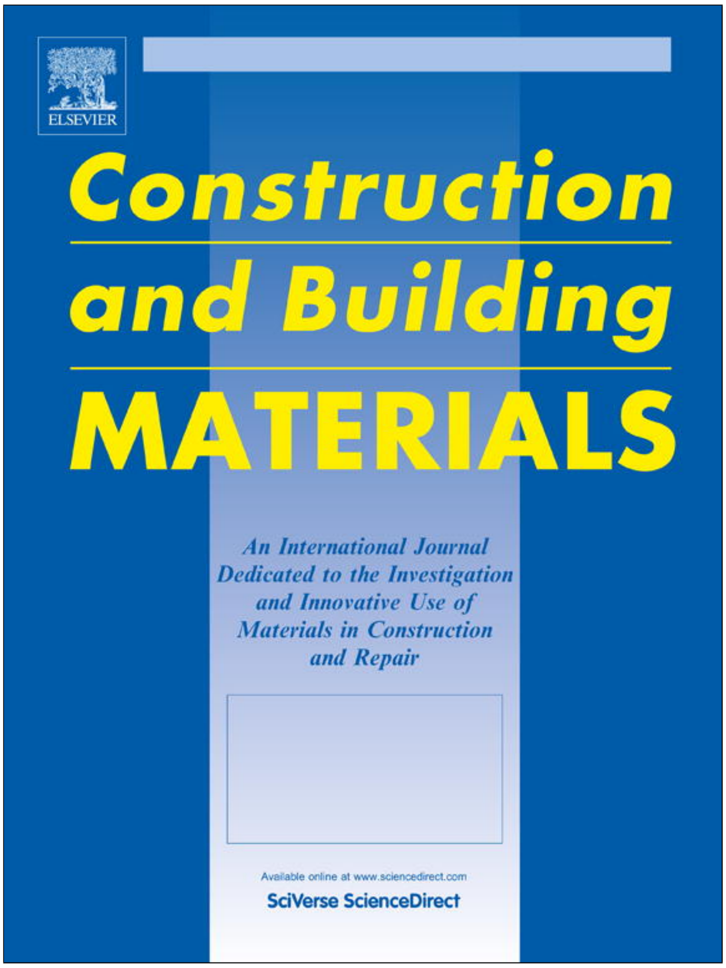

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Water-resistant panels made from recycled plastics and resin

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ABSTRACT

The objective of this work was to contribute to decontaminating the environment, and to solving the housing shortage in our country. The technological products developed in this research are sustainable from the ecological, technical and economic points of view. The developed products were panels for housing and equipment. They were manufactured by recycling plastic materials from food, perfumery or cleaning packaging, waste production from factories due to failures in sheet thickness or ink application. It thus contributes to decontaminating the environment, since most of this waste is buried in municipal land without any use, or accumulated and burned in landfills, causing environmental degradation.

1. Introduction

The start point of this research work is the problem of environmental pollution.

The human produce large quantities of waste. Some of this waste may be "absorbed", by recycling food waste as fertilizer for crops, for example. Other part of the waste is not bio-degradable, as in the case of plastics, and the nature cannot absorb it.

Most part of the waste is accumulated, buried or incinerated in legal or illegal landfills, irrationally wasting resources and causing a negative impact in the environment.

Open dumps create pollution in water, soil, air and food. They produce landscape deteroration, loss of property value, and health consequences. Frequently human feed animals in the dumps, mainly pigs, and after that, acquire illnesses from eating contaminated meat.

The dumps are also places of a hazardous work for collectors.

Waste combustion is justified to prolong the life of the dump and control of disease vectors, but produces air pollution with carcinogenic gases.

Decreasing waste production, recycling materials and adequate disposal of waste that cannot be recycled are viewed as the best possible solutions to this problem.

Recycling is also the best way to reduce extraction of raw materials [1].

The amount of waste that is recycled varies in the different countries. Unlike European countries, there is little awareness of the need for recycling in Argentine.

The city of Cordoba, the second city in population of Argentina, is a representative case: 2.707.604 inhabitants is the population (of the city and the metropolitan area, according to census data 2010), 1272,573 tons of solid waste are generated per year, 10% of this waste (127,257 tons) is being recovered for recycling processes [2].

In important cities of Europe the situation is as follows:

In Berlin, 4070,000 inhabitants is the population (of the city and the metropolitan area, according to census data 2007), 1912,900 tons of solid waste are generated per year, 41% of this waste (784,289 tons) is being recovered for recycling processes.
In London, 14,000,000 inhabitants is the population (of the city and the metropolitan area, according to census data 2007), 6580,000 tons of solid waste are generated per year, 25% of this waste (164,500 tons) is being recovered for recycling processes.
In Paris, 11,836,970 inhabitants is the population (of the city and the metropolitan area, according to census data 2007), 5326,636 tons of solid waste are generated per year, 15% of this waste (798,995 tons) is being recovered for recycling processes [3].

Plastic materials constitute 30% of the total volume of urban solid waste, equivalent to 13.3% by weight. 207,480 tons of plastic waste are generated every year in Argentina [4].

Plastic waste contaminate the environment for a long time:

Polyvinyl chloride (PVC) films do not decompose for 100 years in contact with natural agents. Low density polyethylene (LDPE) bags do not decompose for 150 years. Polyethylene-terephthalate (PET) soft drink bottles and Polypropylene (PP) recipients do not decompose for 1000 years [5].

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Fig. 1. Plastics to be recycled.

Fig. 2. Mill to grind plastics.

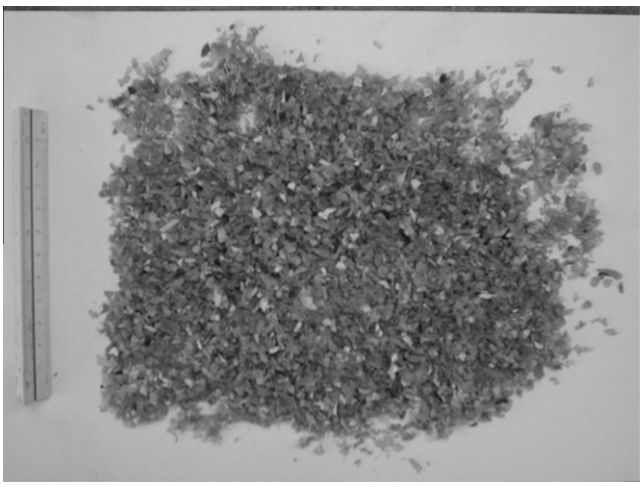


Fig. 3. Plastic grinding.

