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Artículo

Efecto del intemperismo y biodeterioro en compuestos plástico-madera (CPM) elaborados con borato de zinc

Weathering and biodegradation effects in wood-plastic composites (WPC) made with zinc borate

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Resumen

Se evaluaron las propiedades físicas y mecánicas de compuestos plásticos de madera (CPM) elaborados con borato de zinc (BZ) y sometidos a tratamientos de intemperismo y biodeterioro. Se utilizaron concentraciones de BZ al 0, 1, 3 y 5 %; harina de madera de pino, malla 60 y polipropileno, en proporciones de 50/48, 50/47, 50/45 y 50/43, en función de la concentración de BZ. En todos los CPM, se adicionó 2 % de anhídrido maleico de polipropileno (MAPP) como agente acoplante. Los CPM se expusieron al intemperismo natural durante 6 meses y al biodeterioro con *Gleophyllum trabeum* (pudrición parda) y *Trametes versicolor* (pudrición blanca) mediante pruebas de agar (EN 350-1) y bloque suelo (ASTM D 2017-05). Se evaluaron las propiedades físicas de absorción e hinchamiento y las mecánicas de flexión estática, resistencia a la tracción y resistencia al impacto. Además de la alteración de la luminosidad y caracterización morfológica con microscopía electrónica de barrido (SEM). El borato de zinc no tuvo efecto en las propiedades mecánicas de los CPM sin tratamientos. Después del intemperismo, el BZ no incidió sobre la flexión estática y resistencia al impacto; aunque, se observó un efecto positivo en la resistencia a la tracción. En CPM expuestos a la biodegradación por hongos, el BZ influyó positivamente en la resistencia al impacto. Independiente de las bajas tasas de descomposición, el BZ fue eficaz contra la descomposición fúngica; las pérdidas de peso de los CPM expuestos en pruebas de agar y bloque de suelo no mostraron diferencias significativas.

Palabras clave: Biodeterioro, compuesto plástico-madera, intemperismo, propiedades físicas, propiedades mecánicas, pudriciones fúngicas

Abstract

The effects of zinc borate (ZB) on physical and mechanical properties of wood plastic composites (WPCs) were assessed. WPCs were elaborated with 0, 1, 3, y 5 % ZB concentrations, wood flour, mesh 60 and polypropylene in 50/48, 50/47, 50/45 y 50/43 proportions as a function of ZB concentration. 2 % of maleic anhydride of polypropylene (MAPP) was included in all WPCS. Specimens were exposed to natural weathering for 6 months. Bioassays with the fungi *Gleophyllum trabeum* (brown rot) and *Trametes versicolor* (white rot) were conducted by means of agar (EN 350-1) and soil block (ASTM D 2017-05) tests. Moreover, water absorption and swelling as well as static bending, tensile strength and impact strength were evaluated. Other properties like surface brightness and morphological characterization by means of scanning electron microscopy (SEM) were also considered. Zinc borate has no effect on mechanical properties of the untreated WPCS. After weathering, ZB had no effect on static bending and impact strength. However, a positive effect on tensile strength was observed. ZB had a positive influence on impact strength of WPCS exposed to biodegradation by fungi. Regardless of the low decay rates, ZB proved effective against fungal decay; weight losses suffered by WPC specimens exposed in agar and soil block tests showed no significant differences.

Key words*:* Biodegradation, wood plastic-composite, weathering, physical properties, mechanical properties, fungal rots.

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Introduction

Wood-plastic composites (WPCs) are materials that can be made from plastics and particles from natural fibers. It is common to add some additives to improve physical, mechanical or other properties. These additives can serve as couplings, preservatives, colorants or fire retardants. The performance of WPCs products of general use is known to depend on factors such as particle size, wood/polymer ratio, production conditions, wood species, etc.

Weathering and biodegradation are natural processes that act on WPCs. In this regard, there is concern about their resistance when exposed to rain, sun and various microorganisms. The resistance of degraded CPMs depends largely on variables such as the quantity and quality of additives and manufacturing conditions.

Photodegradation by solar radiation is an important factor in the degradation of the WPCs surface which is aggravated by a combination of humidity and temperature. Plastics, in theory, are not susceptible to biodegradation by fungi and insects; however, the carbon hydroperoxide and chromophore groups in the polymer may lead to greater sensitivity to photodegradation of the polymer matrix. Carbonyl groups are probably its main cause, since they induce reactions in polymers exposed to UV radiation. The weathering of polypropylene produces an increase in crystallinity, due to the splitting of the chain (Stark and Matuana, 2004).

It was long considered that the hydrophobic nature of the plastic matrix in CPMs provides sufficient resistance to water absorption by wood fibers or particles and, consequently, to fungal attack. Therefore, research focused primarily on how the effect of particle size, plastic/fiber ratios, and additives affect the physical properties and mechanical performance of WPCs (Lázaro *et al.,* 2016a; Córdova *et al.,* 2020). However, many researchers have documented that WPCs are susceptible to biodegradation (Mankowski and Morrell, 2000; Verhey *et al*., 2001; Pendleton *et al.*, 2002; Fabiyi *et al.*, 2011).

In the biodegradation of WPCs, humidity is critical; therefore, a larger particle size and a higher proportion of wood make them more susceptible to fungal attack, because a greater amount of humidity is absorbed (Mankowski and Morrell, 2000;

Rowell 2012). Consequently, fungal attack is most evident at the wood-polymer interface, but is reduced by using a coupling agent. Wood modification is also a tool for wood-based products (Rowell and Ibach, 2018).

