Innovation in window and door profile designs using a wood-plastic composite

Aldo A. Ballerini
Universidad del Bío-Bío,
Concepción, Chile

Ximena A. Bustos
Composite Materials Laboratory, Universidad del Bío-Bío,
Concepción, Chile

Mario A. Núñez
Composite Materials Laboratory, Universidad del Bío-Bío,
Concepción, Chile

Andrea Wechsler
Composite Materials Laboratory, Universidad del Bío-Bío,
Concepción, Chile

Abstract

Window and door frames were fabricated from UV radiation resistant wood-plastic composites. These frames are suitable for installing in any region of Chile, innovating on construction element profile designs and the material's virtues. The raw materials used for this research were homopolymer polypropylene (40%) and radiata pine wood dust (60%). The profiles were manufactured with a TC 35 Milacron twin screw extruder; additives, including pigments and filters to avoid surface fading caused by UV radiation and environmental effects, were added to the mixture. Natural weathering (3 months) and UV exposure cycle (200h/60ºC) tests were used to evaluate the material. Doors and windows were selected for their high hygrothermic performance. The door frame performance was evaluated by testing for shape and dimension, transverse stiffness, straightness, flatness, squareness, impact, humidity content, and glued joint behavior. The windows were tested for air and water tightness, wind resistance, and thermal transmittance. The effect of the pigment type on fading of the wood-plastic composite material, evaluated with a 200h/60°C UV cycle, was statistically significantly different from the control sample (no additives), which presented more fading for the same exposure time. The effect of the pigment type on the wood-plastic composite fading, as evaluated in the natural weathering test, showed that the red and silver pigments performed better, with statistically significant differences between the average results. The doors met the requirements established by Chilean standards NCh723 and NCh 354, with a good performance. The windows were classified as "special" in terms of air (10a) and water (30e) tightness and "exceptional" in the wind resistance test (20v) (NCh 888). The thermal transmittance test (NCh 851) presented a U value of 3.31 W/m^2 °C.

Keywords: Wood-plastic composites, additives, doors, windows, pigments

Introduction

Although used and produced around the world, wood-plastic composites have only recently been introduced in Chile. Quite a bit of research has been done regarding these materials and industrial production is expected soon, but some details remain to be resolved.

Wood-plastic composites are often manufactured with wood powder or sawdust and are normally between 50% and 70% wood. The composite properties are improved with additives such as compatibilizing agents, pigments, lubricants, and fungicides (Clemons, 2002). At present, wood-plastic products are based mainly on PVC, polyethylene, and polypropylene. The most common manufacturing process is extrusion with double-screw cone-shaped extruders. According to Milacron, the cone screws are designed to apply natural pressure on the spongy fiber, completely eliminating the humidity from high-load wood fibers (Stewart, 2007).

Although research and development have been done with wood-plastic composite materials in Chile for approximately 5 years, is still an incipient area. Only partial studies and research have been carried out and many of these were limited by technological factors. The research done in the Composite Materials Laboratory (LMC) of the Universidad del Bío-Bío on the development of new wood-and-plastic-based composite materials (Ballerini, A., 2004) has resulted in composite materials with higher quality attributes than their closest substitutes in terms of mechanical, physical, and thermal properties and resistance to fire and humidity. The products developed have proven to be excellent alternatives as housing construction elements. The results obtained to date through the research projects carried out by the LMC-UBB are being patented nationally.

Wood-plastic composites are currently used in construction elements, automobile parts, exterior products (e.g., decking and fencing), and doors and windows. They must withstand ultraviolet (UV) light and changes in temperature, provide excellent insulation, and require little maintenance. Several North American wood-plastic composite companies have found a better market in exterior door and window frames than in decking products (terraces) in North America and have switched their focus to the production of a wood-plastic material adequate for such applications.

The Bío-Bío Region is one of the most critical regions in Chile in terms of the climate, with high indexes of wind and rainfall each year. The doors, windows, and siding available on the national market, focused on middle-class housing, present problems related to the climate in the south of the country. These are mainly related to problems of dimensional stability (in the case of wood products), and low performance in terms of water and air tightness. This is associated with the relationship between the type of material and the element’s design, and can generate high maintenance and care costs.