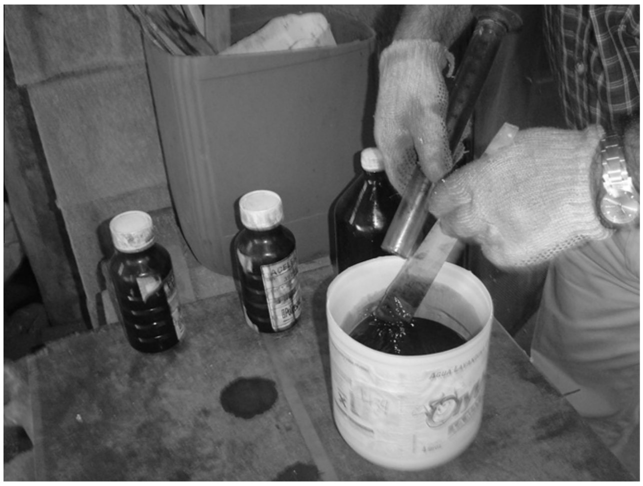


Fig. 4. Making the mix of resin, accelerator and catalyst.

Fig. 5. Impregnating the plastic particles with a spray gun.

Fig. 6. Mold made with iron sheets.

Fig. 7. Applying pressure with a machine.

This research work follows some of the principles of Sustainable Construction:

– Use of recyclable and renewable resources in construction.
– Environmental protection.

Sustainable Construction appeared last century, with the environmental concern that future generations should not be adversely affected by the construction activity [6].

The traditional technologies used in Argentina for construction involve the extraction of raw natural materials (stone, sand, timber, fertile soil, metals, etc.), some of which are non-renewable resources. Very few recycled materials are employed, mostly only those recovered from demolitions [7].

Using recycled materials from other industries – not from the same industry – is very recent in the field of architecture and construction. An example of this is the recycling of construction debris for use in new construction, already known since ancient times in different civilizations: Egyptian, Mayan, Inca, Greek, Roman, etc. [8]. Instead, the recycling of waste from other industries, in this case plastics from food packaging, is a novelty of the XX and XXI centuries. This is the waste material used in the technology presented in this article.

There are numerous precedents worldwide of using recycled plastics in building materials in recent years, which have served as starting point for this work. However, it should be noted that there are differences between these and the building elements developed in this research. These are the following: dosage, constituent materials, processing procedures, design, physical and chemical properties, applications and cost.

The objectives of this research work were:

Fig. 8. The panel is ready.

Fig. 9. Testing flexural resistance.

- Collaboration in the decontamination of the environment.
- Collaboration in solving the housing shortage in our country.
- Development of an environmentally friendly building technology, with recycled plastic materials.
- Development of an economical building technology, suitable for social housing.
- Development of quality building and furniture components such as wall panels, covering, doors and panels.

Most of the objectives were achieved in this research work.

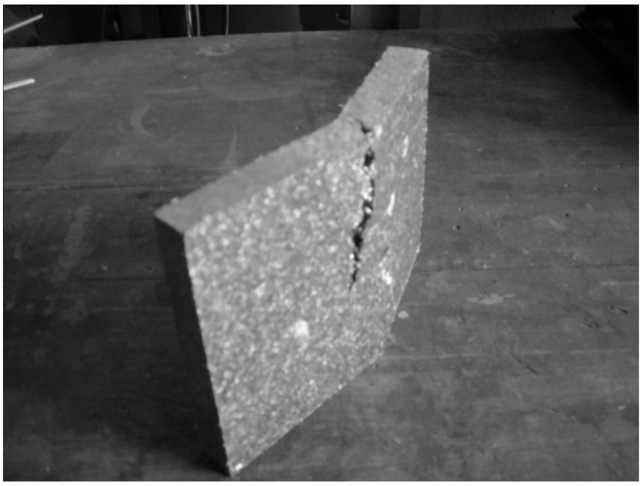


Fig. 10. Specimen tested to flexural resistance.

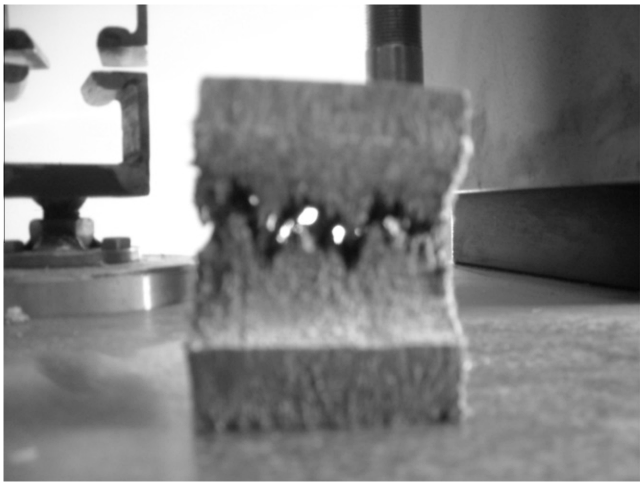


Fig. 12. Specimen tested to traction.

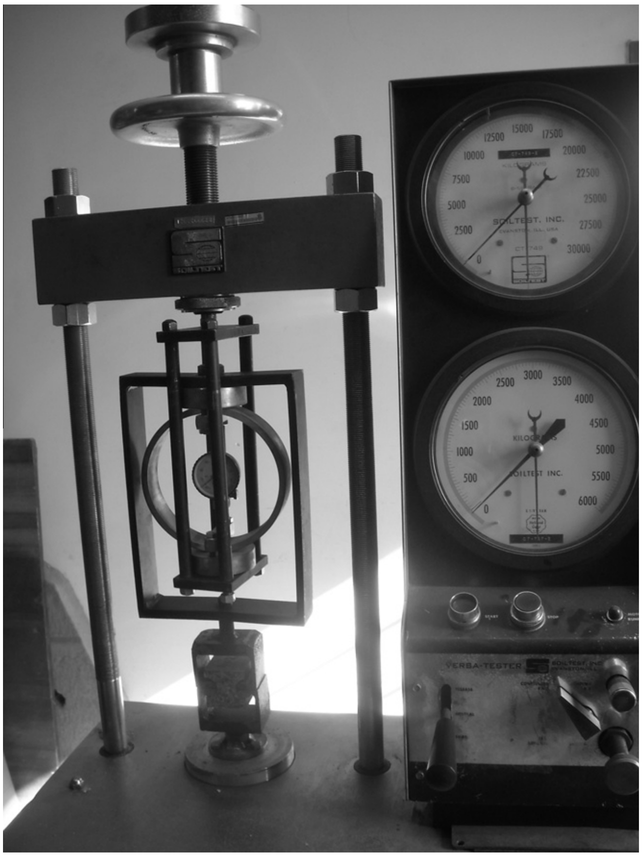


Fig. 11. Testing resistance to traction.

