran

*Corresponding author. E-mail: ashori@irost.org

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Abstract

This work investigates the feasibility of using recycled high density polyethylene (rHDPE), recycled polypropylene (rPP) and old newsprint fiber (ONP) to manufacture fiber reinforced composites. The boards were made through air-forming and hot press. The effects of the fiber loading and coupling agent content on tensile, flexural, internal bond properties and water absorption and thickness swelling of wood-fiber plastic composites were studied. In general, the weight content of ONP is a key parameter that would substantially influence the physical and mechanical properties of the samples. The obtained results showed that the use of maleated polypropylene as coupling agent, improved the compatibility between the fiber and both plastic matrices, and mechanical properties of the resultant composites compared well with those of non-coupled ones. Based on the findings in this study, it appears that recycled materials can be used to manufacture value-added boards without having any significant adverse influence on board properties. It was also found that composites with rHDPE provided moderately superior properties, compared with rPP samples.

Keywords: Coupling agent, Fiber reinforced composite, Mechanical properties, Old newsprint fiber,

1. Introduction

Generating of solid and industrial wastes is increasing at an alarming rate and it is difficult to dispose of the growing volume of municipal solid wastes (MSWs) in landfills because most people will not tolerate MSWs in their neighborhood. Today, MSWs are one of the greatest issues facing mankind. Several countries have made efforts to solve this issue by trying to recycle waste materials (Jayaraman and Bhattacharya, 2004; Kamdem et al., 2004; Talavera et al., 2007; Żenkiewicz and Dzwonkowski, 2007; Cui et al., 2008).

The possibility of using MSWs in the development of composites is very attractive, especially with respect to the large quantity of plastic waste generated daily. Hence, the development of new value added products, to utilize the recovered plastics, is assuming greater importance. The addition of recycled wood fibers to waste plastics renders the resulting composites viable from both the mechanical properties and the environmental points of view. Besides, bio-composite products may be reclaimed and recycled for the production of second-generation composites.

Table 1 shows the total weight and percentage of produced MSWs in Tehran (capital of Iran). In 2006, the total quantities of MSWs in Tehran add up to 84,200 tones, generated by the population of 7.728 million. That is, about 1.1 kg wastes are generated per capita per day (Ashori, 2008a). Paper and paperboard and plastics account for an increasing fraction of MSWs in Tehran, as well as around the world. In 2006, the amount of paper and paperboard and plastics in MSWs reached 18,600 and 9,400 tones, comprising 22.1% and 11.2% of the waste stream by weight, respectively (Table 1). High density polyethylene (HDPE) plus polypropylene (PP) is the largest component, followed by polyethylene terephthalate (PET), polystyrene (PS) and low density polyethylene (LDPE). This creates a substantial amount of polyolefins, especially plastic bottles and rigid containers, which can potentially be recovered for recycling. Plastic products used for packaging are often discarded after a single use resulting in a large supply of waste polymeric materials. Most single polymer plastics made from petroleum are relatively easy to recycle. Therefore, with an efficient collection, separation and recycling system, discarded plastics can be recycled into new products with only the addition of energy. Properties of some waste plastics are similar to those made from virgin materials, with tests indicating only a slight change in mechanical properties of recycled polyethylene (Jayaraman and Bhattacharyya, 2004). Products manufactured from waste plastics are increasing and include fiber reinforced plastic composites (FRPCs) (Kamdem et al., 2004). FRPCs made with waste wood fiber/flour have also gained popularity due to the low cost of recycled wood to the manufacturers (Ashori, 2008b).

Table 1. Composition of materials in Tehran (Iran) municipal solid waste in 2006.

Source	Amount in municipal solid waste	
	Weight ($\times 10^3$ t)	Percentage
Dried bread	35.5	42.1
Paper & paperboard	18.6	22.1
Miscellaneous inorganic	11.1	13.2
Plastics	9.4	11.2
Metals	7.6	9.0
Glass	1.4	1.7
Textiles	0.6	0.7
Total	84.2	100

Source: Ashori (2008a)

The possibility of using recycled materials in the development of FRPCs is very attractive, especially with respect to the large quantity of wood fiber/plastic waste generated daily. Waste paper can meet all the requirements in order to replace inorganic fillers in thermoplastic composites. Advantages associated with bio-composite products include lighter weight and improved acoustic, impact, and heat reformability properties—all at a cost less than that of comparable products made from plastics alone. In addition, these composites may possibly be reclaimed and recycled for the production of second-generation composites. MSWs generated each year contain potentially useful and recyclable materials for composites. Interest is high for the use of MSWs in composites thus providing cost and environmental benefits.

