# Manufacturing Wood–Plastic Composites from Waste Lignocellulose Plus *Haloxylon* Species and Recycled Plastics

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## Abstract

The aim of this research is to show useful utilization of agricultural residues such as cotton stalks and branches of pistachio, pomegranate, and *Haloxylon* species with recycled plastic in manufacturing wood–plastic composite (WPC) panels. Wood–plastic panels were made from a combination of agricultural residues (as natural fiber) and recycled plastic (as resin) at 50 percent, and 60 percent by weight fiber loading. Density and dimensions of the panels were 0.61 g/cm$^3$ and 350 by 350 by 14 mm, respectively. Physical and mechanical properties of the panels including thickness swelling, water absorption, static bending (modulus of rupture and modulus of elasticity ), and internal bond were investigated. Physical and mechanical properties of the WPC panels decreased with an increase in fiber content from 50 percent to 60 percent. Physical and mechanical properties of samples made with 50 percent plastic were higher than samples with 40 percent plastic. The best values of physical and mechanical properties of the WPC panels were found at 10 percent and 5 percent *Haloxylon* particle loading, respectively. The highest values of mechanical properties of WPC panels were found at 50 percent plastic and 5 percent *Haloxylon* particle loading.

Wood–plastic composites (WPC) are widely used in North America, the most common of which are produced by mixing wood flour and plastics to produce a material that can be processed similarly to 100 percent plastic-based products (Sentler 1997, Bowyer and Stockman 2001, Clemons 2002, Ballerini 2004).

WPCs are roughly 50:50 mixtures of thermoplastic polymers and small wood particles. The presence of wood in a plastic matrix can result in a stiffer and lower-cost material than if plastic alone was used. Also, the compression properties (resistance to crushing) for most WPCs are superior to those of wood loaded perpendicular to the grain (Sutherland and Guedes Soares 1997).

WPCs are a combination of wood flour and thermoplastics that form a woodlike material used in the construction of primarily outdoor house decking, but to a lesser extent in railings, furniture, and some automobile parts (Charrier 1991). In recent years there have been a significant number of reports of deck, balcony, and porch failures, some of which have resulted in injury and loss of life (Carradine et al. 2007). As products get more advanced, customers need greater assurance that the product will perform satisfactorily and safely over time (Hesch 1968).

Wood used for WPCs is commonly in the form of wood flour fine particles and typically makes up 50 percent of the WPCs. Either recycled or virgin plastic materials can be used to produce WPC. Some of the thermoplastic resins include low- and high-density polyethylene, polypropylene, and polyvinyl chloride. In general, polyethylene-based WPCs are more thermally stable and ductile in nature. Polypropylene-based WPCs have higher stiffness and tend to be more brittle. Many composite materials are made of a large number of small fibers whose properties, dimensions, and initial defects can only be described realistically by a probabilistic formulation (Simonsen 1995).

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Waste wood and other lignocellulosic materials are abundant. Today the annual global production of lignocellulosic fibers from man-made crops is about 4 billion tons, of which roughly 60 percent comes from agricultural crops and 40 percent from forests (Ntalos 2000).

The social pressure for developing more ecologically friendly building materials (substitutes for plastic, metal, etc.) increases the demand for availability of more natural renewable raw materials. At the same time, the capacity of world's forests to produce wood fibers is decreasing for various reasons (McNatt 1973). The foreseen deficit in wood and wood fibers led to much research and industrial efforts to find alternative lignocellulosic raw material sources. Agricultural residues, planting of fast-growing and annual plants, and recycling of wood products have been looked upon as very important sources (Nielsen and Landen 1994, Groom et al. 1996, Verhey et al. 2002).

However, it is necessary to improve the physical and mechanical properties as well as the appearance of such products to have a strong market share in the wood composite panel industry. There are several ways to improve overall properties of WPC panels, namely, using the right size of raw material, optimum mixture and preparation of the elements in the product, and adding small amounts of additives, i.e., coupling agents, pigments, antimicrobials, or light stabilizers during their production (Olesen and Plackett 1999, Murthy et al. 2009, Taylor et al. 2011).

Annually, a large amount of lignocellulosic materials derived from garden trees, agricultural wastes, and *Haloxylon* trees goes to waste in Gonabad Region, Iran. With this study, we planned for the optimal use of these lignocellulosic materials and more economically efficient use of recycled plastic. Therefore, the main objective of this work is to investigate some of the properties of WPC panels manufactured from agricultural residues with recycled plastic.