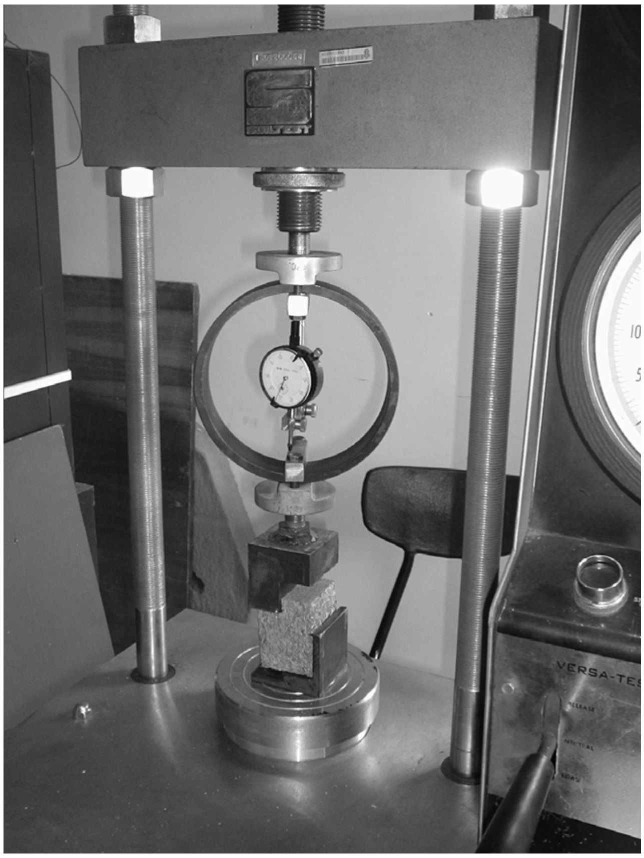


Fig. 13. Testing resistance to cut.

The problem being investigated was to develop an economical, environmentally friendly and quality panel made with recycled plastics.

In this research work little panels with dimensions of 46.0 cm. length, 26.0 cm. width and 1.8 cm. thickness were obtained. Other larger components such as doors or covering were still not obtained.

A study of costs of this panel was done. The technical properties and the cost of this panel were compared with other panels.

2. Background in manufacturing building components with recycled materials

Background in employing recycled plastics such as aggregates in building components using hot processes:

International examples: Panels prepared from residues based on multilayer packages and plastics, reinforced with lignocellulosics residues (peanut shells and rice hulls), developed by Caraschi et al. [9].

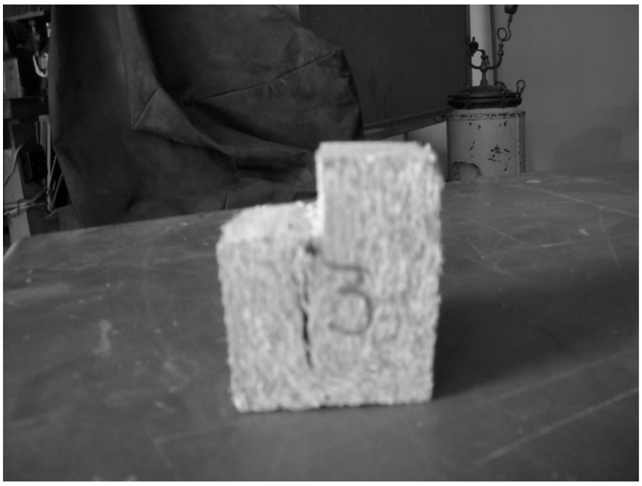


Fig. 14. Specimen tested to cut.

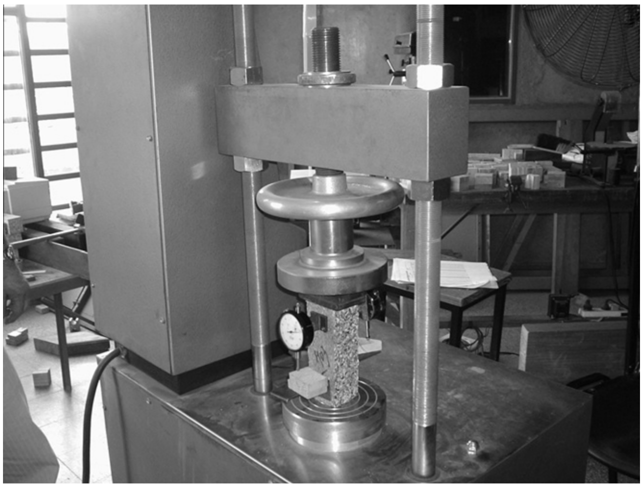


Fig. 15. Testing resistance to compression.

Wood–plastic composite panels developed in Iran by Haftkhani et al. [10].
Panels developed by Ashori and Nourbakhsh with high density polyethylene, polypropylene and fibers from old papers [11].
Wood–plastic composite panels containing fast growing wood fibers developed by Ayrilmis et al. [12].
Plastic composite panels with bamboo and polyvinylchloride (PVC), developed by Wang et al. [13].
Wood–plastic composite panels made from particle of radiata pine and polypropylene, developed by Wechslera and Hiziroglub [14].
Wood–plastic composites based on recycled and virgin high-density polyethylene (HDPE), obtained by Adhikary et al. [15].
Panels made from straw fiber and high-density polyethylene, obtained by Yao et al. [16].
Compounds developed by Avakian and Parekh with different types of plastics from industrial and household waste [17].
Building components obtained by Prusinski with contaminated plastic and sand [18].
Components produced by Nagayasu, with plastics and rubber [19].
Products obtained by Hoedl with various plastics [20].
Materials made from wood fibers bound with molten polymers (both waste materials) developed by Giaccardi [21].

Fig. 16. Specimen tested to compression.

Panels with thermoplastics from municipal solid waste, combined with paper, cardboard or wood chips, obtained in Gaiker Technology Centre of the Basque Country, Spain (information provided by the manufacturer).
Local examples: Panels made with ground Tetra Pack waste from packaging compressed with a hot process, described by Galan et al. [22].
Panels made with ground Tetra Pack waste from packaging, trade mark: T-Plak, produced by the company Rezagos Industriales S.A., located in Pilar, Province of Buenos Aires. They are made of aluminum foil, polyethylene (LDPE) and wood pulp (information provided by the manufacturer).

Background in employing recycled plastics used in building components using cold molding processes, with different binders:

International examples: Sandwich panels resistent to fire, made from glass-fiber/polyester and a glass-fiber/polyester Vermiculux, developed by Galgano et al. [23].
Polymer mortar panels using methyl methacrylate solution of waste expanded polystyrene as binder, obtained by Bhutta et al. [24].
Hybrid fiber-reinforced polymer (FRP)–autoclaved aerated concrete (AAC) panels, developed by Mousa and Nadim [25].
Fiber-reinforced polymer (FRP) sandwich deck panels with sinusoidal core made of E-glass Chopped Strand Mat (ChSM) and polyester resin, obtained by Chen and Davalos [26].
Sandwich panels of concrete with recycled glass fiber reinforced polymer (GFRP), obtained by Correia et al. [27].
Panels developed by Carroll and Mc. Clellan with polyurethane resin and plastic and lignocellulosic aggregates [28].Mixes made by Sawyers with cement, recycled plastics, sand and gravel [29].Panels manufactured by Hammond and Warren

Fig. 17. Testing resistance to aging.