The weight loss caused by fungi in WPCs is proportional to the wood content. Verhey *et al*. (2001) indicated that the WPCs made with pine and without preservative treatment presented a considerable biodeterioration. In addition, the degradation of WPCs exposed to brown rot fungi was greater than that caused by white rot. Pendleton *et al*. (2002) treated WPCs with preservatives and exposed them to brown and white rot fungi, without registering any mass loss with low (30 %) and medium (50 %) wood particle content. However, formulations with high values (> 50%) exhibited considerable bio-deterioration. Their results confirm that higher proportions of plastic prevent the biodegradation of WPCs.

The physical and mechanical properties of WPCs are affected after exposure to weathering and biodegradation. Some of them, such as water absorption, contraction and swelling, static bending, tensile strength and impact are used to evaluate such effects (Fabiyi and McDonald, 2010; Silva *et al.* 2018; Robledo-Ortíz *et al.,* 2020; Córdova *et al.* 2020). In general, adding wood flour to the plastic matrix increases the properties of the mechanical board (Lázaro *et al.,* 2016a).

Silva *et al.* (2006) report that an increase in the moisture content of WPCs results in a decrease in physical and mechanical properties.

In recent years, WPC research has focused on the use of different wood species and knowledge about the use of various additives. Zinc borate (ZB) was tested by different researchers as a preservative (Silva *et al*., 2006; Schirp *et al*., 2008; Gurhan *et al*., 2009). It is commonly used because it has low water solubility and does not leach easily, resists high temperatures (required for extrusion and injection processes) and is economical. In addition, it is of low toxicity to humans (Verhey *et al.*, 2001) and can be used as a fire retardant in plastic, wood and textile products (Gurhan *et al*., 2009).

Low leaching levels are critical to the outdoor use of WPCs because water can remove the additives. WPCs for exterior applications must also resist attack by fungi, insects and bacteria.

In the present research, MPCs with ZB concentrations of 0, 1, 3 and 5 % were exposed to weathering for 6 months (May to November), as well as to biodegradation by fungi for 16 weeks. Before and after the treatment, the influence of the preservative on the physical and mechanical properties was evaluated.

In this context, the objective of this investigation was to find out how ZB affects the physical and mechanical properties of WPCs when exposed to weathering and biodegradation.

Materials and Methods

The pine wood flour (*Pinus* spp.) used was collected from a sawmill located in the state of *Jalisco,* dried and sifted in a 60 mesh (246 μm). Polypropylene (PP) (Formolene 1102KR) was used as the polymer matrix, with a melt flow rate of 4 g 10 min^{-1}. In addition, zinc borate (ZB) (Sigma Aldrich 14470) and maleic polypropylene anhydride (MAPP) (Orevac CA 100) were applied as a preservative and coupling agent, respectively. The composite formulations are presented in Table 1.

Table 1. Composite material formulations.

Formulations	**Wood flour (bms %)**	**PP (%)**	**ZB (%)**	**MAPP (%)**
1	50	48	0	2
2	50	47	1	2
3	50	45	3	2
4	50	43	5	2

PP = Polypropylene; ZB = Zinc borate; MAPP = Maleic anhydrous polypropylene.

Preparation of composite materials

The composite mixes were prepared using a Leistritz micro 26 GL / GG-36D twin-screw extruder. The temperature profile of the extruder was adjusted between 150 °C and 190 °C from the barrel to the die, turning at a screw speed of 60 rpm and a feed speed of 175 rpm. The cooling of the extrudate at the exit of the die was done in water at room temperature. After extrusion, the mixtures were granulated. The WPCs samples were produced by injection molding on a Nissei ES1000. Previously, the granules were dried in an air convection dryer, MATSUI DMZ2-40, at a dew point of 40 °C, for 2 hours at 80 °C. The temperature profile on the injection moulding machine was adjusted to four values: 160/170/185/200 °C.

Water absorption and mechanical properties

Water absorption was determined according to ASTM D570 (ASTM, 1998); prior to testing, three samples of each formulation were dried at 50 °C for 24 hours in order to determine the dry mass and baseline thickness. The samples were completely immersed in distilled water at room temperature. After 2 hours, the mass and thickness were calculated. The procedure was repeated once a day for one week and, finally, every two weeks, until saturation (the average mass increase per two-week period should be less than 1 % of the total mass increase).

The mechanical properties before and after treatment were considered for each formulation and pure PP board. The impact bending strength was assessed on rectangular samples using a Gardner impact tester (falling weight) based on ASTM D5420 standard to determine mean failure energy (EMF) (ASTM, 2010). The bending tests were done with a United Calibration Corporation SFM-10 machine, according to the ASTM D790 standard (ASTM, 2003a). The stress tests were carried out with an Instron 4411 testing machine, based on ASTM D638 (ASTM, 2003b). All samples were analyzed at room temperature.

Alteration of luminosity due to weathering

Water absorption was determined by an adaptation of the TAPPI T 527 standard (TAPPI, 2007). The 80 × 40 × 2.6 mm samples were analyzed in an Elrepho 3000 spectrometer, the exposed surface was 30 mm in diameter, which allowed to cover the edges of the instrument. The procedure was repeated eight times per formulation and a test was performed every 14 days for 6 months in order to assess the alteration of luminosity during exposure to natural weathering.

Morphological characterization of the surface

Microphotographs were obtained for the morphological characterization of the surface, with a scanning electron microscope (SEM), HITACHI TM-1000. Samples of each formulation were analyzed at the beginning and end of the biodeterioration and weathering cycles.

Resistance to weathering

Natural weathering was achieved by exposing WPC specimens outdoors in *Guadalajara,* Mexico (20°74'45.6” N 103°51'45.8 W). The samples were fixed in a wooden frame with a net parallel to the surface as a support, in order to obtain a total outdoor exposure of one of the faces of the WPCs. This was done to allow the free passage of water and prevent flooding. The exhibition started in May and ended in November. Table 2 shows the climatic conditions.