A relatively large body of published literature in the area of virgin fiber-reinforced thermoplastic composites exists (Saheb and Jog, 1999; Lundin et al., 2004; Foulk et al., 2004; Selke and Wichman, 2004; Herrera-Franco and Valadez-Gonzalez, 2005; Ashori and Nourbakhsh, 2008). These studies have successfully proven their applicability to various fields of technical applications, especially for load-bearing applications. However, work done on recycled plastic/wood fiber systems is still limited. In this work, the potential of using MSWs from wood fiber and plastics as materials for making FRPCSs was examined. The effect of fiber loading and coupling agent addition on the mechanical properties and dimensional stability is also investigated.

2. Materials and Methods

2.1. Materials

Fibers: The lignocellulosic material used for this study was recycled old newsprint (ONP) fibers. The characteristics of ONP were determined following the standards outlined in the TAPPI Test Methods (2002). The chemical and morphological characteristics of the ONP were as follows: cellulose 70.2±2.1%, lignin 22 ± 1.6%, extractives (hot water) 4.5 ± 0.7%, ash 1.8 ± 0.2%, fiber length 0.92±0.11 mm, fiber width 26.9 ± 3.2 μm and aspect ratio 82.2 ± 5.8.

Polymer matrix: Recycled high density polyethylene (rHDPE) and polypropylene (rPP) granules were procured from local plastic recycling plant, which were derived mainly from post-consumer plastics wastes. The plastic granules were thoroughly washed with water and dried at 70 ˚C for 12 h. The measured properties of rHDPE and rPP showed melt flow indices, MFI, of 15 and 7g/10 min at 190 ˚C and densities of 0.95-0.97 and 0.90 g/cm^3, respectively.

Coupling agent: Maleated polypropylene (MAPP) was obtained from Eastman Chemical Products, Inc., in the form of Epolene G-3003™, which has an acid number of 8 and a molecular weight of 103,500.

2.2. Board manufacturing

The ONP fibers at an initial moisture content of 3% were sprayed with 40% solids content MAPP anionic emulsion, to achieve a MAPP level of 2 and 4% (dry weight basis). The control boards were not treated with MAPP. A series of composites having 55, 70 and 85 wt% of fibers were prepared. The fibers and matrix polymers were blended using a laboratory scale air-mixing process. The mixtures were then placed in a rectangular mold box with a size of 36 × 31 cm^2 and manually formed. A manually controlled, hot-press (Burkle L100) was used to press the boards at 200 ˚C for 6 min at a maximum pressure of 3 MPa. The boards were then transferred to a cold press and pressed for further 6 min at 5 MPa until they reached a final temperature of 36 ˚C. The board thickness was controlled by using 32 mm spacers. All boards were trimmed to 32 × 27 cm^2, with a density of 0.85 g/cm^3.

2.3. Measurements

2.3.1. Mechanical properties

All specimens were tested following ASTM standard D 790 for flexural, D 638 for tensile strength and modulus, and D 5651 for internal bonding strength. For these tests, the Instron universal testing machine (Model 1186) was used, where a load was applied on the specimen with strain rate of 1.5 mm/min. Test specimen dimensions were according to the respective ASTM standards. Each value obtained represented the average of six samples. All tests were done under controlled conditions (50% relative humidity and 23 °C).

2.3.2. Dimensional stability tests

The thickness swelling and water absorption tests were conducted in accordance with ASTM D 570. Before testing, the weight and dimensions, i.e. length, width and thickness of each specimen were measured. Conditioned samples of each type of composite were either soaked in distilled water at room temperature for 2 h. Samples were removed from the water, patted dry and then measured again. Each value obtained represented the average of six samples.

3. Results and Discussion

3.1. Tensile properties

Results for tensile strengths and moduli of composites as a function of MAPP and fiber content are presented in Figure 1. As it can be seen, performance of composites made from rHDPE was at least as good as that of composites made from rPP, except for 70 wt% fiber loading, where rPP was significantly stronger. In order to evaluate the effectiveness of fiber loading on strength behavior of composites, they have been compared with various coupling agent content. When comparing the tensile properties of the materials, the 55 wt% samples performed significantly better (higher) than other samples. The tensile strength markedly decreased with increasing fiber content by creating poor interfacial bonding among hydrophilic filler, coupling agent and hydrophobic matrix polymer. The decrease in tensile strength is governed by the fact that the ONP fibers with 70 and 85 wt% concentration need more coupling agent in order to improve the bonding strength between the fiber and the matrix polymer. In general, composites made from 4% MAPP exhibited improved strength properties because creating more fiber-MAPP-plastics contact and therefore increasing the potential for bonding. It is clear that, to improve the reinforcing effect of fiber, the presence of coupling agent is vital. In addition, various parameters influence the mechanical properties of fiber-reinforced composites including the fiber aspect ratio, fiber-matrix adhesion, stress transfer at the interface and mixing temperatures (Ashori and Nourbakhsh, 2008).