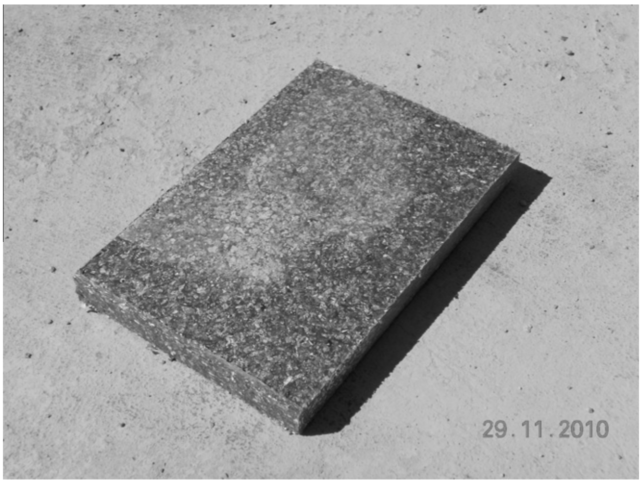


Fig. 18. Specimen tested to aging.

with a foam core made and coverings made of plastic particles bound with portland cement [30].Blocks with cement and crushed polyethylene-terephthalate (PET) bottles, developed by Eco Builders Network in the US [31].

Local examples: The building components obtained in the Experimental Center of Economical Housing in Cordoba, Argentina, by a research team led by the author of this article: Plates with cement and expanded polyestyrene (PS) [32].

Bricks with cement and low density polyethylene (LDPE) [33].

Bricks, blocks and plates with cement and polyethylene-terephthalate (PET) [34].

Compositions with cement and different kinds of plastics [35].

3. Materials

The main material that makes up the products in this technology is the recycled plastic material from food, perfumery or cleaning packaging, all of which is factory production waste resulting from thickness or printing failure (Fig. 1). Their constituent materials are LDPE (low density polyethylene), BOPP (biaxially oriented polypropylene) and PVC (polyvinyl chloride). They are sheets with ink on the surface and with aluminum powder in some cases.

It is a type of waste that cannot be recycled for other uses, since the presence of ink and aluminum powder makes reprocessing difficult, especially in cases of chemical recycling involving fusion of materials. There is an abundant supply of this material, which justifies research into its possible applications. In the province of Cordoba, Argentina, the quantity of this material is 200 tons per month (data calculated by the author, based in information provided by the factories). Sheets donated by a local candy manufacturer were used for this research project.

The binding resin used is nautical polyester. This resin is known in the market for various applications requiring good mechanical properties and weather resistance, since it does not dissolve in water. Some examples are: vehicle bodies, trailers and boats. It is a viscous liquid requiring the addition of an accelerator (a dark purple liquid) and a catalyst (a crystal clear liquid). The accelerator is the component that regulates the reaction setting time, while the catalyst is the one that starts the reaction.

Data provider: Poliresinas San Luis. Address: 110 Street, San Luis Industrial Park, Argentina. Tel.: +54 265 422983. E-mail: sucursalsanluis@poliresinas.com.

4. Experimental method

Four different formulations were programmed in which the variable was the dosage of materials. All the samples were produced in the laboratory of CEVE. Six replicates of each composite were made, for each kind of test.

Dosages by weight:

Formulation 1: plastic residue 78.70%, polyester resin 20.39%, accelerator 0.61%, catalyst 0.30%.
Formulation 2: plastic residue 74.41%, polyester resin 24.5%, accelerator 0.73%, catalyst 0.36%.
Formulation 3: plastic residue 70.13%, polyester resin 28.60%, accelerator 0.85%, catalyst 0.42%.
Formulation 4: plastic residue 65.83%, polyester resin 32.71%, accelerator 0.97%, catalyst 0.49%.

The general procedure used to make the samples was the following: the plastic was crushed in a special mill (Fig. 2) until particles were obtained with a maximum length of 3 mm, fineness modulus: 4.25. (Fig. 3). The amounts of polyester resin and accelerator were measured according to four different dosages, then they were placed in a plastic container and mixed. The catalyst was added and mixed again (Fig. 4). The plastic particles were placed in a horizontal mixer, and impregnated with this mixture using a spray gun (Fig. 5). While performing the impregnation, the material was mixed constantly. Then the impregnated material was transferred to a mold with dimensions of 46.0 cm. length, 26.0 cm. width, and 10.0 cm. hight, made of iron sheets (Fig. 6). The mix was uniformly pressed with an hydraulic machine (Fig. 7). A pressure of 40 tons was sustained for 24 h. Subsequently, the mold was removed and a panel with dimensions of 46.0 cm. length × 26.0 cm. width was ready (Fig. 8). The thickness of the panel was different for each kind of test.

The specimens for the tests were cut and machined from this panel. Dimensions of the specimens:

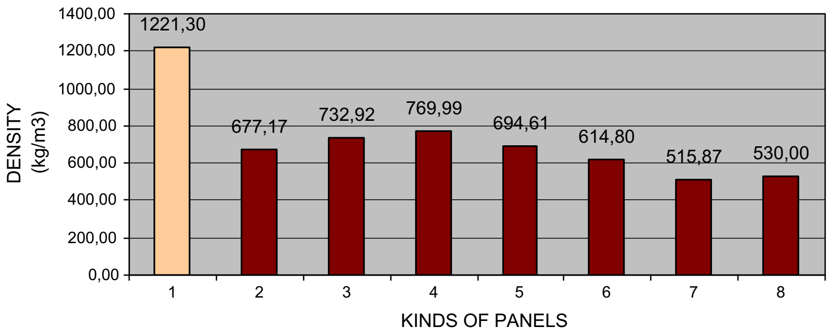
For the test of density: 5.0 × 5.0 × 15.0 cm.
For the test of flexural resistance: 12.0 × 18.0 × 1.2 cm.
For the test of resistance to compression: 5.0 × 5.0 × 15.0 cm.
For the test of resistance to traction: 6.0 × 5.0 × 6.0 cm.
For the test of resistance to cut: 5.0 × 5.0 × 6.4 cm.
For the test of water absorption: 5.0 × 5.0 × 15.0 cm.
For the test of thickness swelling by immersion in water: 12.0 × 18.0 × 1.2 cm.

Table 1
Properties of the panel made with resin and recycled plastic developed in CEVE.

Property	Value	Unit	Followed norms
Density	1221.30	kg/m^3	IRAM 11561
Water absorption (in percentage) immersed for 24 h.	0.46	%	IRAM 12528
Thickness swelling (in percentage) immersed for 24 h.	0.00	%	DIN 68761
Flexural resistance,			
Perpendicular to the fibers	12.11	N/mm^2	NBR 7190
Resistance to traction, parallel to the fibers	25.39	N/mm^2	NBR 7190
Resistance to traction, perpendicular to the fibers	1.31	N/mm^2	NBR 7190
Resistance to compression, parallel to the fibers	50.43	N/mm^2	NBR 7190
Resistance to compression, perpendicular to the fibers	91.24	N/mm^2	NBR 7190
Resistance to cut, parallel to the fibers	25.39	N/mm^2	NBR 7190
Resistance to cut, perpendicular to the fibers	18.71	N/mm^2	NBR 7190
Modulus of elasticity, parallel to the fibers	8461.80	N/mm^2	NBR 7190
Resistant to aging			
(UV rays and moisture)*	No resistant	_	ISO 9933

* Resistant to aging: The accelerated aging test of specimens was carried out in a standardized chamber by the action of alternating ultraviolet light and moisture cycles. This treatment simulates the course of 4.6 years in a test period of 400 h, corresponding to weather conditions in Cordoba. After that, a flexural resistance test was performed on the aged specimens, and this result was compared with the same test on specimens without aging. Result: The flexural resistance decreased by 60% with aging, and a surface discoloration was observed, partial detachment of particles and partial swelling in the specimens.