Table 2. Precipitation, relative humidity and temperature during exposure.

Month	Precipitation (mm)	Relative moisture (%)	Temperature (°C)		
			Maximum	Medium	Minimum
May	14	52	33	24	13
June	57	61	34	24	16
July	244	84	28	22	16
August	132	77	27	22	16
September	47	72	27	21	15
October	79	66	26	18	13
November	0	59	26	16	8

Biodegradation test

Soil block test

Tests were conducted in accordance with ASTM D1413 (ASTM, 2007). The soil was organic, with a pH value of 6.8, sieved through 6 meshes (3.3 mm). Decomposition chambers consisting of a 500 mL glass flask filled halfway with soil were prepared. The soil moisture content was adjusted to 35 % by adding distilled water. The water holding capacity (WHC) was set between 30 and 40 %.

Small feeding strips of alder (*Alnus* sp.) and pine (*Pinus* sp.) were placed in bottles for brown (*Gleophyllum trabeum* (Pers.) Murrill) and white (*Trametes versicolor* L.) Lloyd) rot fungi, respectively. The bottles were closed and sterilized during 30 + 15 min at 121 °C. After cooling, the feed strips were inoculated with agar cut from the active growth edge of the respective fungus. Vials were incubated at 27 °C until mycelium covered the surface of the feeder strip.

The WPC samples were dried at 100 °C for 24 h to calculate the baseline moisture. They were then immersed in distilled water at room temperature for 90 days to reach a humidity level that would allow fungal attack (around 25 %), which was verified by evaluating the mass of the immersed WPCs. The WPC samples were then sterilized at 121 °C for 15 minutes. The samples were incubated during 16 weeks at 27 °C.

After the exposure, the samples were removed and carefully cleaned of the mycelium adhered to the surface. They were then dried and weighed to calculate the final moisture content and mass loss.

Moisture content was evaluated to verify whether the conditions were suitable for fungal growth, while mass loss was used to determine the degree of decay. Based on the assumption that the moisture content and mass loss would occur only in the wood component, these values were calculated as a function of the amount of wood in the WPCs (50 %).

Agar block test

The tests were performed according to the BS EN 113:1997 standard (BS EN, 1997), ASTM D2017 (ASTM, 2005) and the procedures described by Silva *et al*. (2006). The decomposition chambers were 115 mm diameter Petri dishes with 3 % malt extract agar (MEA). The medium was inoculated with 4 mm diameter mycelium caps cut from the edges of the actively growing culture. White and brown rot fungi were grown for 14 and 21 days, respectively. The WPC samples were sterilized at 121 °C during 15 minutes and placed in the Petri dishes in two small glass vials.

WPC samples were exposed for 16 weeks. At the end of this period, they were removed, cleaned of the adhering mycelium and weighed according to the procedure described in the soil block test.

Results and Discussion

Weathering

Alteration of luminosity

The alteration of luminance in the WPCs was evaluated based on the adaptation of the TAPPI T 527 standard (TAPPI, 2007), after six months of exposure to the weather, as summarized in Table 3.

Table 3. Alteration of the luminosity in the WPCs after exposure to natural weathering for six months.

Alteration of the luminosity (%ΔL)	**ZB concentration (%)**			
	0	**1**	**3**	**5**
Baseline	7.7	8.8	9.6	10.3
Final	29.9	32.5	31.6	32.8

The effect of weather on the brightness of the WPCs is shown in Figure 1. It is evident that both ZB and non-ZB WPCs cleared up after exposure to the weather. Those containing ZB became slightly clearer, regardless of the amount of ZB. Generally, the color of the WPCs mainly reflects the color of the wood component due to the presence of extractives (Fuentes *et al.,* 2018).

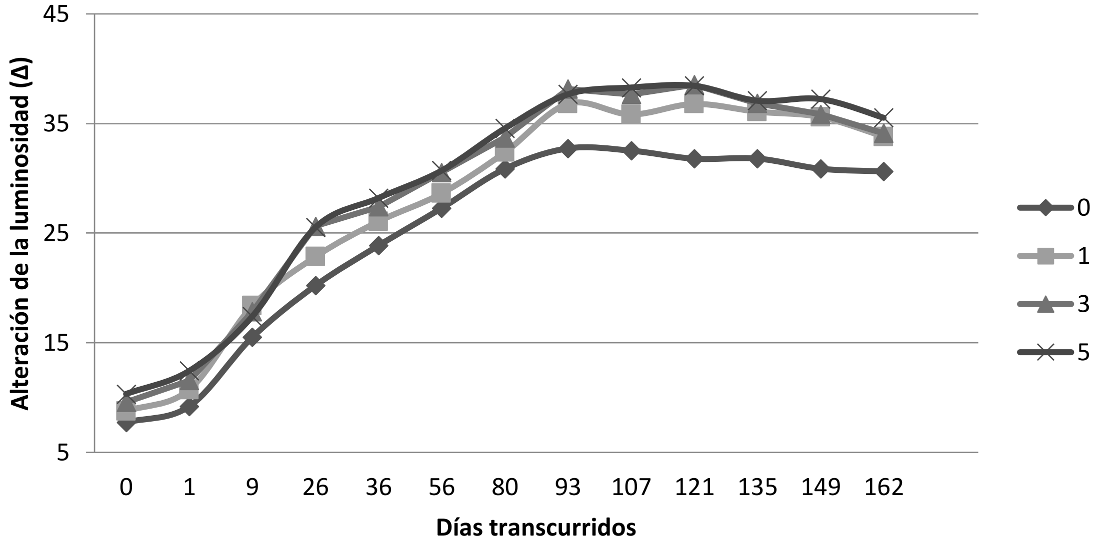

Figure 1. Alteration of luminosity in WPCs after six months of exposure to weathering.