As a hybrid, wood-plastic composites have the best virtues of both materials, with excellent physical and mechanical properties. Nonetheless, photodegradation remains a problem in wood-plastic composites and is complicated by the fact that the components are degraded through different mechanisms. The effects of this differential break-down include lost force, rigidity, and surface quality. Photostabilizers are compounds developed to protect polyolefins and combat UV degradation. They are generally classified according to the decay mechanism they combat. UV absorbers (UVA), hydroperoxide decomposers, and free radical sweepers are important photostabilizers for polyolefins (Stark, Clemons, Ibach, Matuana, 2003). Depending on the surface quality of the composite element, its durability can also be improved with paints and other finishing products (English, Falk). Additives and colorants for plastics improve the treatments designed to tailor formulations for specific wood-plastic composite applications.

The present document proposes an innovation in the national development of wood and plastic composite materials. Pigments and UV filters are applied to decrease fading caused by UV rays using wood subproducts. This innovation in the design of construction elements such as windows and doors solves the problem of poor insulation presented by these elements through an adequate design for the final application.

Materials and methods

Doors and windows resistant to UV rays and intended to be installed in the Bío-Bío Region were developed using a wood-plastic composite material. The material was developed in parallel with the design of the construction elements.

The material was developed by adding pigments of different colors and in different formats to wood-plastic mixtures. The pigments used were powders: green Irgalite GFNP and blue Irgalite GBP (Ciba, Germany), drizpearl: red F3RK70 170 and brown HFR, the latter in concentrations of 0.5% and 1% (Clariant, Switzerland); and Masterbatch: silver (Topcolor, Chile). The results are compared with wood-plastic composite controls with and without the UV filter for plastic Tinuvin 123 S (Ciba, Germany). The material was subjected to natural aging assays and a UV chamber (200h/60ºC).

The results were evaluated with an experimental general factorial design with two replicates.

Factors	Levels	Response of Variable
Pigment	Green Blue Red Brown 0.5% Brown 1% Silver Pattern	Total color difference (ΔE)
Presence of UV filter	Yes No	Total color difference (ΔE)

Table 1. Experimental design for evaluating the UV exposure cycle and natural aging assays.

The test pieces were manufactured by mixing pellets of the wood-plastic composite (60% radiata pine wood, 40% homopolymer polypropylene, lubricants) with the previously mentioned pigments and UV filter. The mixture was made in a Thermo Haake rotating mixer and was later molded in a hot-plate press with a cooling system, generating test pieces of 3 x 75 x 150 mm^3.

UV exposure cycle assay (200h/60ºC)

In the UV exposure cycle assay, samples were exposed to UV rays for 200 hours in a UV

X-ritecolor radiation chamber (irradiation 0.80 $W/m^2/nm$, type of radiation UV-A:340 nm, 6 fluorescent lamps). Measurements were taken every 21 hours with an X-ritecolor spectrophotometer. The assay was based on the standard ASTM G53, with a SPIN D65/10º, using a standard illuminant D65 (day light) and standard observer 10º (angle of the incidence of the light).

Natural aging assay

The natural aging assay consisted of exposing samples to the environment for three months, then evaluating the fading and deterioration of the material. The samples were placed outside on an aluminum stand (1 x 1 m^2) tilted 45º and facing North, thereby assuring exposure to the sun, according to the standard ASTM D1006. For the first 15 days of exposure the materials were checked every three days; during the next two months, they were checked every seven days; and over the last month, the color of the material was evaluated every 15 days with an X-ritecolor spectrophotometer.

Figure 1. Aluminum stand with wood-plastic composite samples.

Door and window design, manufacture, and assays

The most appropriate designs for doors and windows made of wood-plastic composites and intended for use in the zone were determined. A double-contact, outdoor-facing window was developed with a system of weather-stripping seals along its contact points, a decompression chamber, a drainage system for water from leaks and condensation, an inset *españoleta* closing system with three points of fixation and butt hinges rather than flap hinges, which are easier and safer to use. A door with wood-plastic leaves and frames was designed; the hollow areas inside decrease its final weight. The faces are HDF and the filling is Aislapol insulation and shingles.