Table 2
Comparison of density between the panel made with resin and recycled plastic developed in CEVE and other conventional panels made with wood particles.



REFERENCES
1: Panel with resin and recycled plastic developed in CEVE.
2: Uncoated particle board. Brand name: Faplac.
3: Particle board coated with melamine. Brand name: Masisa.
4: Uncoated MDF board. Brand name: Masisa.
5: MDF board coated with melamine. Brand name: Masisa.
6: Oriented Strand Board (OSB). Brand name: Masisa.
7: Phenolic board. Brand name: Troya.
8: Plywood board. Brand name: Faplac.

For the test of modulus of elasticity: 5.0 × 5.0 × 15.0 cm.
For the test of resistant to aging: 12.0 × 18.0 × 1.2 cm.

The following machines were used to produce the samples:

Plastic grinding mill with a three-phase motor of 10 hp, 1400 rpm, brand name Hengnuo, made in China.
Horizontal mixer with a three-phase motor of ¾ hp, 1500 rpm, and a recipient of 50 l volume, brand name Setec, made in Argentina.
Spray gun to paint application, brand name Maer, model 408, made in Argentina.
Standing pressing machine with an hydraulic pump, 40 tons of pressure, brand name Hermes Dupraz, made in Argentina.

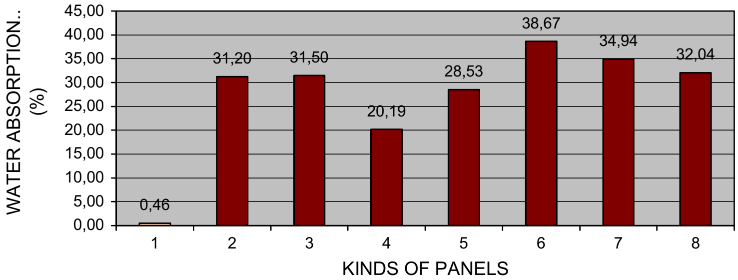
There are examples worldwide in applying a similar procedure [23,26]. In these cases it was also employed polyester resin to bind different aggregates, using cold molding processes, to develop building components.

But there are several differences between these examples and the the method described in this paper: in the case of the panel with resin and recycled plastic developed in CEVE it was used a pressing machine, and the aggregates were plastics; in these examples it was not used pressure; and the aggregates were different.

The technical properties of these panels were established by laboratory testing at:

– The Structural Design Research Workshop Laboratory, Faculty of Architecture, Urbanism and Industrial Design, National University of Cordoba. Address: Haya de la Torre, University City (5000), Cordoba, Argentina. E-mail: tideunc@gmail.com Tel./fax: +54 351 4802654.
– The Test Laboratory of Structure Department, Faculty of Exact Physical and Natural Sciences, National University of Cordoba. Address: Av. Velez Sarsfield, University City (5000), Cordoba, Argentina. E-mail: labestruct@gtwing.efn.uncor.edu Tel./fax: +54 351 4334145.

Table 3
Comparison of water absorption between the panel with resin and recycled plastic developed in CEVE and other conventional panels made with wood particles.



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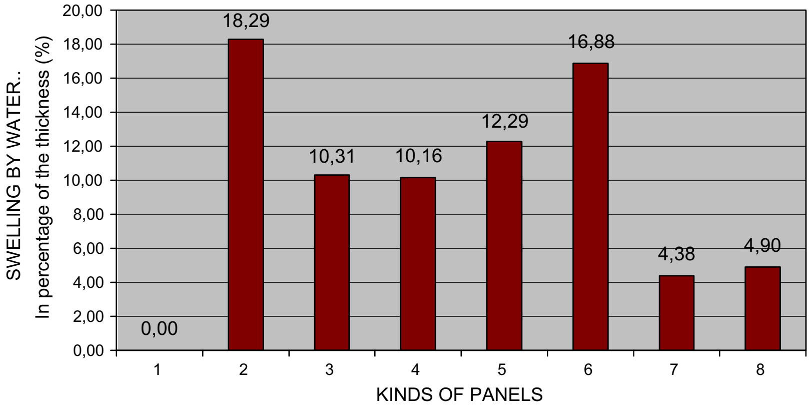
5: MDF board coated with melamine. Brand name: Masisa.
6: Oriented Strand Board (OSB). Brand name: Masisa.
7: Phenolic board. Brand name: Troya.
8: Plywood board. Brand name: Faplac.

This test was carried out following IRAM Norm 12528, in the Structures Laboratory at the National University of Cordoba.
The test was made after being submerged for 24 hrs.

Table 4
Comparison of swelling by water between the panel made with resin and recycled plastic developed in CEVE and other conventional panels made with wood particles.



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5: MDF board coated with melamine. Brand name: Masisa.
6: Oriented Strand Board (OSB). Brand name: Masisa.
7: Phenolic board. Brand name: Troya.
8: Plywood board. Brand name: Faplac.

This test was carried out following DIN Norm 68761.
The test was made after being submerged for 24 hrs.

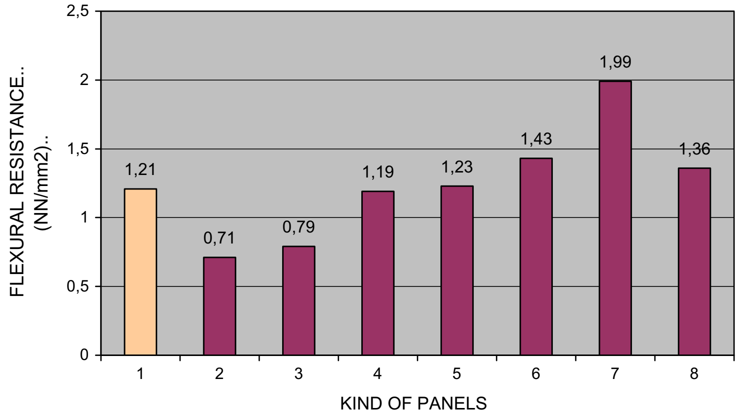
The following machines were used to test the samples:
For all the tests of mechanical resistance: Pressing test machine, 30,000 kilograms of pressure, brand name Soiltest, made in Evanston, Illinois, US.
For the test of aging: Weathering machine brand name QSun/3000 Xenon Test Chamber, made in Florida, US.

