Some of the Properties of Wood Plastic Composites

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Abstract

In this study some of the important properties of experimentally manufactured wood–plastic composites (WPC) were determined. Specimen having 60% and 80% particle and fibre of radiata pine (Pinus radiata) were mixed with polypropylene (plastic) and four different additives, namely Struktol TR 016 which is coupling agent, CIBA anti-microbial agent (IRGAGUARD F3510) as fungicide, CIBA UV filter coating (TINUVIN 123S), CIBA blue pigment (IRGALITE), and their combinations.
Based on the initial finding of this work static bending properties of the samples enhanced as above chemicals were added into both particle and fibre-based specimens. Thickness swelling of the samples were also improved with having additives in the panels. Micrographs taken on scanning electron microscope (SEM) revealed that coupling agent and pigment resulted in more homogeneous mixture of wood and plastic together. Two surface roughness parameters average roughness (Ra) and maximum roughness (Rmax) used to evaluate surface characteristics of the samples showed that particle based samples had rougher surface characteristics than those of fibre based ones. No significant influence of chemicals added in the samples was found on surface roughness values of the samples manufactured from particle and fibre of radiata pine.

Keywords: Radiata pine; Particle; Fibre; Wood–plastic composites; Coupling agent

Introduction

Wood-plastic composites (WPC) are widely used in USA, the most common type of such panels are produced by mixing wood flour and plastics to produce a material that can be processed similar to 100% plastic based products (Ballerini 2004, Charrier 1999, Groom, Shaler and Mott.1996, Simonsen 1995). Some of the major advantages of WPC include their resistance against biological deterioration for outdoor applications where untreated timber products are not suitable. The sustainability of this technology becomes more attractive when the low cost and high availability of fine particles of wood waste is considered.

These composites are transformed by extrusion processes to obtain applications including profiles, sheathings, decking, roof tiles, and window trims, with improved thermal and creep performance compared with unfilled plastics (English and Falk 1995, Tangram Technology 2002, Verhey Steven and Laks 2002). However, it is necessary to improve their physical and mechanical properties as well as appearance of such products to have a strong market share in wood composite panel industry. There are several ways to improve overall properties of WPC panels, namely using right size of raw material, optimum mixture and preparation of the elements in the product, and adding small amounts of additives such as coupling agents, pigments, antimicrobials or light stabilizers during their production (Nielsen and Landen 1994, Plueddemann 1982).

Most of the physical and mechanical properties WPC depends mainly on the interaction developed between wood and the thermoplastic material. One way to improve this interaction is incorporating a coupling agent as additive. In general, the additives help the compatibility between hydrophilic wood and hydrophobic plastic allowing the formation of single-phase composite. WPC also have problems when they are exposed to UV rays, their natural wood or pigmented colour may tend to fade away. Therefore, depending on the final application, UV filters have to be added to stabilize their colours for a longer time. When designing a commercial composite, the effect of particle size is one of the most important parameters affecting overall products properties. The use of optimum large particles might improve the mechanical properties of a composite, but the incorporation of a preservative should also be considered if it will be used for an application where biological resistance of this product is important (Verhey, Lacks, Richter, Larkin 2002).

Radiata pine is one of the main species having with an annual production of 27 million of cubic meters in Chile. It's an excellent prime source for pulp and paper manufacture in Chile and many other countries. Additional products from radiata pine include interiors and exteriors panels, furniture manufacture, trimming, and structural lumber. Although research and technological development in the area of WPC in Chile has been increasing. But no comprehensive work has been done in this area (Ballerini 2004). Therefore the main objective of this work is to investigate some of the properties of WCP panels manufactured from radiata pine furnish and plastic, which is virgin polypropylene, with addition of various chemicals to provide an initial data in this area.