## Materials and Methods

### Materials

Wood particles with dimensions of approximately 12 by 8 by 3 mm were supplied from surplus of lignocellulose such as branches of trees of pistachio, pomegranate, and *Haloxylon,* and the cotton stalks in Gonabad, Iran. Polymeric materials were as produced from recycled plastics in Iran. The moisture content of the wood particles according to ASTM D-1037 (American Society for Testing and Materials [ASTM] 1999), as determined by oven-dry weight, was found to be 8.4 percent. Recycled plastic (polyethylene) was prepared in the form of small particles with dimensions of 10 by 10 by 1 mm. Tables 1 and 2 show the list of the wood particle percentages used for panel production.

### Flat-pressed WPC panel manufacture

Flat-pressed WPC panels were manufactured using a Ranjbar hydraulic hot press with dimensions 600 by 600 mm at the laboratory of Zabol University in Iran. Wood particles were manually mixed with plastic particles, and then the mixture was formed into a mat on a metal caul plate, using a 350 by 350 mm forming frame. Wax paper was used to avoid direct contact of the plastic particles with the metal plates of the hot press. The WPC mats were then subjected to the hot pressing. The maximum press pressure, pressing temperature, and total press cycle were 35 kg/cm$^2$, 180°C, and 25 minutes, respectively. At the end of the press cycle, the WPC panel was removed from the press for cooling. The nominal panel size was 350 by 350 by 14 mm after the cooling process. A total of 12 experimental panels, three for each type of panel, was manufactured. The average density of the WPC panels with dimensions 152 by 76 by 14 mm was 0.61 g/cm$^3$ (Fig. 1).

*Table 1.—Mechanical test results.*

| Panel type | Percentage[a] | Mechanical properties: Modulus of rupture (MPa) | Modulus of elasticity (MPa) | Internal bond (N/mm$^2$) |
|---|---|---|---|---|
| A | 40% plastic<br>5% *Haloxylon* | 3.54 | 50.79 | 0.30 |
| B | 40% plastic<br>10% *Haloxylon* | 4.12 | 65.39 | 0.24 |
| C | 50% plastic<br>5% *Haloxylon* | 4.77 | 72.88 | 0.37 |
| D | 50% plastic<br>10% *Haloxylon* | 3.38 | 57.19 | 0.32 |

[a] Plastic:wood (40%:60%, 50%:50%) and *Haloxylon*:mixture of waste lignocellulosic (5%:95%, 10%:90%).

### Determination of mechanical properties

Modulus of rupture (MOR) and modulus of elasticity (MOE) of the specimens were conducted according to ASTM D-1037 (ASTM 1999). A total of 12 specimens with dimensions of 250 by 50 by 14 mm, perpendicular to the panel surface, was tested for each type of panel to determine MOR and MOE. The bending specimens were tested by a HOUNS Field H25KS testing machine with a load cell with a capacity of 25 kN.

Internal bond (IB) tests were conducted on the specimens cut from the experimental WPC panels according to ASTM D-1037 (ASTM 1999). A total of 24 specimens with dimensions of 50 by 50 by 14 mm was used for each type of panel to determine the IB strength.

### Determination of water resistance

Water resistance of the panels, thickness swelling (TS), and water absorption (WA) were evaluated according to

*Table 2.—Physical test results.*

| | | Physical properties | | | | |
|---|---|---|---|---|---|---|
| | | | Thickness swelling (%) | | Water absorption (%) | |
| Panel type | Percentage[a] | Density (g/cm$^3$) | 2 h | 24 h | 2 h | 24 h |
| A | 40% plastic<br>5% *Haloxylon* | 0.63 | 9.12 | 10.89 | 49.26 | 58.07 |
| B | 40% plastic<br>10% *Haloxylon* | 0.62 | 9.8 | 11.87 | 49.3 | 57.20 |
| C | 50% plastic<br>5% *Haloxylon* | 0.65 | 5.48 | 7.28 | 24.14 | 45.67 |
| D | 50% plastic<br>10% *Haloxylon* | 0.56 | 5.50 | 6.46 | 38.3 | 46.59 |

[a] Plastic:wood (40%:60%, 50%:50%) and *Haloxylon*:mixture of waste lignocellulosic (5%:95%, 10%:90%).