The presence of chromophore groups in PP and pine wood flour promote the absorption of ultraviolet (UV) light, when exposed to the elements, so that the lignin component is degraded by the action of these groups (Stark and Matuana, 2004). The erosion of the wood component in WPCs results in a cyclical erosion of the surface which, in consequence, increases the amount of lignin exposed to degradation and causes the formation of new functional chromophore groups, such as carboxylic acids, quinones and hydroperoxy radicals (Fabiyi and McDonald, 2010). In addition, surface erosion may remove certain water-soluble wood extracts that cause the luminosity observed in the WPCs.

According to Temiz *et al.* (2007) and Fuentes *et al.* (2018), UV radiation can illuminate WPCs by causing cracks in the surface of the polymer matrix, which bleaches the wood particles.

SEM

Figure 2 shows the SEM microphotographs of untreated WPCs. There were no differences in any WPCs made with various ZB concentrations, except for the WPC with 5 % ZB, in which certain crystals (arrows) attributable to a higher concentration of ZB were observed.

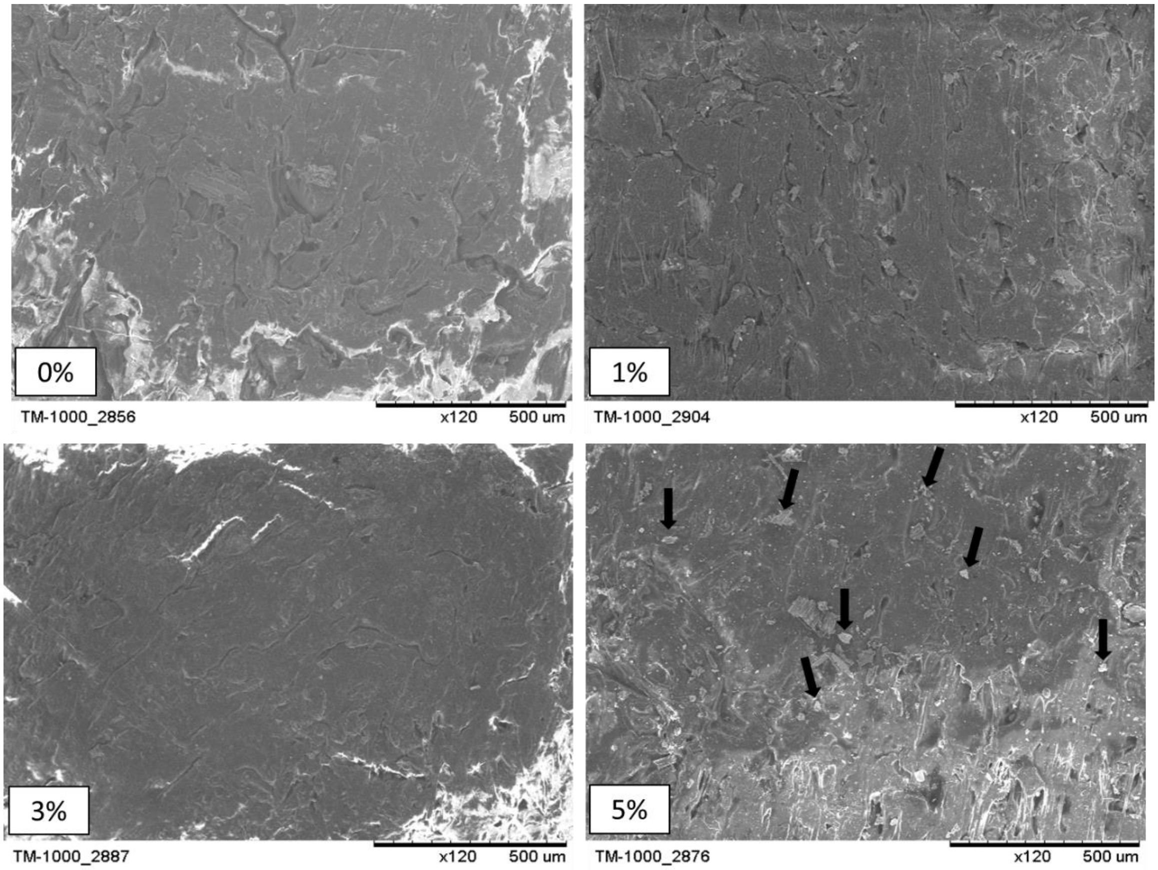

Figure 2. SEM microphotographs of the surface of WPCs produced with different ZB concentrations without exposure.

All the WPCs exposed to weathering exhibited degradation after treatment. Fabiyi and McDonald (2010) have cited similar results.

Figure 3 shows SEM images of the WPCs subjected to weathering. They exhibit less degradation when the ZB concentration increases, possibly due to the antioxidant effect of ZB (Cárdenas, 2012). In general, cracking was evidenced in all worn out WPCs; this may be due to polymer chain cleavage caused by photoxidation, which results in highly crystallized PP zones whose origin is the cleavage of chain molecules in the amorphous phase (Fabiyi and McDonald, 2010). This causes a greater fragmentation of the bond between the polymer and the wood, which can be seen on the surface of the WPCs.