Materials and methods

Commercially produced polypropylene in the form of pellets and wood material of radiate pine (*Pinus radiata*) were used to manufacture experimental panels. Wood particles were manually screened on a sieve and classified into two portions, 10 mesh particles and 50 mesh fibres. Four different types of chemicals Struktol TR 016 which is coupling agent, CIBA anti-microbial agent (IRGAGUARD F3510) as fungicide, CIBA UV coating (TINUVIN 123S) and CIBA blue pigment (Irgalite) were added into the samples. Table 1 shows the list of the chemicals and their percentages used for panel production. Wood particles and fibres were dried in an oven before they were mixed with polypropylene. First plastic material was put into mixer rotating at 75 rpm having a temperature of 165^{o}C for 2 minutes followed by adding the chemicals for each type of mat. In the next step particles or fibre were added into the mixture and rotated for another 3 minutes completing a total mixing time to 5 minutes. Figure 1 illustrates the mixer used for panel manufacture. Mixed samples then were pressed in a hot press with a 20 cm by 20 cm platen capacity. Each batch of sample was pressed using a temperature of 165^{o}C and a pressure of 40 bar for 5 minutes. The press was cooled off while the samples were still under compression before they were removed and conditioned in a climate chamber with a temperature of 20^{o}C and a relative humidity of 55%. Average target thickness of the panel was 2.5 mm. Modulus of elasticity (MOE) and modulus of rupture (MOR) of the samples were determined on a Comten Testing Unite equipped with a load cell with a capacity of 2,000 kg Figures 2A, 2B, and 3 show some of fibre and particle based samples and bending test set-up, respectively.

MATERIAL	ABBREVIATION	DESCRIPTION	SOURCE
Radiata Pinus fiber	**WF**	Subproduct of Radiata pinus furniture manufacture process. 50 mesh	CATEM, Concepcion Chile (Wood High Technology Center)
Radiata Pinus particles	**WP**	Subproduct of Radiata pinus furniture manufacture process. 10- 50 mesh	CATEM, Concepcion Chile (Wood High Technology Center)
Polypropylene	**PP**	Virgin polypropylene pallets	Petroquim, Polypropylene producer, Talcahuano, Chile
Eastmann Epolene maleated polyethylene (polypropylen)E 43	**E 43**	Maleated polypropylene wax	Eastman chemical companies, USA
Struktol TR016	**TR 016**	A blend of fatty acid metal soap and an amide.	Struktol chemical companies, USA
CIBA Antimicrobial agent IRGAGUARD F3510	**IRG**	Contains a broad-spectrum fungicide that is highly effective against mold, rot, blight and stain.	Ciba chemical company
CIBA Plastic UV filter TINUVIN 123S	**TN**	UV plastic fiber. Liquid hindered amine light stabilizer (HALS) based on aminoether functionality, absorbed into highly porous polypropylene.	Ciba chemical company
CIBA Wood UV filter lignostab	**LG**	Lignin stabilizer for color stabilization of natural, tinted or stained wood and for the durability improvement of wood substrates coated with clear and transparent pigmented finishes.	Ciba chemical company
CIBA Irgalite Blue Pigment	**BP**	Concentrate powder pigment	Ciba chemical company

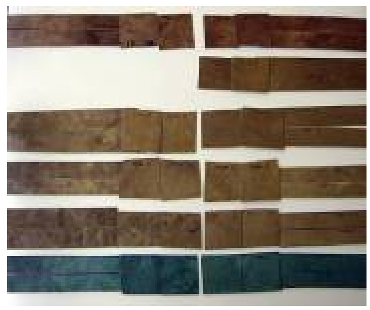
Table 1. List of the chemicals used as additive in panel manufacture.

	FIBER BASED PANELS		**PARTICLE BASED PANELS**	
PANEL TYPE	**60/80 ratio**	**80/20 ratio**	**60/40 ratio**	**80/20 ratio**
A	60% wood fiber 40% polypropylene	80% wood fiber 20% polypropylene	60% wood particles 40% polypropylene	80% wood particles 20% polypropylene
B	60% wood fiber 40% polypropylene 2% TR016	80% wood fiber 20% polypropylene 2%TR016	60% pine wood 40% polypropylene 2% TR016	80% wood particles 20% polypropylene 2% TR016
C	60% wood fiber 40% polypropylene 2% TR016 6% IRG	80% wood fiber 20% polypropylene 2% TR016 6% IRG	60% wood particles 40% polypropylene 2% TR016 6% IRG	80% wood particles 20% polypropylene 2% TR016 6% IRG
D	60% wood fiber 40% polypropylene 2% TR016 1.2% LG 1.2%TN	80% wood fiber 20% polypropylene 2%TR016 1.6% LG 0.6% TN	60% wood particles 40% polypropylene 2% TR016 1.2% LG 1.2% TN	80% wood particles 20% polypropylene 2% TR016 1.6% LG 0.6% TN
E	60% wood fiber 40% polypropylene 2% TR016 0.05 g BP	80% wood fiber 20% polypropylene 2%TR016 0.05 g BP	60% wood particles 40% polypropylene 2% TR016 0.05 g BP	80% wood particles 20% polypropylene 2% TR016 0.05 g BP

