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MATERIALS ENGINEERING | RESEARCH ARTICLE

Fire retardant treatment of low contamination for panels made from recycled plastic films and polyester resin

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Abstract: The aim of this research was to propose a fire retardant treatment with low contamination additives for panels manufactured with recycled plastics from packaging of food industries and polyester resin. The panels made with this technology are more ecological than the traditional ones, made with shavings and fibers of wood, because they incorporate plastic wastes as raw material instead of natural resources. Because of the likely deterioration of the panel when exposed to UV-Radiation in outdoor application, they are recommended to inside buildings as coating walls and the manufacture of furniture, whereby they have to comply with the class RE-3 “low flame propagation material”, according to IRAM 11910-3:1994, NBR 9442: 1986 and ASTM E 162: 1994 Norms. Several fire retardant treatments were tested, and their influence on the flexural resistance of the panels. By other hand, a comparative study of costs was performed between the panels commercially available, and the panels developed with this technology. The use of HT-E free of halogens is proposed, which obtains a classification RE-3 and not significantly alter the flexural resistance of the panels.

ABOUT THE AUTHORS

Gaggino Rosana is an Architect and PhD in Architecture and Design. Is independent Researcher in The National Council of Scientific and Technological Research (CONICET).

Kreiker Jerónimo has a degree in Chemistry and PhD in Chemistry Science, and Master in Quality Engineering. Is Adjunct Researcher in National Council of Scientific and Technological Research (CONICET).

The researchers Dra. Gaggino and Kreiker, PhD, works together in the Experimental Centre of Economical Housing (CEVE), and the Economical Housing Association (AVE) in Argentine. Both works on several projects on new materials and building components using urban and industrial wastes for application in social houses. This research contributes to the global objectives of this group, and the results are actually in evaluation for the manufacture of prototype furniture and the envelope to walls to improve the thermal behaviour of the experimental social houses.

Currently Dra. Gaggino serves as director of the Research Centre CEVE, and Kreiker, PhD, serves as Vice-director.

PUBLIC INTEREST STATEMENT

The increase in the pollution caused by the intense activity of man is widely known, and requires immediate actions to reduce the negative impact of human activity. As an alternative to reduce environmental deterioration caused by waste plastics from the packaging of the sweets industry, we developed a technology which allows the recycling of this type of waste, difficult to treat in the traditional industry of the recycling of plastics. We promote the use of the waste to manufacture panels in a resin matrix, resulting in a component suitable for indoor use. This work presents the results of a fireproof treatment of low contamination that enables the panels to meet with the Argentinian legislation on this type of materials for use inside houses, both for walls as for the manufacture of furniture.

Subjects: Composites; Polymers & Plastics; Waste & Recycling

Keywords: construction; ecology; agglomerated panels; recycled plastic; fire retardant treatment

1. Introduction

The intense industrial activity and the urban development generate a large amount of plastic waste of different composition each year. In general these wastes come from household waste or companies that generate it as a scrap of their productive processes or by the packaging. As it is known, the plastic degradation takes hundreds of years, increasing the environmental problem that its manufacture, use and discard generate. In order to mitigate the environmental degradation, several strategies are being used, including recycling and reuse the wastes in new components or production processes, with the dual advantage of enhancing a waste recycling and avoid the use of virgin raw material (Seoanez Calvo, 2000).

The construction industry is an important target to introduce the components manufactured with plastic wastes, due to the magnitude of insertion as the diversity of applications that can be proposed.

The use of recycle plastic for the manufacture of panels or particleboard have been intensely studied in the last years, and in a general way the manufacture process involve a thermo-fusion process of the raw material, followed by a moulding with pressure. There are few works of scientific research describing the properties of the panels (Breslin, Senturk, & Berndt, 1998; Singh, Hui, Singh, Ahuja, & Feo, 2017), because in general these developments have been made by companies with commercial purposes and the products and technologies are protected by patents. In fact there are a lot of examples of commercially products, available in the web sites (<https://www.ecosheet-agri.co.uk/index.php>, June 26, 2013; https://www.plaspanel.com.au/products_recycled.html, June 26, 2013; <https://www.dogma.org.uk/vtt/environment/cases/gaikers.pdf>, June 26, 2013) but scarce scientific articles.