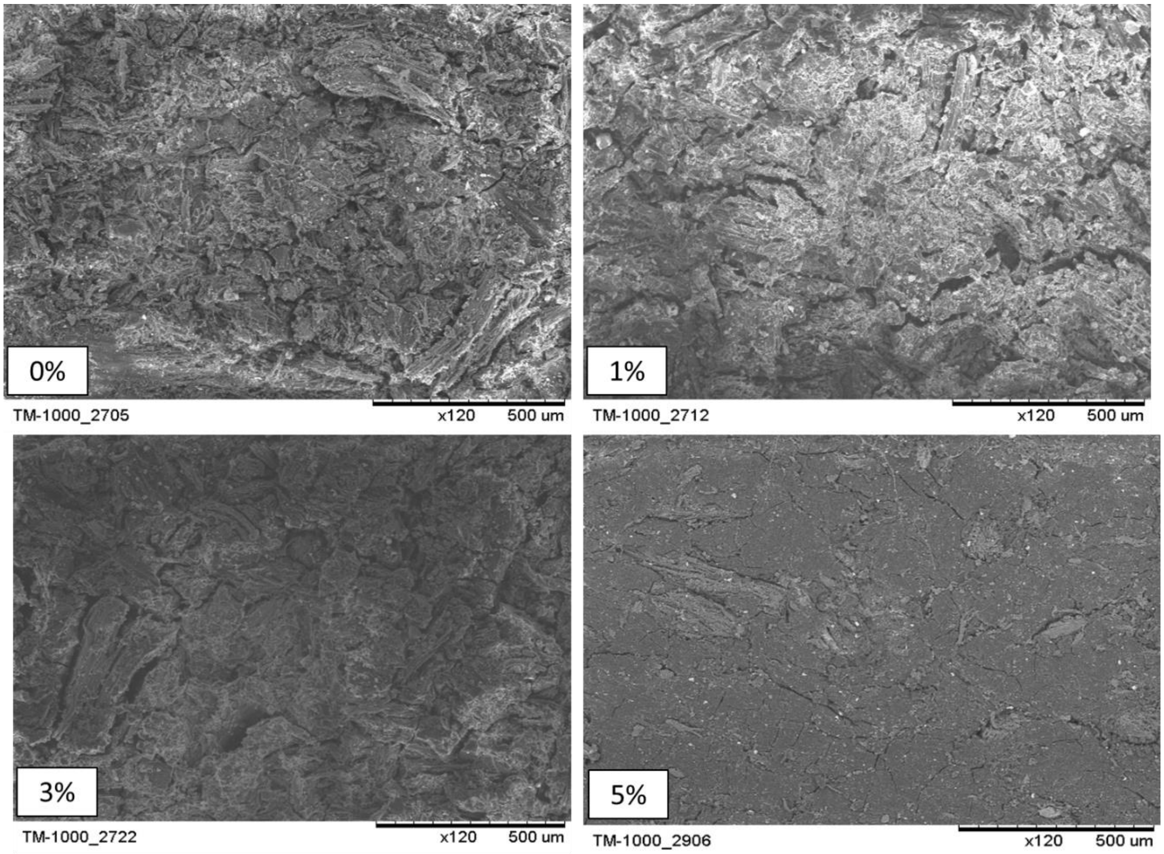

Figure 3. SEM microphotographs of WPCs produced with different concentrations of ZB exposed to weathering.

Physical and mechanical properties

Physical properties

The baseline moisture of the WPCs was 0.3 % for all ZB concentrations. The WPCs were immersed in distilled water for 162 days in order to attain 18 % humidity levels (Figure 4). Lower moisture absorption responds to higher ZB levels. Cárdenas (2012) documented this behavior in degraded WPCs, which inhibited fungal colonization and, consequently, loss of mass in incubation, due to the limited accessibility of water to the fungus (Papadopoulos, 2010; Fabiyi *et al.,* 2011).

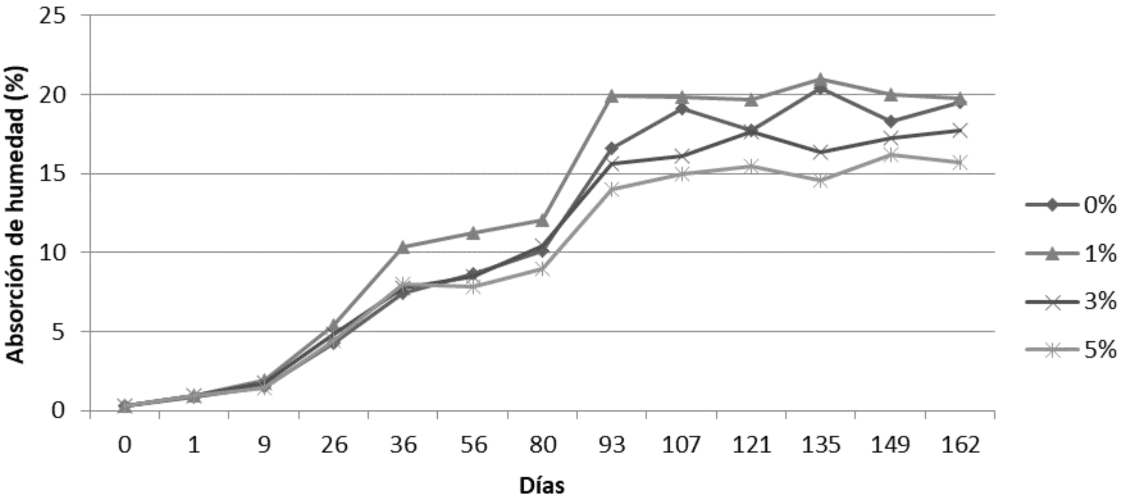

Figure 4. Influence of ZB concentration on water absorption of WPCs.