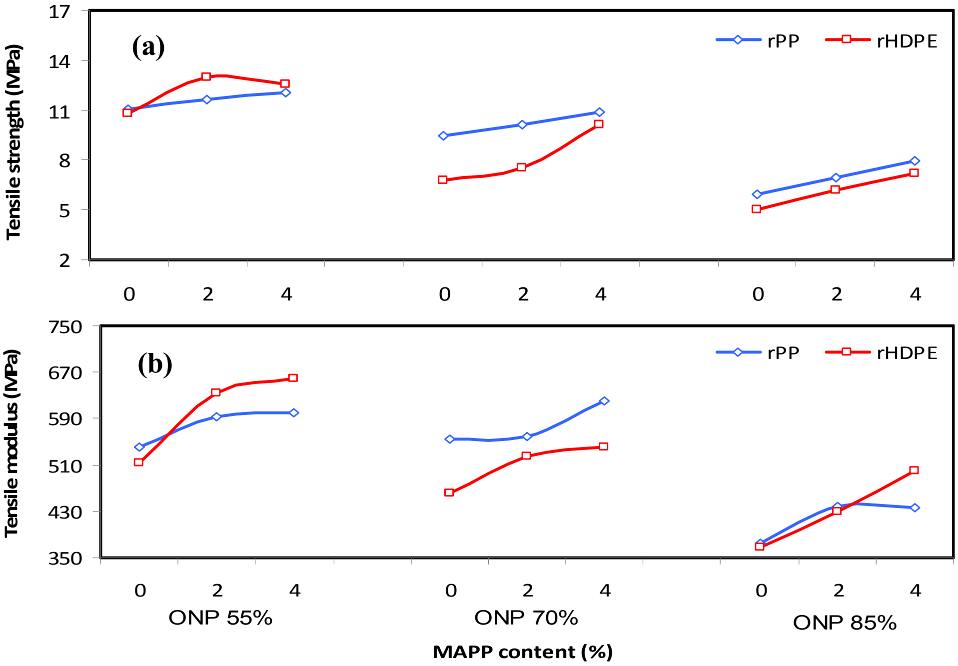

Figure 1. Comparisons of tensile strengths (a) and moduli (b) of the composites.

3.2. *Flexural behavior*

Figure 2 illustrates the results of flexural tests done on the composite specimens with and without coupling agent treatment. From these figures the benefit of the ONP fiber reinforced thermoplastics is readily apparent. Flexural strength and modulus reached the maximum value at 85 and 4 wt% of fiber and MAPP content, respectively. However, the addition of 2 and 4 wt% MAPP to polymer matrix significantly improved the flexural properties of composites as compared to 0 wt% of coupling agent. As expected, composites with high fiber content and treated with MAPP exhibited better flexural strength than the untreated ones. The improvement in flexural properties of the composites can be attributed to high strength and modulus of cellulosic fibers and the improved interfacial adhesion between the matrix and fiber which leads to more uniform distribution of applied stress and requires more energy for fiber debonding (Nourbakhsh et al., 2008).