On the other hand, there is abundant bibliography upon panels made with recycled plastics and ligno-celulosic wastes, the named wood-plastic particleboards (Haftkhani, Ebrahimi, Tajvidi, & Layeghi, 2011; Nourbakhsh, Karegarfard, & Ashori, 2010; Wang, Wong, & Kodur, 2007) or examples using Low Density Polyethylene (Adhikary, Pang, & Staiger, 2008; Yao, Wu, Lei, & Xu, 2008), Polypropylene (Kakroodi, Leduc, Gonzales Nuñez, & Rodriguez, 2012; Wechsler & Hiziroglu, 2007), and other plastics (Ashori & Nourbakhsh, 2009; Cui, Lee, Noruziaan, Cheung, & Tao, 2008). In the most of the cases, the process involve the thermo-fusion of the raw material, taking advantage that one or more recycled plastics can melt and so act as binder.

Unfortunately, in some cases the thermo-fusion process of the recycled plastic is not possible, due to the decomposition the raw material because of the presence of additives, or interfering materials, and the same raw material acting as binder is not possible. In these cases the only way of manufacture components is using an external binder.

In a previous research work we described the elaboration of panels using plastics wastes from industrial process and polyester resin as binder (Gaggino, 2012). Plastic waste from packaging was used as raw material, and it was basically a heterogeneous mixture of Low Density Polyethylene (LDPE), Bi-oriented Polypropylene (BOPP) and Polyvinyl Chloride (PVC). This residue came from a factory of food sweets, and has a local availability of approximately 200 tons monthly. Although the material has the advantage of being clean and does not need wash before the use, it presents as main disadvantage the variability in their composition and the presence of surface ink or aluminium powder, which is not suitable for reuse by means of melt-extrusion or chemical recycling. For these reasons the way to recycling the waste that we proposed was using a resin as external binder to conform the material. The panels made with this technology have a flexural resistance similar to the chipboard with wood chips. Its main advantage with respect to conventional panels is its lower water absorption, and

swelling null after immersed in water for 24 h. The panels showed as main disadvantage more degradation due to exposure to ultraviolet radiation, which limits its application in outdoor.

In the previous article, we proposed the use of these panels in indoor environments, thus it was necessary to evaluate the fire resistance properties of panels and to develop a flame retardant treatment to ensure that the material meets with the RE-3 “Low flame propagation Material” classification according to Norm IRAM 11910-3:1999, which is according to NBR 9442:1986 and ASTM E 162:1994 (American Society For Testing And Materials, 1994; Associação Brasileira de Normas Técnicas, 1997; Instituto Argentino de Normalizacion, 1994), what would allow the proposed use.

Taking into account that the products of combustion of resin polyester and the plastic wastes uses in the manufacture of panels have negative effects on the health of people (Braun & Levin, 1986), is necessary to propose a treatment to slow the spread of flames, in order to give time to the evacuation of homes where these panels are used, before toxic fumes affect people in case of fire.

There is a significant amount of additives commercially available for fireproof protection and fire retardant. In general, the additives containing halogens give better results because the release of halogen gas through a radical mechanism (Hastie, 1973). These additives present as main advantage the higher power for fire inhibition but they are harmful to human health (Shaw et al., 2010). Other inorganic additives were used in the past, but the main disadvantage of them were the remarkable decrease of mechanical properties of materials, besides a less effective fire retardant behaviour than halogenated compounds (Jang, Chung, Kim, & Sung, 2000; Lyons, 1970).

In this article we show the results of the fire retardant behavior of the panels manufactured with three different treatments. An inorganic additive, an halogen free additive and a surface coating treatment were evaluated as fire retardants, and the incidence of these additives in the flexural resistance of the panels was evaluated.