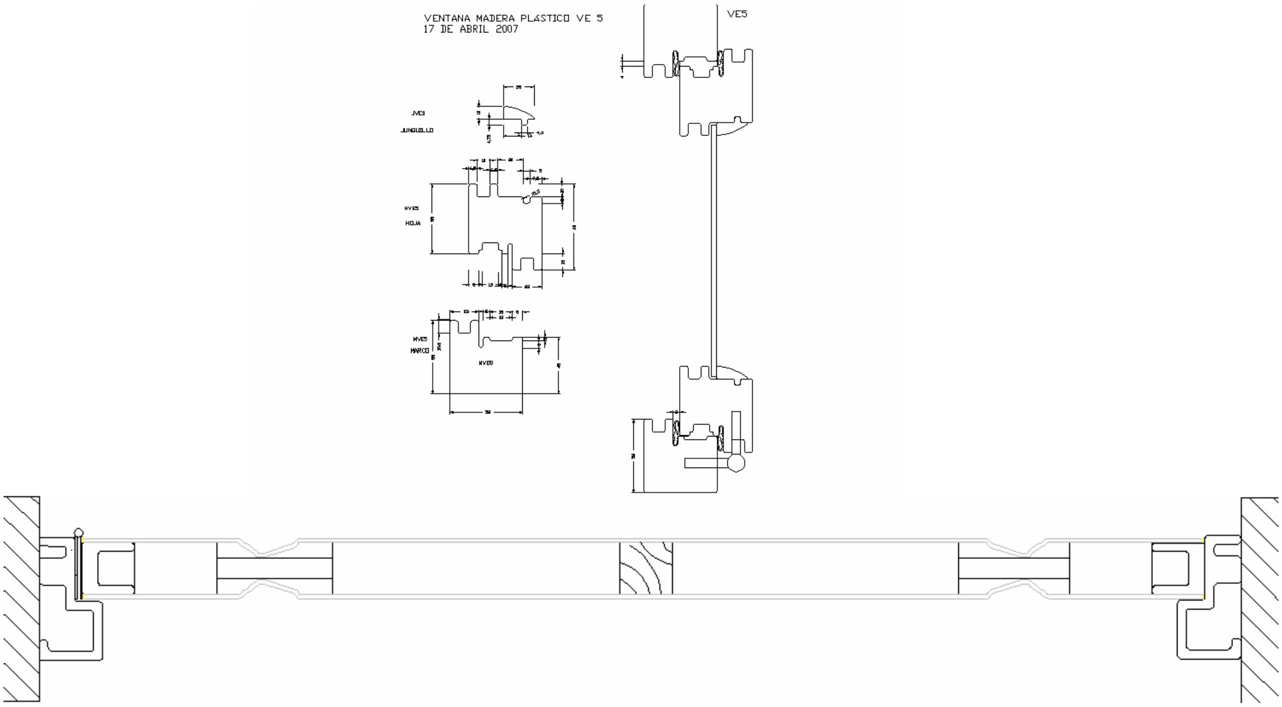


Figure 2. (A) Cutaway of the developed wood-plastic window (B) and the wood-plastic door.

The doors and windows were made in the LMC-UBB. Profile extrusion was done with a 35-mm diameter cone-shaped double-screw extruder. The raw materials were radiata pine sawdust and homopolymer polypropylene with lubricants. The heads were acquired specifically for the extrusion of these profiles.

Figure 3. Extrusion of profiles for door leaves using a cone-shaped double-screw extruder (Milacron TC 35).

Once extruded, the profile prototypes were assembled and assayed. Windows were tested, in terms of Chilean standards, for water and air tightness and wind resistance in the infiltration chamber of the Laboratory of Construction Sciences. The doors were tested using a physical-mechanical evaluation based on the NCh 723 and NCh 354. The following measurements were taken: dimension and shape tolerance, slam cycles (slamming the door in different cycles to simulate its opening and closing, testing its resistance), exterior glued joint behavior, interior rectitude, flatness, transversal rigidity and residual deformation, and impact resistance.

Figure 4. Wood-plastic door and window installed in a pilot house, Universidad del Bío-Bío.

Results

Results of the UV exposure cycle assay (200h/60ºC)

The following shows the results obtained with the X-ritecolor equipment. The values presented in Table 2 show the total color difference (DE) obtained after 200 hours of exposure to the UV cycle.

Table 2. Accelerated UV cycle exposure results (200h/60ºC).