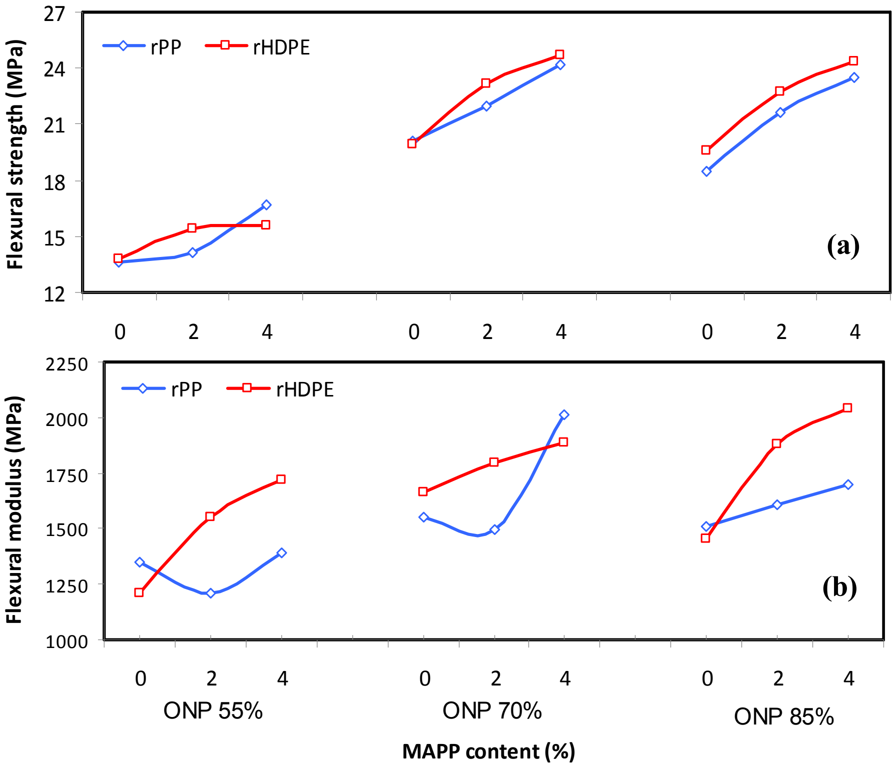

Figure 2. Comparisons of flexural strengths (a) and moduli (b) of the composites.

3.3. *Internal bonding strength*

As can be derived from Figure 3, composites with high ONP fiber content possess low internal bonding strength. Wood fiber is a kind of stiff organic filler, so adding fiber could decrease the internal bonding strength of composite. In agreement with previous researches (Yang, 2007; Nourbakhsh and Ashori, 2008), the internal bonding strength of the composites increased with increasing coupling agent. The internal bonding strength increases with MAPP content from 0.07 to 0.61 MPa. Whereas, without coupling agent, the internal bonding strength of the composites are in the range of 0.06 to 0.42 MPa at the same fiber loading. The maximum internal bonding strength was in boards with 55 wt% fiber and 4 wt% MAPP. However, internal bonding values for boards with different amounts of fiber were not significantly different from each other. It was found that composites with 4 wt% MAPP provided significantly higher internal bonding, compared with uncoupled samples. As mentioned before, the use of MAPP improves interaction and adhesion between the fibers and matrix.

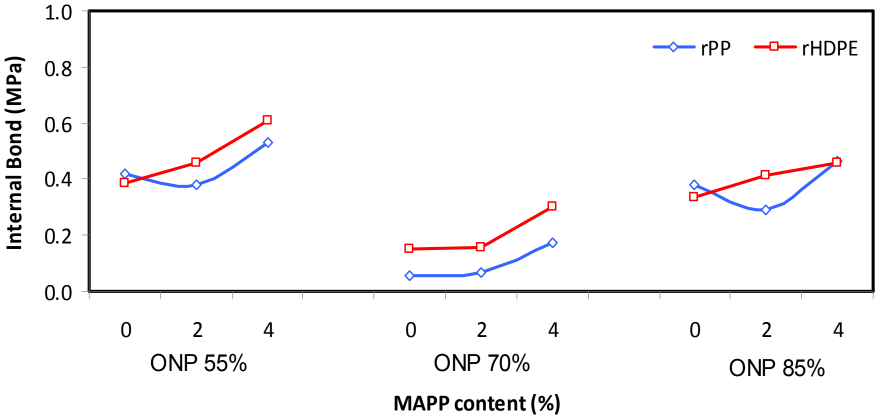

Figure 3. Comparisons of internal strengths of the composites.

3.4. *Water absorption*

Water sensitivity is an important criterion for many practical applications of FRPC products. Figure 4a shows the percentages of the water absorption for the composites, which vary depending upon the fiber loading and coupling agent content. The water absorption increases with increasing fiber content in the composites.

It believes that polymers do slightly absorb moisture, indicating that moisture is absorbed by the lignocellulosic fibers in the composite. With the increase in the fiber content, there are more water residence sites thus more water is absorbed. Additionally, large number of porous tubular structures present in fiber accelerates the penetration of water by the so-called capillary action. Similar results have been published by Ashori (2008a). Water absorption in a fibrous composite is dependent on temperature, fiber loading, orientation of fibers, permeability of fibers, surface protection, area of the exposed surfaces, diffusivity, void content, hydrophilicity of the individual components, etc.