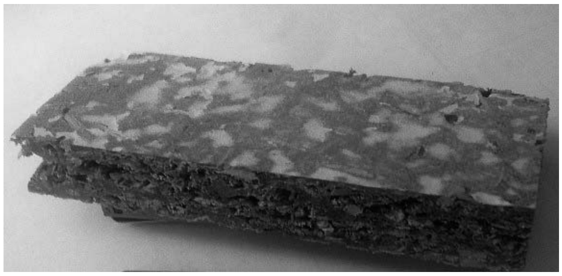

*Figure 1.—Wood–plastic composite (WPC) panel (152 by 76 by 14 mm).*

ASTM D-1037 (ASTM 1999). Twelve specimens, 150 by 150 by 14 mm, from each type of panel were used for the TS and WA properties. Before tests, the samples were conditioned at 20°C. The thickness of each sample was measured at four points, and the weight of each sample was measured. Then the samples were submerged in water taken from the same location to calculate swelling values. Density of the specimens was evaluated according to the test method specified in ASTM D-1037 (ASTM 1999).

## Statistical analysis

An analysis of variance (ANOVA) was conducted ($P < 0.05$) to evaluate the effect of the percentage of plastic and *Haloxylon* particles on the physical and mechanical properties of WPC panels. Significant differences among the average values of the WPC groups were determined using the Tukey multiple-range test.

# Results and Discussion

The *Haloxylon* has poor technological properties and an approximate density of 1 g/cm$^3$; because of the high density, it has no industrial use and it is used to stabilize sands in Iran. Therefore, it does not have suitable properties to produce industrial panels, so we decided to use it at 5 percent and 10 percent as dry weight in thermoplastics. The selection of the percentages is based on given percentages of wood and plastic that have resulted in suitable properties, and also according to other WPC research.

The results of ANOVA are shown for mechanical and physical properties of WPC panels in Table 3.

*Table 3.—Results of analysis of variance test for mechanical and physical properties of wood–plastic composite panels (interaction between plastic and* Haloxylon*).*

| Dependent variables[a] | Sum of squares | df | Mean square | $F$ | Significance[b] |
|---|---|---|---|---|---|
| MOR | 2.858 | 3 | 0.953 | 1.022 | 0.439 ns |
| MOE | 694.148 | 3 | 231.383 | 0.329 | 0.805 ns |
| IB | 0.023 | 3 | 0.008 | 3.320 | 0.087 ns |
| TS 2-h water soaking | 43.554 | 3 | 14.518 | 1.535 | 0.288 ns |
| TS 24-h water soaking | 59.666 | 3 | 19.889 | 1.686 | 0.256 ns |
| WA 2-h water soaking | 385.728 | 3 | 128.576 | 3.790 | 0.067 ns |
| WA 24-h water soaking | 357.098 | 3 | 119.033 | 3.997 | 0.060 ns |

[a] MOR = modulus of rupture; MOE = modulus of elasticity; IB = internal bond; TS = thickness swelling; WA = water absorption.
[b] 95% confidence level; ns = not significant.

## Mechanical properties

The mechanical properties are shown in Table 1 and Figure 2. The highest MOR value was 4.77 MPa for panel type C and the lowest MOR value was 3.38 MPa for panel type D. The highest and lowest MOE values were 72.88