Pigment	Presence of UV filter	Average L*(Amount of light reflected) 0 hr.	200 hr.	Change in average (%)	ΔE
	NO	45.26	45.66	0.88	0.97
Green	YES	44.64	45.89	2.80	0.88
	NO	39.12	39.85	1.87	0.78
Blue	YES	41.29	42.52	2.99	0.56
	NO	30.30	30.98	2.24	0.45
Brown 1%	YES	32.75	33.49	2.26	0.73
	NO	34.98	35.75	2.22	0.87
Brown 0.5%	YES	35.88	37.27	3.87	1.20
	NO	40.92	41.79	2.11	0.59
Red	YES	42.55	43.90	3.17	1.03
	NO	48.89	49.50	1.24	0.13
Silver	YES	46.62	48.88	4.85	0.94
	NO	57.30	58.62	2.31	2.43
Control	YES	62.73	61.67	-1.69	0.68

Results of the Natural aging

Table 3 shows the total difference of color (DE) values obtained in the three-month natural aging assay.

Table 3. Natural aging assay results.

Pigment	Presence of UV filter	Average L* (amount of light reflected) 0 day (0hr.)	90 days (2160 hr.)	Change in average (%)	ΔE
	NO	46.70	72.10	54.40	21.50
Green	YES	30.36	69.74	129.73	21.97
	NO	37.40	64.50	72.48	24.83
Blue	YES	39.61	62.33	57.37	23.71
	NO	29.97	46.61	55.52	18.76
Brown 1%	YES	31.68	47.30	49.29	17.36
	NO	34.36	54.61	58.92	18.75
Brown 0.5 %	YES	38.93	54.24	39.34	16.61
	NO	42.52	54.06	27.14	11.79
Red	YES	42.60	53.97	26.69	10.45
Silver	NO	48.23	66.04	36.92	17.25
	YES	50.23	65.86	31.13	14.72
	NO	59.51	80.10	34.61	15.96
Control	YES	63.28	75.32	19.02	21.27

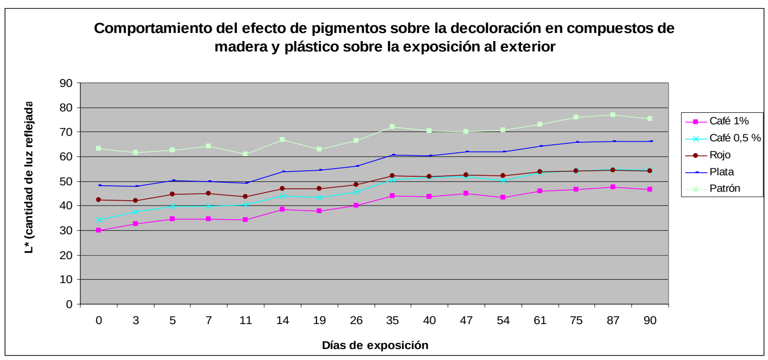
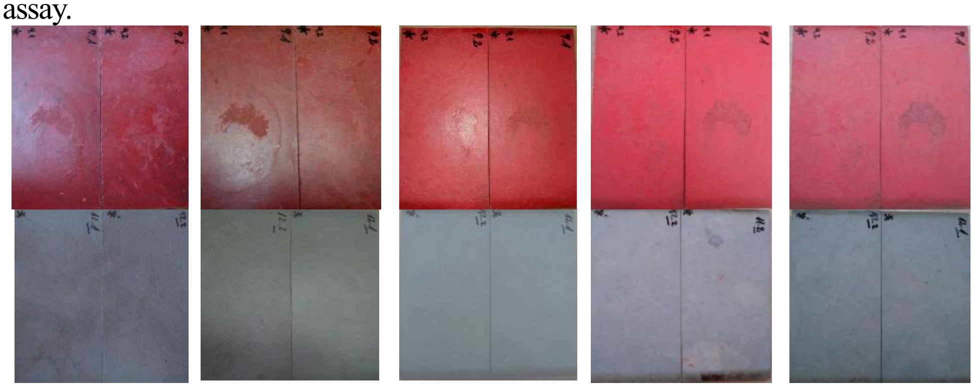


Figure 5. Behavior of the effect of the fading on the UV radiation.

Following are digital images showing the samples with the best performance in the natural aging assay.



Day 0 **Day 19** **Day 54** **Day 75** **Day 90**

Figure 6. Wood-plastic composite samples with red and silver pigment for different exposure periods.