The thickness swelling test was performed in wet WPCs (162 days) 10 % increases were obtained in relation to the baseline sizes (Figure 5). Maximum increases of 8 % were observed in the first 30 days. The size and concentration of the wood particles are critical. Higher values make it extremely difficult for the polymer matrix to properly encapsulate the wood particles; therefore, the main surface of the wood flour is exposed, reaching significant levels of moisture (Lázaro *et al.,* 2016b).

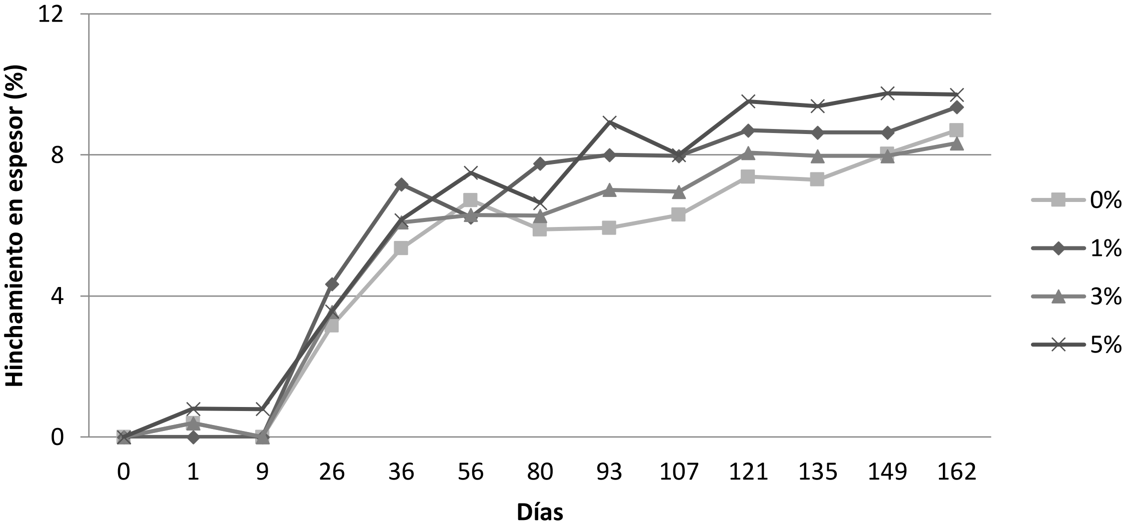

Figure 5. Effect of ZB concentration on increasing WPC swelling.

Mechanical properties

In general, ZB had no effect on WPCs before exposure to weathering; however, after six months, all mechanical property values of WPCs decreased, except for the MOR at stress. The positive effect of ZB on samples exposed to weathering (% ZB) was observed in tensile strength (MOR) and bending tests. One possible explanation is the antioxidant effect of ZB on WPCs exposed to weathering (Cárdenas, 2012). The values are summarized in Table 4.

* * *

Table 4. Mechanical properties of WPCs with and without exposure to weathering (six months).

Treatment	ZB (%)	Mechanical properties				
		Static bending		Tension		Impact (J/m)
		MOE MPa	MOR MPa	MOE MPa	MOR MPa	
Unexposed	0	956 [a]	38 [a]	1568 [a]	21 [a]	677 [a]
	1	979 [b]	35 [a]	1594 [a]	21 [a]	682 [a]
	3	987 [b]	36 [a]	1654 [b]	21 [a]	670 [a]
	5	1047 [b]	38 [a]	1533 [c]	21 [a]	660 [b]
Exposed	0	869 [a]	34 [a]	1456 [a]	19 [a]	663 [a]
	1	806 [a]	30 [a]	1365 [b]	22 [b]	649 [b]
	3	882 [a]	31 [a]	1415 [a]	24 [b]	640 [b]
	5	791 [b]	31 [a]	1500 [c]	25 [b]	638 [c]

*Values in [] with the same letter symbolize absence of statistically significant difference. MOE: Modulus of elasticity; MOR: Modulus of rupture.

Biodeterioration

Mass loss

Table 5 shows the effect of ZB concentration on weight loss of WPCs exposed to brown and white rot fungi.

Table 5. Effect of ZB on weight loss of WPCs by brown and white rot fungi (16 weeks at 27 °C).

ZB (%)	***Trametes versicolor* (L.) Lloyd**		***Gleophyllum trabeum* (Pers.) Murrill**		**Control**	
	Agar	**Soil b.**	**Agar**	**Soil b.**	**Agar**	**Soil b.**
0	1.5 [a]	2.6 [a]	3.1 [a]	3.6 [a]	0.5 [a]	1.7 [b]
1	0.8 [b]	0.8 [b]	0.5 [b]	1.6 [b]	0.4 [a]	1.6 [b]
3	0.5 [b]	1.1 [b]	0.5 [b]	1.1 [b]	0.4 [a]	1.6 [b]
5	0.4 [b]	0.7 [b]	0.4 [b]	0.9 [b]	0.4 [a]	1.7 [b]

*Values in [] with the same letter symbolize absence of statistically significant difference.

In general, none of the WPCs with and without ZB in the presence of white or brown rot fungi exhibited a mass loss that may affect their subsequent use. WPCs without ZB registered a decrease in mass of 3.1 and 3.6 % when exposed to *G. trabeum* in agar and soil block tests, respectively. The degradation of WPCs by fungi was strongly affected by the ZB concentration, even the treatment with the lowest amount (1 %) reduced the mass loss of all the samples by more than 50 % compared to controls. Several authors (Pendleton *et al.*, 2002; Silva *et al.*, 2006; Fabiyi *et al.*, 2011) reported higher percentages (> 20 %) in WPCs with 50 % wood content, when subjected to rotting fungi.