2. Experimental section

2.1. Materials

Plastic wastes: from packaging of sweets and food products provided by a local factory, composed of a heterogeneous mixture of Polyethylene, Bi-direction Polypropylene and Polyvinyl Chloride, Figure 1. The material was crushed in a machine to a 3 mm particle size (fineness modulus of 4.25).

Resin: type Polyester Nautical, brand name: Polial 340, Accelerator: Cobalt Octoate, brand name: OCo 2.5%. Catalyst: Methyl Ethyl Ketone Peroxide, brand name: Perly OX 101. These materials were provided by Poliresinas Factory, located in Cordoba.

Figure 1. Wastes used for the manufacture of panels.



This type of resin was chosen because of its water resistant properties (one of its main applications is as a binder in panels for marine use). The panels developed in this research, manufactured with plastic particles and polyester resin, not swell when submerged in water and therefore are suitable to be used in wet areas of a house (for example, in furniture under countertops for kitchens or bathrooms), unlike the traditional panels made with wood chips and urea-formaldehyde resin that decompose in wet environments.

Fire retardant treatments: In this work they were used Borax powder (Sodium Tetraborate) Industrial Grade, provided by Proveeduría Científica Factory; Flame retardant halogen free HT-E powder, provided by Fullchem Factory; and Fireproof coating for textile Industrial Grade provided by Venier Factory. All these materials were bought in Córdoba.

2.2. Manufacture of panels

Panels with plastics and polyester resin were prepared to determine the rate of spread of flame and the flexural resistance with different fire retardant treatments. Specimens for testing were prepared as follows: resin and the catalyst were mixed manually. On the other hand the plastic particles were added to a horizontal mixer and then were impregnated with the activated resin using a spray machine. The mixture was mixed during 5 min.

In the Panel 1.1, the fire retardant additive was applied by two hand of a superficial coating.

Panels 1.2 and 1.3 were made adding the fire retardant additive to the plastic particles before the activation of the resin. Then the impregnated material was placed into the mould, and pressed to 33.5 kg/cm² using an hydraulic press machine. The temperature during the press process was 24°C. The pressing process took 2 h, after that the panel was removed from the mould, Figure 2. The density of panel so obtained was 1,221.3 kg/m³.

The experimental design of panels is described in Table 1.

Figure 2. Panel of plastic particles and polyester resin.



Table 1. Fire retardant treatments of panels

Panel	Fire retardant treatment	Observations	Application
1	-	-	-
1.1	Venier paint	Two hand	Superficial coating
1.2	HT-E powder	5%	Added during the process
1.3	Borax powder	5%	Added during the process

Table 2. Flame spread index and Flexural resistance of panels

Panel	I average	Class	Flexural resistance (N/mm ²)
1	109.47	RE 4	7.53
1.1	112.83	RE 4	7.53
1.2	66.37	RE 3	5.67
1.3	65.92	RE 3	4.82

Dosage of panels: Plastic wastes 65.83%, Polyester resin 32.71%, Accelerator 0.97%, and Catalyst 0.49%. This final dosage was chosen after trying different combination of materials, by having the flexural resistance similar to that of chipboard without coatings of traditional type. Other formulation with a minor proportion of resin gives as a result panels with a lesser mechanical resistance. In a previous work the results of different experiments were published, to choose the best dosage of raw materials, where the parameters taken into account were the mechanical resistance, the density and the cost (Gaggino, 2012).

The panels were conditioned to meet the requirements of the specified tests, using a special plastic cutting wheel.

2.3. Flame spread index and flexural resistance

The Flame spread index test was determined in the laboratory for fire test of the Research and Development Center in Constructions of the National Institute of Industrial Technology (INTI), according to IRAM Norm 11910-3:1999 “Materiales de Construcción, Reacción al fuego, determinación del índice de propagación de llama – método del panel radiante” which is according to NBR 9442:1986 and ASTM E 162:1994.