Quality control results for doors and windows

The windows were certified in air tightness assays, with an infiltration of 6.9 m^3/h for a pressure difference of 100 Pa. The infiltration coefficients are 7.13 m^3/hm^2 (infiltration referring to the total window surface) and 1.74 m^3/hm (infiltration referring to the length of the window joint). In the water tightness assay, the water spilled over the lower interior rail after being applied for two minutes at a pressure of 450 Pa (leakage limit). In the wind resistance assay, the windows presented a maximum deflection of 0.57 mm at a pressure of 2000 Pa; as a reference, the Chilean standard sets the maximum admissible deflection at 6.17 mm under 2000 Pa of pressure. The assay to determine the thermal transmission coefficient revealed a U value (thermal transmission) of 3.31 W/m^2 ºC for the windows.

In the dimension and shape tolerance assay, according to NCh 354, the doors showed admissible tolerance in length (+/- 4 mm), width (+/- 3 mm), and thickness (+/- 1 mm). The results were within the limits established by the standard.

The doors evaluated registered an average of 2.98 % humidity content (the standard requires less than 12%). The results of the impact assay showed no visible external faults in the doors such as breaks, separations among the plates, separations of the plates from the frame, or others. No evidence was recorded of deterioration. The door performance was satisfactory in the impact resistance assay. The residual deformation assay revealed that the wood-plastic composite material does not present dimensional changes compared with the behavior of the pieces of the filler wood. The doors presented a good performance when submitted to a cycle of 25000 slams in the slam test. The hinges used never lost their functionality, nor did they present a loss of union between the door and the hinges, the screws worked well under impacts; therefore, in none of the assays did the doors lose their functionality after 25000 cycles of use, in total, 20 hours of continuous impact.

Conclusions

In general, all the pigments evaluated presented a good performance when faced with exposure to UV light, unlike the control, which showed greater fading of the material. The UV filter Tinuvin123 S behaved well when exposed to UV light, both in natural aging and UV exposure cycle assays. The samples assayed with this product presented less fading, with no statistically significant differences. The pigments that performed best when faced with exposure to the exterior for three months were the red, silver, and brown (both concentrations) pigments, and the control.

The siding used by the company Masonite presented a good behavior when faced with exposure to the UV cycle and exposure to the exterior. In general, the pigments evaluated performed well when faced with the UV exposure cycle (200h/60ºC). We recommend assaying for longer time periods in order to evaluate the behavior of the pigments when exposed to UV light.

The element designs were tested through the assays indicated above. Given the results, the windows were classified as “special” in terms of air (10 A) and water (30 E) tightness. With respect to wind resistance (20V), they were classified as "exceptional". Finally, the thermal transmission of the doors had a U value of 3.31 W/m^2 °C, ranking as average in relation to similar products made of other materials. The doors met the requirements established by Chilean standards NCh 723 and NCh 354, performing well in relation to doors with tepa leaves.

For the serial manufacture of these elements, we recommend maintaining the designs proposed and working with a wood-plastic mixture that is 60% radiata pine wood, 40% polypropylene, lubricants, Tinuvin 123 S, and red or brown pigment or siding.

References

ASTM G 53. Standard Practice for OperatingLight- and Water- Exposure Apparatus.

ASTM D1006. Standard practice for conducting exterior exposure test of paints on Wood.

Ballerini A., 2004. Proyecto Innova Bio Bio, 05-B1-355 "Desarrollo de tecnologías constructivas de componentes de viviendas en base a un material madera plástico: Diseño y especificaciones producto-proceso" Concepción, Chile.

Clemons, C. 2002. "Wood-Plastics Composite in the United States: Interfacing of Two Industries". Forest Product Journal. Vol 52 Nº6. P 10-18.

NCh 354. Hojas de puertas lisas de madera - Requisitos generales

NCh 723. Hojas de puertas lisas de madera- Métodos de ensayos generales

NCh 851. Aislación térmica – Determinación de coeficientes de transmisión térmica por el método de la cámara térmica

NCh 888 .Arquitectura y Construcción-Ventanas-Requisitos básicos

Stark, N., Clemons, C., Ibach. R., Matuana. L., February 2003, Durability of Wood and Polyethylene Composite Lumber, Final Report, USDA Forest Service, Forest Product Laboratory.

Stewart, R., Febrero 2007. Fierce Competition Drives Advances in equipment, Materials, and processes, North America Cover story, Wood Fiber Composites, Plastic engineering.