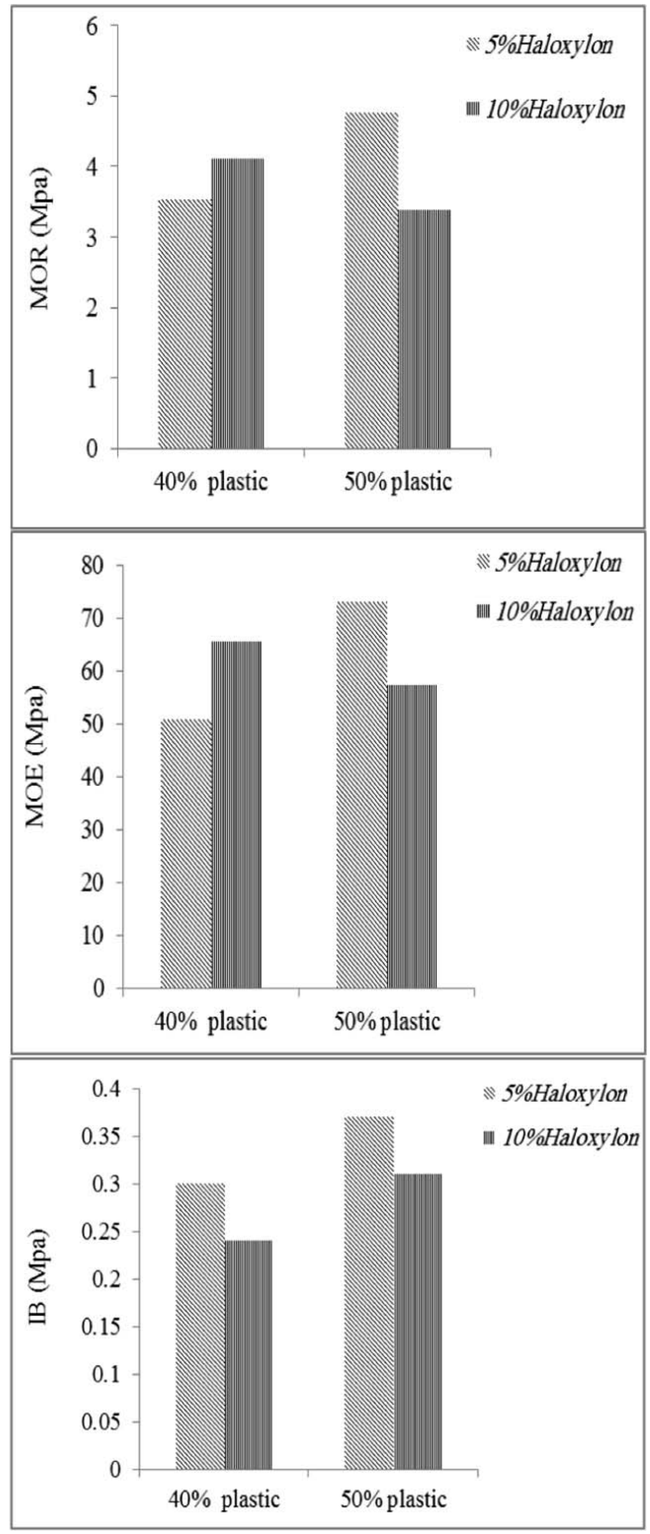


*Figure 2.—Mechanical properties results. MOR = modulus of rupture; MOE = modulus of elasticity; IB = internal bond.*

MPa and 50.79 MPa for panel types C and A, respectively. Overall, the samples did not show any significant difference in static bending (MOR and MOE). With an increase in percentage of plastic in the panel, MOR and MOE values increased. In similar studies, it has been observed that the flexural strength decreases with increasing wood flour content from 60 percent to 80 percent (Kazemi Najafi et al. 2010). It is often assumed that the increase of polypropylene WPCs reduces the MOE but this assumption is not always true. The increase of polypropylene is always associated with changes in other important factors that are related to the MOE. By changing the amount of plastic, the amount of wooden material and the mixed moisture will change and will affect the MOE (Klyosov 2007).

With an increase in percentage of *Haloxylon* particles in the panel, MOR values decreased and MOE values increased. The obtained result is because of the same reason mentioned above.

The IB values of the WPC panels were significantly increased by the increased percentage of plastic, but with the increased percentage of *Haloxylon* particles, IB values decreased, whereas panel types A, B, C, and D did not show any significant difference at 95 percent confidence level.

Generally in WPCs with a high wood percentage, plastic plays the role of matrix (glue) for bonding wood particles together, which is due to the melting of plastic. Therefore, when the plastics percentage increases, the value of these connections will also increase, which results in increasing mechanical strength.

The type B WPC panels had the lowest IB value, with 0.24 N/mm$^2$, whereas the highest IB value, 0.37 N/mm$^2$, was found for the WPC panel type C (Table 1). The treatment groups were determined according to the Tukey multiple-range test. There was no significant difference for MOR, MOE, and IB (Table 3).

In a previous study, it was determined that industry particleboard had the same IB values as that of WPC panels (Klyosov 2007). However, MOR and MOE values of WPC panels were lower than industry particleboards (Jiang 2009).

## Physical properties

The TS results of 2- and 24-hour water soaking tests are presented in Table 2 and Figure 3. The samples did not show a significant difference after the TS tests. The lowest TS values were 5.48 percent and 6.46 percent for samples C and D for 2- and 24-hour water soaking, respectively (Table 2). WA of the samples after the 2- and 24-hour water soaking test are shown in Table 2 and Figure 3. WA values for plastic showed a significant difference at 95 percent confidence level. WA of the WPC panel type C was lower than the other