The first tests carried out in laboratories were the following: density, flexural resistance perpendicular to the fibers (Figs. 9 and 10), resistance to traction perpendicular to the fibers (Figs. 11 and 12), water absorption and thickness swelling by immersion in water.

The selection criteria of the samples was standard deviation.

After these first tests, the most advantageous formulation was selected (formulation number 4). This formulation have the lowest percentage of water absorption, the highest value of flexural resistance perpendicular to the fibers, and no thickness swelling by immersion in water.

Table 5
Comparison of flexural resistance (perpendicular to the fibers) between the panel with resin and recycled plastic developed in CEVE and other conventional panels made with wood particles.



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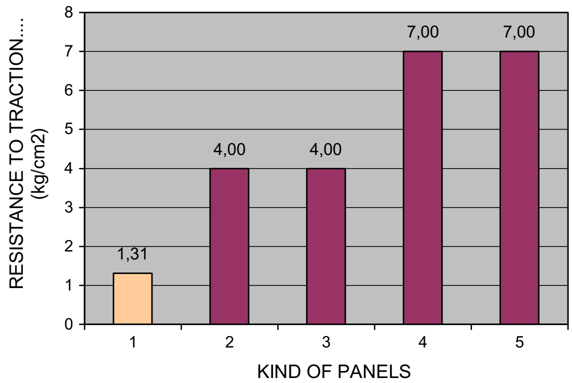
6: Oriented Strand Board (OSB). Brand name: Masisa.
7: Phenolic board. Brand name: Troya.
8: Plywood board. Brand name: Faplac.

This test was carried out following NBR 7190, in the Structural Design Research Workshop Laboratory at the National University of Cordoba.
The Table shows characteristic values.

Table 6
Comparison of resistance to traction (perpendicular to the fibers) between the panel made with resin and recycled plastic developed in CEVE and other conventional panels made with wood particles.



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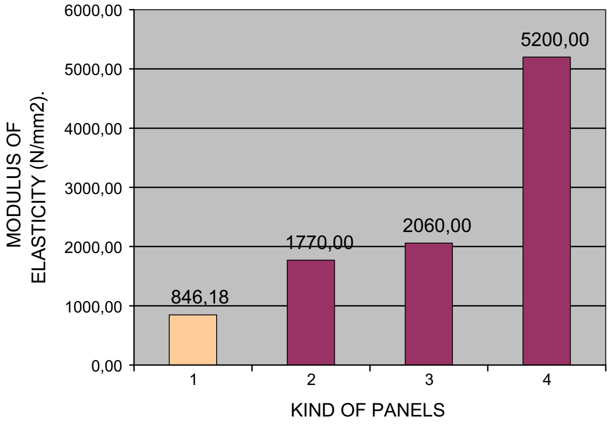
3: Particle board coated with melamine. Brand name: Masisa.
4: Uncoated MDF board. Brand name: Masisa.
5: MDF board coated with melamine. Brand name: Masisa.

Test 1 was carried out following NBR 7190, in the Structural Design Research Workshop Laboratory at the National University of Cordoba.
Tests 2 to 5 are values reported by the manufacturers of the products.
The Table shows characteristic values.

After the selection of this formulation, was completed the study by performing other tests: resistance to traction parallel to the fibers, resistance to cut perpendicular to the fibers (Figs. 13 and 14), resistance to cut parallel to the fibers, resistance to compression perpendicular to the fibers (Figs. 15 and 16), resistance to compression parallel to the fibers, modulus of elasticity parallel to the fibers, and resistance to aging (Figs. 17 and 18).

Table 7
Comparison of modulus of elasticity (parallel to the fibers) between the panel made with resin and recycled plastic developed in CEVE and other conventional panels made with wood particles.



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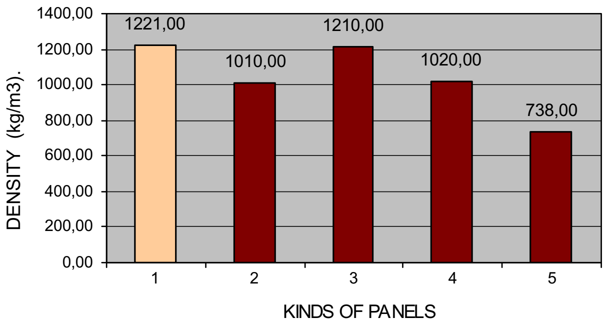
3: Uncoated MDF board. Brand name: Masisa.
4: Oriented Strand Board (OSB). Brand name: Masisa.

Test 1 was carried out following NBR Norm 7190, in the Structural Design Research Workshop Laboratory at the National University of Cordoba.
Tests 2 to 4 are values reported by the manufacturers of the products.

Table 8
Comparison of density between the panel made with resin and recycled plastic developed in CEVE and other panels made with recycled plastic by other authors.



REFERENCES
1: Panel with resin and recycled plastic developed in CEVE.
2: Panel with wood fibers and polypropylene developed by Wechslera and Hiziroglub.
3: Panel with wood particles and polypropylene developed by Wechslera and Hiziroglub.
4: Panel wood flour and high density polyethylene developed by Adhikary et al.
5: Panel with bamboo granule and polyvinyl chloride developed by Wang et al.

The technical properties of formulation number 4 are reported in this article (see Table 1).

The reported mechanical resistance values are the "characteristic values".

For the determination of characteristic values was used this formula taken from statistics, following NBR Norm 7190.

$$f_k = \frac{(2f_1 + f_2 + \cdots + f_{(n/2)-1} - f_{(n/2)}) \cdot 1,1}{(n/2) - 1} \quad (1)$$

f_k is the characteristic resistance, f_1 the breaking stress 1, f_2 the breaking stress 2, n the number of samples.

After the study of the properties of the panels ellaborated in CEVE with formulation number 4, a comparison was made between their main technical properties and other conventional panels made with wood particles, available in the market (see Tables 2–7).

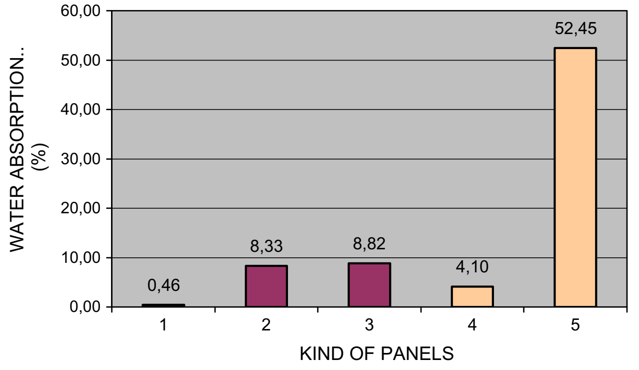
It was also made a comparison between the main technical properties of the panels made in CEVE with formulation number 4 and other similar nonconventional panels made with recycled plastic of other authors (see Tables 8–11).

Finally, the production cost of the panels was compared (see Table 12).