Table 2. Ratio of the raw material and additive agents used for panel manufacture.

Figure 1. Rotating mixer.

(A)



(B)

Figure 2 (A). Various types of fiber based samples.
(B). Various types of particle-based samples.

Figure 3. Static bending test set-up.

Four samples with a size of 5 cm by 5 cm were used to determined thickness swelling (TS) of the panels. The thickness of each sample was measured at four points. Then samples were submerged in distilled water for 2 hours and 22 hours before thickness measurements were taken from the same location to calculate swelling values. Surface roughness of the samples was also determined using a stylus type profilometer. A portable stylus equipment consisted of a main unit and pick-up which had a skid-type diamond stylus with 5μm tip radius and 90^o tip angle (Figure 4). The vertical displacement of the stylus is converted into electrical signal and digital information. Different roughness parameters such as average roughness and maximum roughness can be calculated from that digital information and profile of the surface can be developed as shown in Figure 5. Description of these parameters is discussed in previous studies [5,6]. Six random measurements were taken from the surface of tested bending samples to evaluate surface characteristics of the panels. Micrographs were also taken from the cross section of the samples with 3 mm by 3 mm face surface area to evaluate effect of wood plastic interaction on both particle and fibre based samples. Figures 9A through 9D show typical micrographs taken from the samples.

Figure 4. Roughness measurement profilometer.

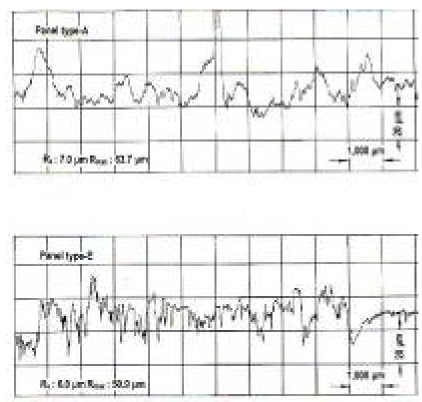


Figure 5. Typical roughness profiles of particle and fibre based samples.

Results

Mechanical and physical properties of the panels manufactured from combination of plastic and wood material and fibre with addition of various types of chemicals are shown in Table 2. Average MOE value of the samples containing 60% and 80% wood fibre without having any chemicals was found 2,109 MPa (Figure 6). When these samples were added coupling agent bending properties of the samples increased to 3,560 MPa which is 38% higher than that of the specimen made without any chemicals. Panel types C, D, and E having chemicals listed in Table 1 also improved MOE values of the samples as compared to those made with combination of plastic and wood fibre. However panel type D which was added UV filter in the form of flakes and pallets showed only 11.6% lower MOE than the samples with fungicides added. This could be due to non-homogeneous mixture of three elements, namely wood fibre, plastic, and UV filter. Also it seems that using 1.2 % of UV filter would be considered quite high and may be responsible for such finding. Using less amount of the UV filter agent could be more feasible approach to eliminate negative effect of the filter on MOE values of the samples. Overall bending properties of the samples are comparable to those found in two previous studies [3,9]. In the case of panel type C bending characteristics of the samples were not substantially reduced due to fungicide content. Fibre based panels manufactured with coupling agent pigment had the lowest MOE values which may be due to chemical reaction between coupling agent and pigment reducing bonding between wood and plastic components. Modulus of elasticity of the samples made using wood particles also had similar trend to above panels. Fibre based panels had only 3.3% higher MOE values than that of particle based samples at 95% confidence level. However fibre based panels containing coupling agent had significantly higher MOE than those of specimens manufactured from particle based using the same chemicals as can be seen in Table 2 and Figure 6. This finding may suggest homogeneous mix of fibre and plastic along with coupling agent resulted in a better bounding between the elements in contrast to particle types of panels which can also be seen in Figures 9A and 9B which were taken from the cross section of the samples using SEM. Once chemicals, fungicides, UV filter, and pigments were added into particle based panels their MOE characteristics also enhanced and become similar to the values of the samples manufactured from fibre based samples. Overall MOR values of both particle and fibre types of sample followed similar trend of MOE values. Thickness swelling of the samples as a result of 2- and 24-hr water soaking test are presented in Table 2. The highest thickness swelling value was 17.8% for the wood fibre base panels without addition of any chemicals for 24-hr water soaking. It appears that when coupling agent, UV filter, and fungicides had relatively positive influence on thickness swelling on fibre based samples as can be seen on Figure 7. When coupling agent was added into the samples their thickness swelling was reduced more than half in the case of fibre based panels. Dimensional stability of the fibre base panels type B, C, D, and E did not show any significant difference at 95% confidence level. Overall thickness swelling characteristics of the particle based samples had lower values than those of fibre type of the samples. Separation between fibres as a result of water soaking for 24-hr was observed on the micrographs taken on SEM as illustrated in Figures 9C and 9D.