The lower mass losses observed in this study may have been due to the smaller particle size used to manufacture WPCs, as well as to the extrusion process, which adequately encapsulated the wood particles, making them inaccessible to weathering; thus, colonization and decomposition by fungi were limited. Also, it effectively inhibits the penetration of low molecular weight diffusible agents, such as the enzymes required for fungal degradation (Hill *et al*., 2005). The low fungal ability to colonize the composite material was confirmed by SEM images, which did not show the presence of hyphae or fungal cells on the surface of the WPCs.

Alteration of luminosity

Table 6 presents the alteration of luminosity in the WPCs after attack by fungi. Untreated and ZB-treated WPCs showed a change in luminosity. The humidity inside the incubation chambers may have caused this color modification (Cárdenas, 2012). WPCs exposed to fungi may generate chromophore groups that cause surface change (Fuentes *et al.,* 2018). However, it is not feasible to attribute them to the fungal infection, because all WPCs showed similar color values to those observed in the WPCs used as controls.

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Table 6. Effect of ZB concentration on the alteration of the luminosity in WPCs exposed for 16 weeks to soil block test.

Alteration of luminosity(%ΔL)	**ZB concentration (%)**			
	0	**1**	**3**	**5**
Initial	7.7 [a]	8.8 [a]	9.6 [a]	10.3 [a]
Control	13.5 [b]	14.8 [b]	13.8 [b]	16.1 [b]
Gleophyllum trabeum (Pers.) Murrill	12.8 [b]	14.8 [b]	17.7 [c]	18.5 [b]
Trametes versicolor (L.) Lloyd	14.0 [b]	13.1 [b]	14.1 [b]	18.9 [b]

*Values in [] with the same letter symbolize absence of significant difference.

SEM

Control samples of the WPCs are shown in Figure 6. When the WPC was produced without ZB, a large degradation of moisture was observed. This effect is explained by the fact that ZB delays the absorption of moisture (Cárdenas, 2012).

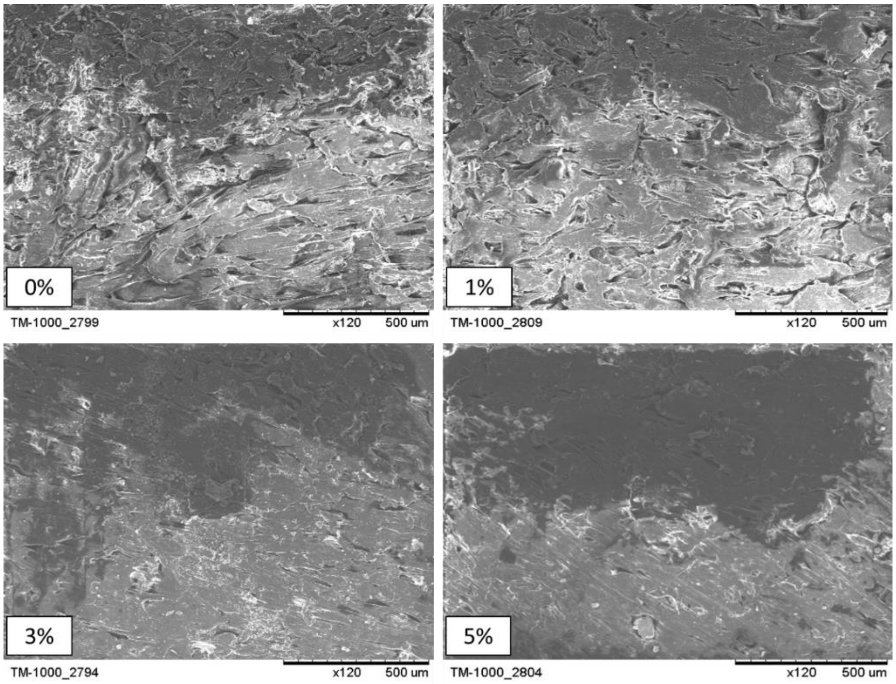

Figure 6. SEM microphotographs of the surface of unexposed WPCs (controls).

WPCs produced with ZB concentrations above 1 % and in the presence of *G. trabeum* showed better resistance to the action of the fungus (Figure 7). In addition, larger spaces or cracks were observed on the surface of the WPCs; this is evidence of damage to the wood particles, which can extend to components such as cellulose, lignin and hemicelluloses. *G. trabeum* causes damage to the wood, according to the maximum weight loss values in the gravimetric analysis. Biodegradation is associated with the presence of cavities in the wood.