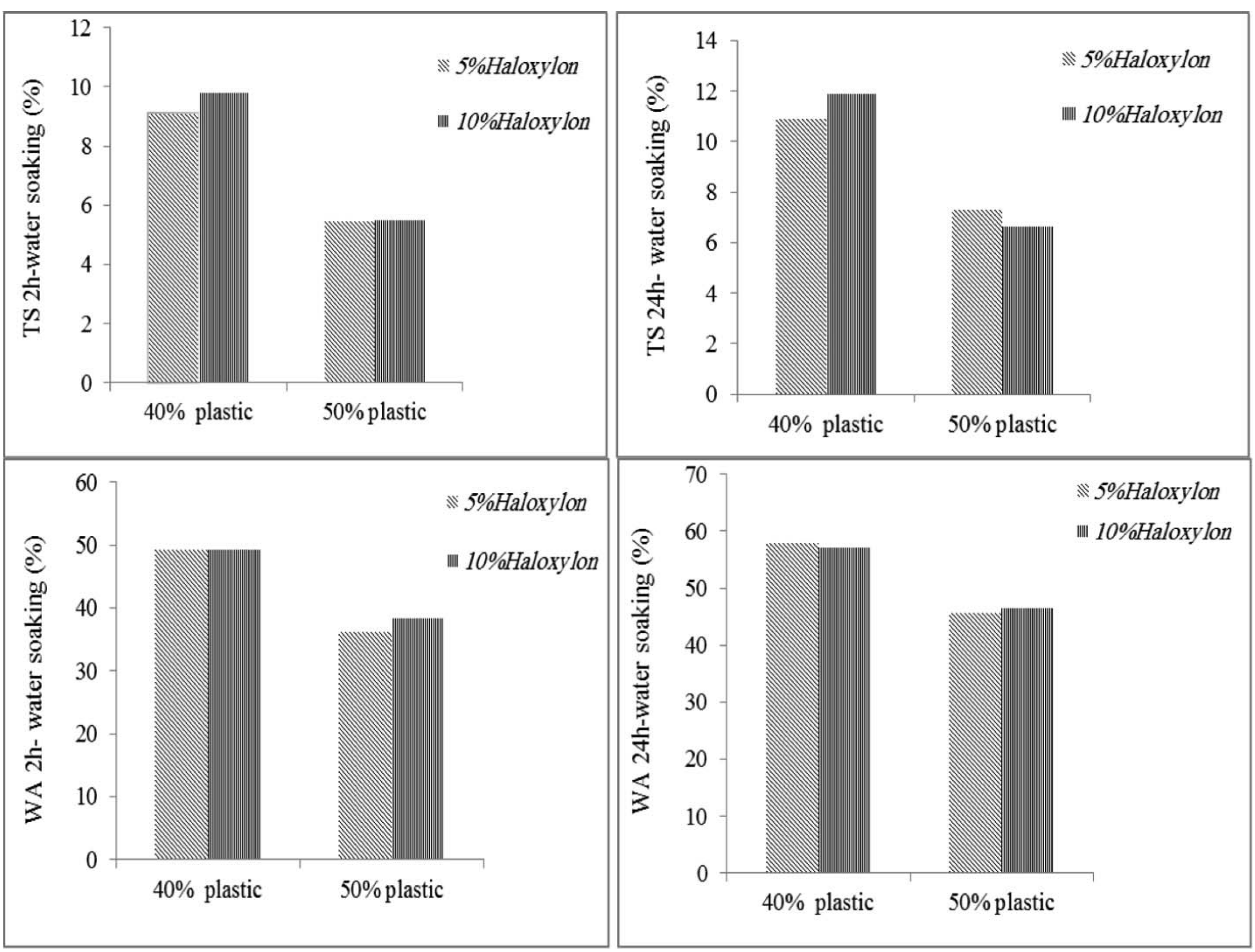


*Figure 3.—Physical properties results. TS = thickness swelling; WA = water absorption.*

panel types, 24.14 percent and 45.67 percent, respectively (Table 2). Significant differences between groups were determined individually for these tests by Tukey's multiple-comparison test. No significant difference was observed between groups for TS and WA values (Table 3).

With the increasing amount of lignocellulosic material compared with the polymer, WA and TS swelling of composites increases. As the polymer materials and especially thermoplastic polymers are hydrophobic materials due to being nonpolar, this is contrary to the polar and hydrophilic nature of cellulose fibers, and the addition of lignocellulosic amplifiers to the polymer matrix increases the WA in composites (Karnani et al. 1997). On the other hand, hydrophilic hydroxyl groups available to cellulose chains lead to the formation of new hydrogen bonds in water molecules, resulting in WA and TS (inflammation of dimensions) of WPCs (Wu et al. 2003, Mishra et al. 2004).

## Conclusions

In this work, particles from pistachio, pomegranate, *Haloxylon*, and cotton stalk with recycled plastic were used to make experimental WPC panels. In light of the preliminary results of this study, both physical and mechanical properties of samples were improved by increasing the percentage of plastic in the panels. Increase of *Haloxylon* mixed with other wooden materials in the manufacture of particleboard reduces the flexural strength and IB because it has the high extractives and short fibers. Changes in the amount of *Haloxylon* in the mix of the raw materials have little impact on the stability of dimensions of particleboard (Dosthoseini 2007).


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