The flexural resistance was determined in the Laboratory of Research and Structural Design (TIDE) in the Faculty of Architecture and Urbanism of the National University of Cordoba, Argentine. The pressing machine was a 30 tn brand name Soiltest, and the test was made according to NBR 7190 Norm, which apply for panels of wood. More physical and mechanical properties of Panel 1 (without fire retardant treatment) were published in a previous article (Gaggino, 2012).

3. Results

The Table 2 shows the results obtained for the determination of the flame spread index corresponding to panels manufactured with the different fire retardant additives, together with the flexural resistance values.

The Panel 1 (without fire retardant treatment) was classified as RE 4 “Medium flame spread”. The same classification corresponds to Panel 1.1, which was treated with superficial coating Venier. The Panel 1.2, manufactured with HT-E powder and Panel 1.3 manufactured with Borax powder, show similar value and were classified as RE 3 “Low flame spread”. The Panels 1 and 1.2 show similar values for the flexural resistance, due to the scarce effect of the coating upon the mechanical properties of panels. The Panel 1.2 shows a lesser flexural resistance than the reference, in this case the decrease was in a 75% respect Panel 1. In the case of Panel 1.3 the effect of the additive was more important, and this panel shows a flexural resistance of 64% respect to the reference, and with this mechanical behavior the panels could not be suitable for the manufacture of furniture.

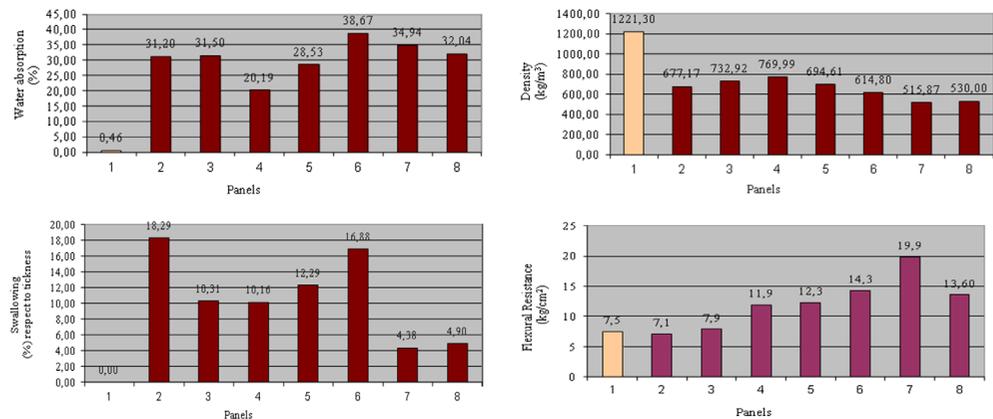
3.1. Other technical properties

The Table 3 shows the results of tests made in the Panel 1 (without any fire retardant treatment). An additionally, a comparative analysis was conducted between the properties of these panels developed in CEVE with those of other conventional panels manufactured with wood chips commercially available in our country, Figure 3. All the panels are 18 mm thickness.

Table 3. Technical properties of the panel made with recycled plastics and polyester resin in CEVE, published in previous a work

Property	Value	Unit	Reference norm
Density	1,221.30	kg/m ³	ASTM C 67
Water Absorption (%) Immersed in water for 24 h	0.46	%	ASTM C 67
Swelling Immersed in water for 24 h	0.00	%	ASTM D 1037: 99
Flexural resistance perpendicular to the fibers	7.53	kg/cm ²	NBR 7190
Flexural resistance parallel to the fibers	25.39	kg/cm ²	NBR 7190
Resistance to traction perpendicular to the fibers	1.31	kg/cm ²	NBR 7190
Compression resistance parallel to the fibers	50.43	kg/cm ²	NBR 7190
Compression resistance perpendicular to the fibers	91.24	kg/cm ²	NBR 7190
Cut resistance parallel to the fibers	25.39	kg/cm ²	NBR 7190
Cut resistance perpendicular to the fibers	18.71	kg/cm ²	NBR 7190
Modulus of elasticity parallel to the fibers—MOE	8,461.80	kg/cm ²	NBR 7190
Aging accelerated (UV-ray and humidity)	Do not meet	–	ISO 9933
Thermal conductivity	0.19	W/mK	ISO 8301 and ASTM C518

Figure 3. Analysis of different properties of panels.