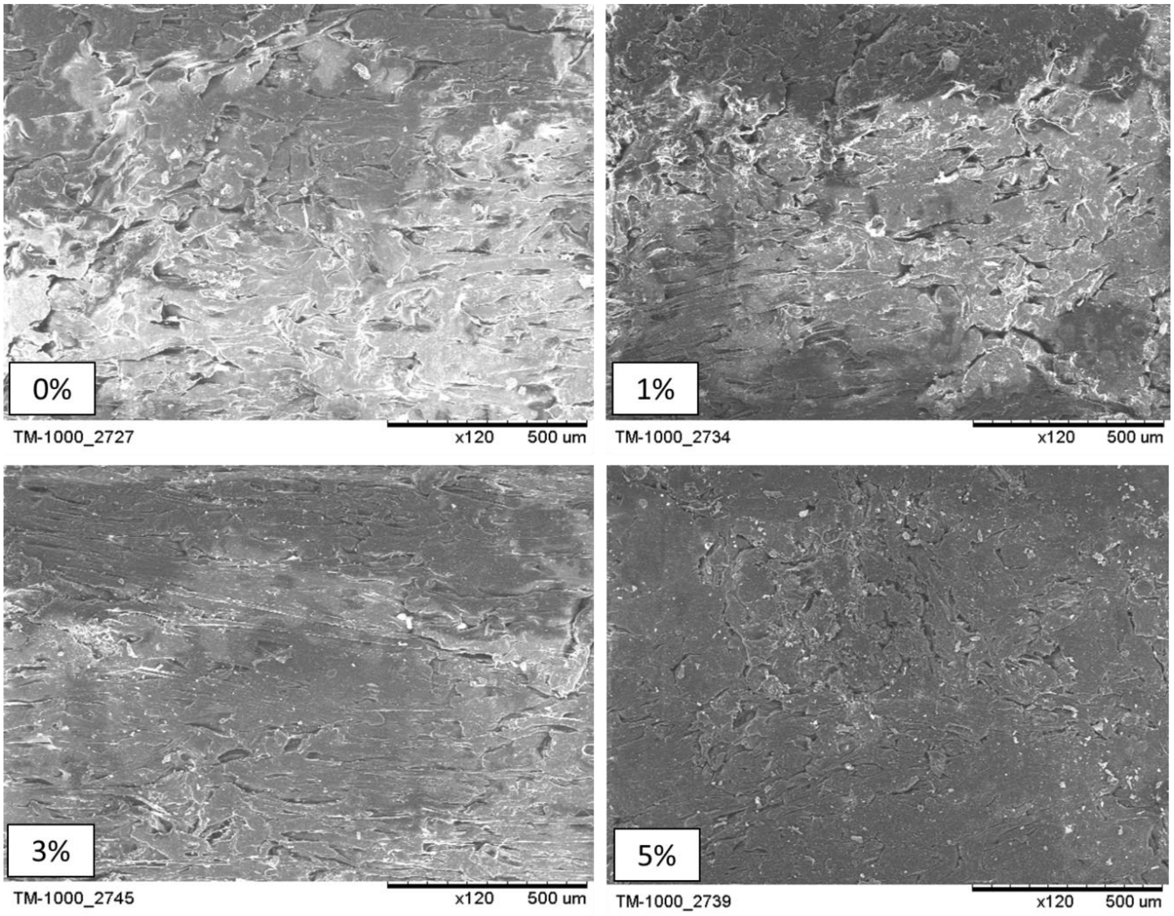

Figure 7*.* SEM microphotographs of the surface of the WPCs exposed for 16 weeks to *Gloeophyllum trabeum* (Pers.) Murrill).

Mechanical properties

ZB had no effect on pre-treatment WPC samples. The results for the soil block treatment are summarized in Table 7. The mechanical properties of WPCs placed on agar are not shown, due to the low weight losses registered.

Table 7. Effects of fungal attack on the mechanical properties of WPCs exposed to different concentrations of ZB.

Treatment	ZB (%)	Mechanical properties				
		Static bending		Tension		Impact (J/m)
		MOE (MPa)	MOR (MPa)	MOE (MPa)	MOR (MPa)	
Baseline	0	956 [a]	38 [a]	1568[a]	21 [a]	677 [a]
	1	979 [a]	35 [a]	1594[a]	21 [a]	682 [a]
	3	987 [a]	36 [a]	1654[b]	21 [a]	670 [a]
	5	1047 [b]	38 [a]	1533[c]	21 [a]	660 [b]
Control	0	854 [a]	38 [a]	1363[a]	26 [a]	719 [a]
	1	834 [a]	36 [a]	1563[b]	24 [a]	670 [b]
	3	847 [a]	36 [a]	1557[b]	24 [a]	701 [b]
	5	915 [b]	36 [a]	1570[b]	25 [a]	740 [c]
G. trabeum	0	857 [a]	39 [a]	1277[a]	28 [a]	599 [a]
	1	852 [a]	34 [b]	1409[b]	23 [b]	650 [b]
	3	883 [b]	36 [b]	1496[b]	25 [b]	694 [b]
	5	873 [a]	36 [b]	1561[c]	24 [b]	622 [b]
T.versicolor	0	861 [a]	38 [a]	1609[a]	25 [a]	608 [a]
	1	890 [b]	35 [a]	1493[a]	23 [a]	656 [b]
	3	900 [b]	36 [a]	1572[b]	24 [a]	731 [b]
	5	909 [b]	36 [a]	1544[b]	24 [a]	723 [b]

*Values in [] with the same letter symbolize absence of statistically significant difference. MOE: Modulus of elasticity; MOR: Modulus of rupture.

The static bending property exhibited resistance loss due to water absorption, given the similarity between the values of the control treatment and those of the WPCs exposed to fungi. The impact registered an increase in the concentration of ZB in the manufacture of WPCs, probably due to the effect of ZB as a moisture inhibitor.

As for the tension, it was higher as a function of the concentration of ZB in the WPCs, which is similar to that cited by Silva *et al*. (2018). However, an equal increase in all ZB concentrations was observed in the samples exposed to the agar tests. The average final moisture content of the WPCs was 20 %.

Conclusions

Weathering has a negative effect on the mechanical properties of WPCs, except for the tension. The effect of ZB is observed in the tension (MOR) and impact, with higher values in those WPCs elaborated with a larger amount of ZB.

ZB is a suitable preservative for WPCs, as it increases resistance to fungal colonization and discoloration.

Mass loss of WPCs exposed to agar and soil block tests have no significant differences.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Aldo Joao Cárdenas Oscanoa: development of the experimental work, writing and revision of the manuscript; Francisco Javier Fuentes Talavera: design and monitoring of the experiments, preparation and correction of the manuscript; Jorge Ramón Robledo Ortíz: support and supervision of the experimental work, support in the preparation of the essay tests, revision of the manuscript; Juan Carlos Meza Contreras and Ricardo Gonzáles Cruz: writing and revision of the manuscript.

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