Panel Type	Static Bending (MPa)		Water absorption (%)		Thickness swelling (%)		Surface roughness (µm)	
	FIBER BASED SAMPLES							
	MOE	**MOR**	**2-h**	**24-h**	**2-h**	**24-h**	R_a	R_{max}
A	2,109	11.80	3.21	8.33	11.3	18.6	1.98	16.71
B	3,560	18.74	5.73	12.84	5.2	13.3	4.05	33.84
C	3,208	14.53	5.11	6.53	5.4	8.9	4.48	33.94
D	2,778	14.28	4.79	10.96	5.8	11.8	4.09	32.11
E	2,155	12.74	5.22	9.49	3.9	11.0	3.54	28.35
	PARTICLE BASED SAMPLES							
A	2,058	12.01	4.76	8.82	5.5	12.5	5.84	41.68
B	3,034	13.90	6.67	14.71	6.7	12.2	6.61	66.43
C	3,254	14,60	4.07	7.50	3.8	5.9	6.70	49.07
D	2,656	14.10	7.19	15.36	7.9	13.4	8.11	50.18
E	2,191	12.89	7.46	14.61	7.5	12.1	6.96	57.78

Table 3. Mechanical and physical test results.

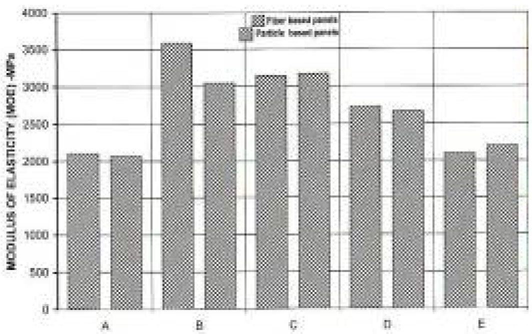


Figure 6. Average modulus of elasticity of the samples made from 60% and 80% fibre and particles.

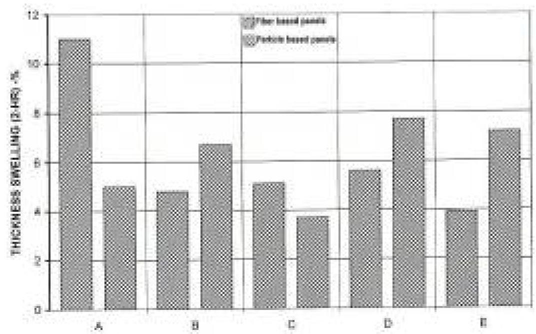


Figure 7. Thickness swelling for 2-hr water soaking test.