The comparison between the panel developed with plastics and resin in CEVE and conventional panels prepared with wood chips that are commercially available reaches the following observations:

- The flexural resistance of the panel 1 developed with plastics and resin in CEVE is similar to the panel 2, chipboard without coatings.
- The swallowing of the panel 1 immersed in water is null, unlike the conventional panels.
- The water absorption of the panel 1 is lesser than the conventional panels.
- The panel 1 has a higher density than the conventional panels.

4. Analysis of costs

The analysis of cost of the developed panels was made, in the conditions described at the method Section 0, in a laboratory scale. The analysis of cost is showed in Table 4. Data of the panels commercially available is from the Journal of the Architects College, on December of 2015, in the Province of Cordoba, and taxes are not included (Arquitextos, 2015).

Table 4. Cost of panels made in CEVE and other commercially available in Cordoba, Argentina

Panels of 18 mm thickness	Name	Composition	Fire retardant treatment	Cost (U\$/m ²)
Manufactured in CEVE	1	Recycled plastic and polyester resin	Without	16.00
	1.1		Venier coating, two hand	16.40
	1.2		HT-E powder, 5%	16.26
	1.3		Borax powder, 5%	16.13
Traditional panels commercially available	2	Panel of chipboard without coatings. Brand name: Faplac	-	10.00
	3	Panel of chipboard with coating of melamine. Brand name: Masisa	-	12.70
	4	Panel of MDF (medium density fiber) without coating. Brand name: Masisa	-	11.60
	5	Panel of MDF (medium density fiber) with coating of Melamine. Brand name: Masisa	-	16.20
	6	Panel of OSB (oriented strand board). Brand name: Masisa	-	9.86
	7	Panel of Phenolic. Brand name: Troya	-	17.30
	8	Panel of Plywood. Brand name: Faplac	-	18.66

The Panel 1.2 with the most effective fire retardant treatment and good mechanical properties has a similar cost than the Panel 5 of MDF with melamine coating, widely used for low cost furniture. The Panel 1.2 with HT-E powder is a good alternative for furniture and inner equipment, with a good quality-cost rate.

5. Conclusions

Related to the fire retardant treatment, flexural resistance and costs:

- The surface coating Venier, did not influence on the fire behavior and neither decreased the flexural resistance.
- Both, the HT-E and Borax treatments, improved the behavior in front of fire, and showed similar effect complying with the requirement of RE3 material suitable to be used in indoor spaces, but the fire retardant treatment HT-E, do not modify significantly the mechanical properties.
- The use of panel 1.2 with HT-E treatment is recommended for furniture and for wall covering, because it is fire resistant with the use of a free halogen additive which is not harmful for health. Besides, it recycles wastes, it has good mechanical properties and it is resistant in wet environment and the cost is similar to MDF commercially available.

Related to other physical and mechanical properties:

- All the panels developed in CEVE with recycled plastic and polyester resin are suitable for use in covering for walls and panels for furniture, because they have a good mechanical resistance. The flexural resistance of Panel 1 is similar to the Panel 2 of chipboard without coatings.
- The main advantages of these panels are: do not swell after the water exposure, in contrast to the traditional panels. They have lesser water absorption than the traditional manufactured with wood chips.

- Its density is higher than the traditional panels.
- Its main disadvantage is a low resistance to UV-ray, so they are not suitable for external use.

Glossary

I	Index of superficial spreading flame
Class RE3	“Material of low flame spread” (I between 26 and 75). Meets with the Class B of Brazilian Norm NBR 9442/1986
Class RE4	“Material of medium flame spread”. (I between 76 and 150). Meets with the Class B of Brazilian Norm NBR 9442/1986

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