5. Results

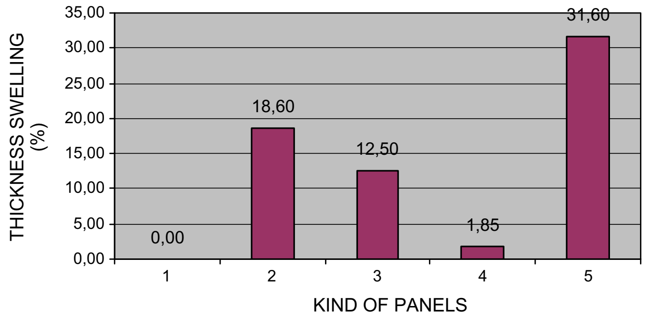
The products obtained in this research work are panels of different thicknesses that could be used for dividing rooms or wall coverings, and slats and boards for furniture. They are named "Panels

Table 9
Comparison of water absorption between the panel made with resin and recycled plastic developed in CEVE and other panels made with recycled plastic by other authors.



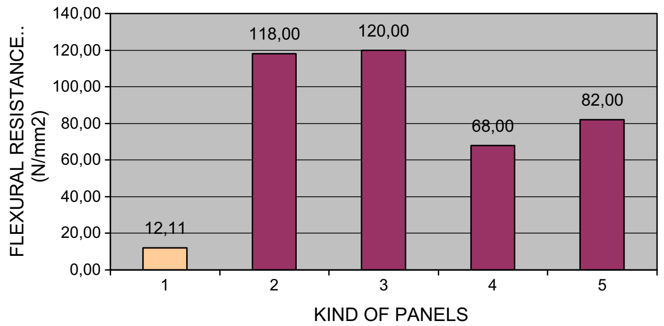
REFERENCES
1: Panel with resin and recycled plastic developed in CEVE.
2: Panel with wood fibers and polypropylene developed by Wechslera and Hiziroglub
3: Panel with wood particles and polypropylene developed by Wechslera and Hiziroglub
4: Panel wood flour and high density polyethylene developed by Adhikary et al.
5: Panel with bamboo granule and polyvinyl chloride developed by Wang et al.

Table 10
Comparison of thickness swelling between the panel made with resin and recycled plastic developed in CEVE and other panels made with recycled plastic by other authors.



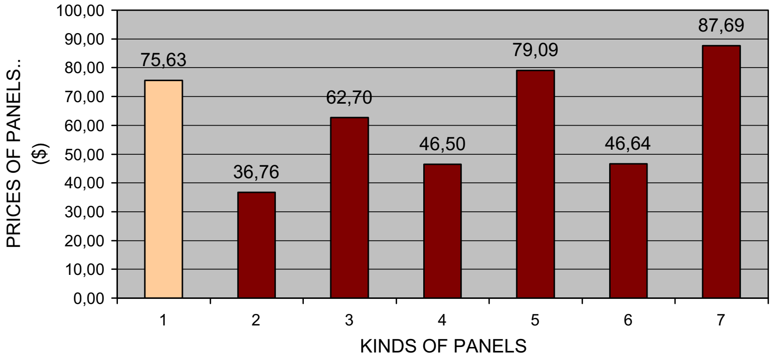
REFERENCES
1: Panel with resin and recycled plastic developed in CEVE.
2: Panel with wood fibers and polypropylene developed by Wechslera and Hiziroglub.
3: Panel with wood particles and polypropylene developed by Wechslera and Hiziroglub.
4: Panel wood flour and high density polyethylene developed by Adhikary et al.
5: Panel with bamboo granule and polyvinyl chloride developed by Wang et al.

Table 11
Comparison of flexural resistance between the panel made with resin and recycled plastic developed in CEVE and other panels made with recycled plastic by other authors.



REFERENCES
1: Panel with resin and recycled plastic developed in CEVE.
2: Panel with wood fibers and polypropylene developed by Wechslera and Hiziroglub
3: Panel with wood particles and polypropylene developed by Wechslera and Hiziroglub
4: Panel wood flour and high density polyethylene developed by Adhikary et al.
5: Panel with bamboo granule and polyvinyl chloride developed by Wang et al.

Table 12
Comparison of prices between the panel with resin and recycled plastic developed in CEVE and other conventional panels made with wood particles.



REFERENCES:
1: Panel with resin and recycled plastic developed in CEVE.
2: Uncoated particle board. Brand name: Faplac.
3: Particle board coated with melamine. Brand name: Masisa.
4: Uncoated MDF board. Brand name: Masisa.
5: MDF board coated with melamine. Brand name: Masisa.
6: Oriented Strand Board. Brand name: Masisa.
7: Phenolic board. Brand name: Troya.

Note 1: The prices are updated to 12 / 12 / 2011.
Note 2: The price of panel 1 has been calculated at CEVE laboratory.
Note 3: The prices of panels from 2 to 7 were provided by the Company Nahuel (Address: Mario Canale 2460, Cordoba, Argentina).

with resin and recycled plastic developed in CEVE" in this publication. The technical properties of these panels are reported.

The tests were in accordance with the following Norms (see Table 1):

IRAM: Argentina Institute of Standardization and Certification.
NBR: Brazilian Technical Standards.
DIN: German Institute for Standardization.
ISO: International organization for Standardization.

Other product of this investigation is a comparison between the panel with resin and recycled plastic developed in CEVE and other conventional panels made with wood particles, available in the construction market. The compared panels were the following:

Panel with resin and recycled plastic developed in CEVE: It is a result of this investigation, formulation number four. It is made from plastic residue, polyester resin, accelerator and catalyst, following the process described in the experimental method. See the technical properties of this panel in Table 1.

Uncoated particle board: It is a conventional panel, available in the market. The wood particles of this board are held together by adhesive urea. It is used in coating for walls, walls and floor areas not exposed to moisture, as well as commercial facilities, props and scenery. In furniture, as an integral part of furniture, and parts for subsequent coating. Brand name: Faplac. See technical information provided by the manufacturer [36].

Particle board coated with melamine: It is a conventional panel, available in the market. It is similar to number 2, but is coated on both sides with decorative films impregnates with melamine resins, which gives a completely closed surface, non-porous, waterproof, tough and wear resistant surface. No further finishing. It can be used in all types of office furniture, living rooms, bedrooms, kitchens and bathrooms, hospitals and commercial facilities. It also offers perfect endings for covering walls, partitions and ceilings. Brand name: Masisa. See technical information provided by the manufacturer [37].

Uncoated MDF board (medium density fiberboard): It is a conventional panel, available in the market. It is a wood fiber board radiata pine connected by urea–formaldehyde adhesives. The wood fibers are obtained by thermo-mechanical process and bonded with adhesive that polymerizes by high pressures and temperatures. Applications: for furniture and moldings. It is easy to paint, which allows excellent finishes, with a significant paint savings and reduced tool wear. It is good for moldings. Brand name: Masisa. See technical information provided by the manufacturer [idem pr.].

MDF board coated with melamine: It is a conventional panel, available in the market. This board is similar to number 3, but it is coated on both sides with decorative films impregnated with melamine resins.