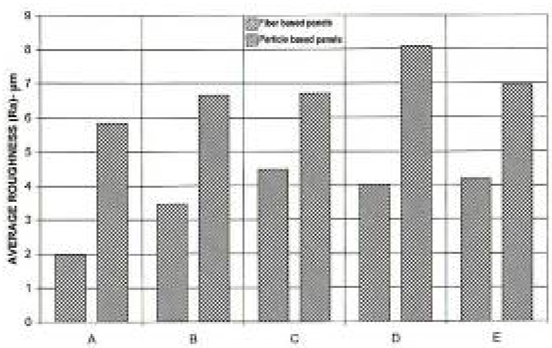


Figure 8. Average roughness (R_a) roughness values of the samples.

Based on the roughness parameters obtained from the surface of the samples fiber based panels resulted in significantly different R_a and R_{max} values than those of particle based ones. For example particle type samples made without having any chemical had 5.64 µm R_a which is 3 times higher than fibre based panels as illustrated in Figure 8. In a previous study it was determined that commercially produced fibreboard panels had much smoother surface than particleboard panels [5]. Even if very fine particles are used on the face layer of the particleboard pits and falls due to larger geometry of particle than fibres resulted in rougher surface characteristics [5]. This concept was also reflected in particle, fibres and plastic based experimental panels made in this study. It appears that as coupling agent, UV filter, and pigment were added into both types of panels their surface roughness increased due to not having well developed contact between wood based material and plastic on the surface layers.

Conclusion

In this work, particles and fibres from radiata pine along with different chemicals as additives used to make experimental WPC panels. In the light of the preliminary results of this study both physical and chemical properties of the samples were improved with addition of four types of chemicals into the panels. It seems that using less than 1.2% anti-microbial agent as fungicide would yield better properties of the samples. Initial data from the study would assist to develop WPC panel manufacture in Chile. In further studies, manufacturing of the panels by extrusion method with more than two particle and fibre percentages would be desirable to have a better understanding of panel properties. Also linear expansion, tension parallel to the surface of the samples should be tested to have more comprehensive information about the samples.

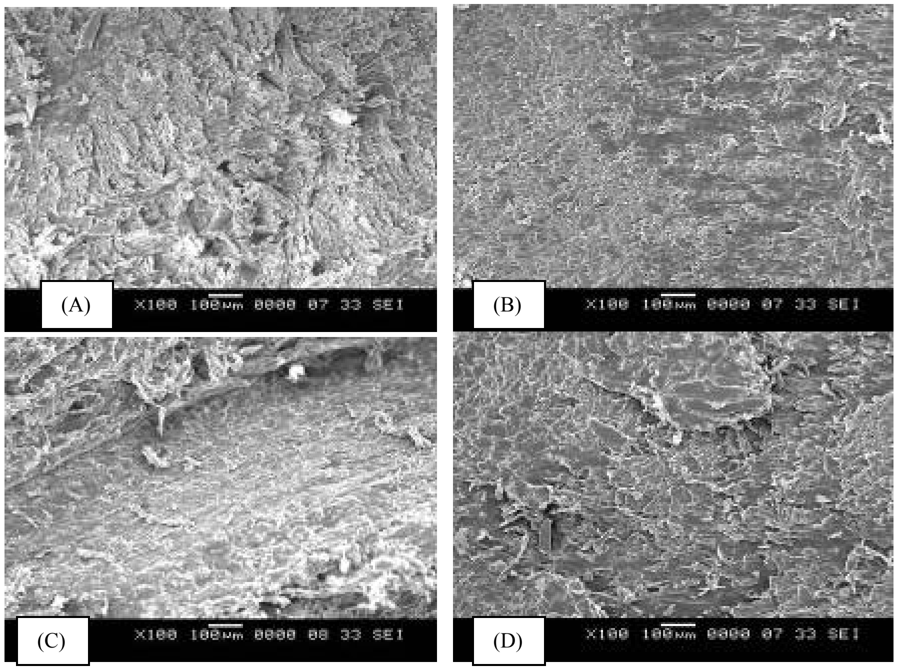


Figure 9. Photographs taken from the cross section of the samples on scanning electron microscope. (9A). Sample with 60% particle without any additives. (9B). Sample with 60% particle with pigment and coupling agent. (9C). Dry sample with 60% fibre with no additive. (9D). Water soaked sample with 60% fibre with no additive.

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