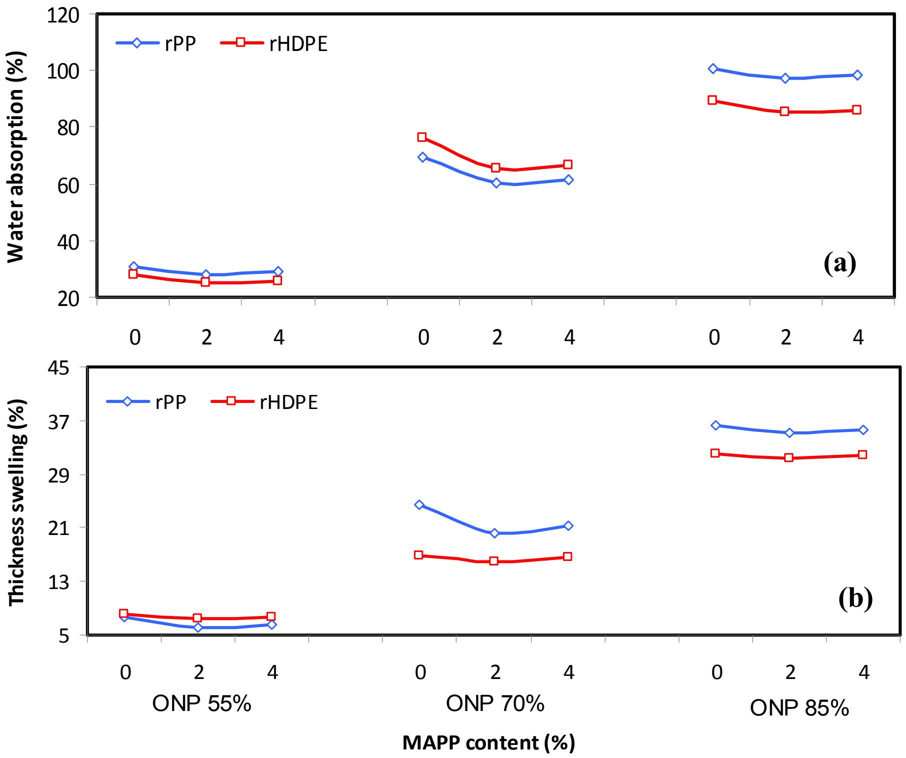

Figure 4. Comparisons of water absorption (a) and thickness swelling (b) of the composites.

3.5. Thickness swelling

The thickness swelling of the rHDPE and rPP composites increases with the water absorption and thus has a similar trend to the water absorption regarding the impacts of ONP fiber to plastics ratio and coupling agent (Figure 4b). When the coupling agent increases, the bonding of fiber and matrix increases and decreases the absorption of water by fibers. If the water absorption decreases, the thickness swelling decreases. For rHDPE composites, the thickness swelling values varied from 7.4 to 36.3%. Interestingly the composites made of rHDPE have lower thickness swelling compared to those made of rPP at the same fiber/MAPP content. It is also noted that samples made with lower content of fiber have lower thickness swelling and this is true both for the composites made from rHDPE and those made from rPP. However, addition of MAPP reduced thickness swelling for the same fiber content. The composites with 55 wt% of ONP fiber and 2 and 4 wt% MAPP had the lowest thickness swelling.

Thickness swelling and water absorption could easily be controlled by adding water repellent chemicals in production. Also heat treatment of fiber is known to add some enhancement of dimensional stability of the boards.

4. Conclusions

In this study, FRPCs were made from both rHDPE and rPP with different amount of ONP fiber and MAPP content. The physical and mechanical properties, important for products and their utilization, were investigated for the effects of coupling, fiber loading and plastic types. Following conclusions are drawn from the current work:

Results indicate that the mechanical properties of the composites made from post-consumer rHDPE are similar to or, in some cases, better than the composites made from the rPP. The composites with low ONP content and coupled with the MAPP have better mechanical properties than all of the non-coupled ones. However, the composites made with lower fiber content without the coupling agent show lower flexural properties. The water absorption and thickness swelling increase with the fiber content; however, adding coupling agent reduces (improves) these properties significantly. The composites of 55 wt% of rHDPE with the 2–4 wt% MAPP can achieve adequate stability. The results of the present work clearly show that ONP, rHDPE and rPP can be successfully used to produce stable and strong FRPCs. Mechanical properties and dimensional stability of composites can be achieved by addition of coupling agent in production.

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