Its surface does not allow the growth of microorganisms, making ideal aseptic environments, resisting heat and aggressive use of fluids for cleaning. No further finishing. Brand name: Masisa. See technical information provided by the manufacturer [idem pr.].

OSB (oriented strand board): It is a conventional panel, available in the market. It is a structural panel with oriented perpendicular strips of wood, in different layers, which increases their mechanical strength and rigidity. These strips are bonded with resins under certain temperature and pressure. Applications: for base roof deck, lateral stiffening diaphragm, flats, scales, T beams, pallets, dividing walls, furniture. Brand name: Masisa. See technical information provided by the manufacturer [idem pr.].

Phenolic board: It is a is a conventional panel, available in the market. It is made from particles of wood bonded with phenolic resins. The pressing temperature is 130 °C. Pressure exceeds

15 kg / cm. This board is resistant to moisture, water, acids, alkalisto dilute and solvents. Applications: general construction, flooring, fencing construction, packaging, partitions, mezzanines, etc. Brand name: Troya. See technical information provided by the manufacturer [38].

Plywood board: It is a conventional panel, available in the market. The construction of this board is based on overlapping plates or sheets of textured wood alternating the direction of the fiber and glued together. This alternative arrangement of the fibers (right angle) is what gives a great dimensional stability, high resistance to warping and no natural direction of rupture. Its main uses are interior woodwork, rear drawers and funds quality furniture, marquetry, models, crafts, framing, packaging, siding and interior decorative wall cabinet. Brand name: Faplac. See technical information provided by the manufacturer [idem [36]].

Other product of this investigation is a comparison between the panel with resin and recycled plastic developed in CEVE and other nonconventional panels made with recycled plastics, developed by other authors. Unlike the panel developed in CEVE, these panels are made applying a hot pressing procedure, without resin.

The compared panels were the following:

Panel with resin and recycled plastic, developed in CEVE by the author of this paper.
Panel with wood fibers and polypropylene, developed by Wechslera and Hiziroglub [14].
Panel with wood particles and polypropylene, developed by Wechslera and Hiziroglub [idem pr.].
Panel with wood flour and high density polyethylene, developed by Adhikary et al. [15].
Panel with bamboo granule and polyvinyl chloride, developed by Wang et al. [13].

See the details of each one with the references.

6. Discussion of results

The following conclusions were reached, comparing the panel with resin and recycled plastic developed in CEVE with other conventional panels:

– *Density*: higher than that of conventional panels (see Table 2).
– *Water absorption:* much lower than that of conventional panels (see Table 3).
– *Thickness swelling by water:* no swelling, unlike conventional panels (see Table 4).
– *Flexural resistance perpendicular to the fibers:* almost equal to that of MDF coated with melamine board (see Table 5).
– *Resistance to traction, perpendicular to the fibers:* lower than that of conventional panels (see Table 6).
– *Resistance to aging:* like conventional panels, the panel with resin and recycled plastics developed in CEVE is not suitable for outdoor use, but for different reasons. In the case of the panel with resin and recycled plastics developed in CEVE, there is low resistance to ultraviolet rays. In the case of conventional panels, there is little resistance to moisture.
– *Modulus of elasticity parallel to the fiber:* lower than that of conventional panels (see Table 7).

The following conclusions were reached, comparing the panel with resin and recycled plastic developed in CEVE with other nonconventional panels made by other authors:

– *Density*: higher than that of other panels made with recycled plastic, developed by other authors (see Table 8).
– *Water absorption:* much lower than that of other panels made with recycled plastic, developed by other authors (see Table 9).
– *Thickness swelling by water:* no swelling, unlike other panels made with recycled plastic, developed by other authors. (see Table 10).
– *Flexural resistance perpendicular to the fibers:* much lower than that of other panels made with recycled plastic, developed by other authors. (see Table 11).

7. Costs

The industrial scale level study has not yet been performed. At a laboratory level, the results are satisfactory, while the cost of the panel with resin and recycled plastic developed in CEVE is similar to that of a MDF board coated with melamine (see Table 12). The machines used for the production of the panels in this cost study were the described in the point "Experimental Method".

Improvement of the molding and compressing equipment would lower the cost. Annex 1 contains a detailed cost study of the panel manufactured with this technology.

8. Conclusions

In relation to technical objectives: The material tested is suitable for use in panels and wall covering, and slats and boards for furniture, on account of the technical properties studied. Its main feature is that it does not swell under water, unlike conventional panels known in the market made with wood particles. The flexural resistance is similar to that of MDF board coated with melamine. The density is higher than that of conventional panels made with wood particles. The resistance to ultraviolet rays is low, which rules out outdoor use.

In relation to environmental objectives: The components obtained have advantages with regard to other conventional ones, since they reduce plastic waste that causes pollution, instead of using up natural resources.
In relation to economic objectives: According to preliminary studies – at the laboratory level, not yet on an industrial scale – the components developed have a production cost similar to other widely accepted ones in the market, such as the MDF board coated with melamine.

What must be borne in mind is that the potential production of these components and their cost is conditioned absolutely by the possibility of obtaining the main raw material – the plastic waste – which varies greatly. For this research, the material was donated entirely by a local company, which thus avoided paying the municipality for the sanitary landfill.

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Appendix A. Price of the panel with resin and recycled plastic developed in CEVE

Dimensions of the panels: 26.0 cm × 46.0 cm × 1,8 cm
Updating date: December 2011
Calculation for 1000 panels
Factory data
Daily production: 5 m^2. of panels
Hours of work: 8 h per day
Total number of factory workers: 1 skilled workman

Materials	Unit	Calculation	Unit price	Price per item
Cost of materials				
Recycled plastic	kg	1720.00	0.00	0.00
Nautical poliester resin	kg	430.00	10.80	4644.00
Catalyst	cm^3	21.50	28.40	610.60
Accelerator	cm^3	11.00	16.90	185.90
SUBTOTAL A				**5440.50 $**

Factory workers	Unit	Calculation	Unit price	Welfare costs	Unit with welf. cost	Price per item
Cost of labor force						
Skilled workman	h	200.00	5.60	5.06	10.66	2131.25
SUBTOTAL B						**2131.25 $**

TOTAL $A + B$ = 7571.75 $.

Description	$A + B$%	Price per item	Remarks
Other costs			
Depreciation	3	227.15	Includes use of the mill, the mixer, the spray guns, the molds, etc.
General expenses	5	378.59	Includes rent of land, electricity, administrative expenses, etc.
Benefit	12	908.61	Of the business owner.
TOTAL C		**151435 $**	

TOTAL $A + B$ + C = 9086.10 $/1000 PANELS = 9 $/PANEL = 75.63 $/$m^2$ = 18.48 U$A/$m^2$.
Note 1: the labor force work does not include panel unloading at the working site or freight.
Note 2: dollar quotation at the time of this calculation: 1 $ (peso argentino) = 0.24 U$A (USA dollars).

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