PLEA 2020 A CORUÑA

35th PLEA Conference on Passive and Low Energy Architecture

Planning Post Carbon Cities

Editors:
Jorge Rodríguez Álvarez
&
Joana Carla Soares Gonçalves

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Planning Post Carbon Cities

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Manufacture of a Lego® type brick from recycled high density polyethylene

Brick manufactured using a process of mechanical recycling thermopressing and thermoforming of HDPE

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ABSTRACT: *The aim of the research was to manufacture a brick from recycled high-density plastic using processes of mechanical recycling, thermopressing and thermoforming. The final result was the development of an experimental design methodology and the manufacturing of a LEGO®-type brick for use in self-assembly modular wall construction. This research by design of an adaptable architectural brick component, provide a film as semi-finished product with a thermal conductivity of 0.103 W/mK and a mechanical characterization by a compression test in which none of the HDPE-based components shows apparent deformation.*

KEYWORDS: Recycled plastics, Brick, Thermoforming, Design materials, Secondary Raw materials

1.INTRODUCTION

The present article concerns the manufacture of a fillable, stackable, interlocking brick-like architectural element using recycled high-density polyethylene (HDPE) as a secondary raw material. A number of industrial thermoplastic manipulation processes were used, namely mechanical grinding of high-density polyethylene (HDPE) to create flakes, pressing or thermofusion to produce a homogeneous film, and thermoforming to manufacture a three-dimensional shape. The final result was a two-part prototype which can be fitted together with others and filled with material

2.PLASTIC DISPOSAL AND RECYCLING FOR ARCHITECTURE APPLICATION

There are an estimated 8.3 billion tonnes of plastic on the planet, of which 75% is waste [12].

Of the solid waste produced by cities in Chile, 12% are plastics and artificial polymers [10], materials which are highly recyclable and thus have considerable potential for use as a secondary raw material [9]. In 2013, the most common plastic raw materials present in the Chilean market were HDPE (25%), LDPE (21%), PP (13%), PVC (12%), and PET (10%) [2]. Various legislation concerning the issue is currently in place, including Law 21,100, which prohibits the use of plastic bags in the commercial sector [3], and the Extended Producer Responsibility Act (Law 20,920), which assigns responsibility for waste disposal to both the user and the manufacturer. However, Chile's regulations have tended to focus on banning plastic waste rather than repurposing it. One discipline that offers significant potential for reuse of plastic waste is Architecture, as the field's design perspective is open to new sustainable construction materials, components and systems that may obtain certain benefit from the characteristics of thermoplastic materials.

3.RECYCLING AND REPURPOSING OF HDPE THERMAL AND MECHANICAL TESTING

Thanks to the versatility of their molecular structure, plastics offer a number of advantages over other architectural materials. By means of a special moulding process, polyethylene may acquire a partially reticulated structure with a special set of properties, of which heat resistance is of particular note [11]. In the context of plastic recycling, the present research proposes a process of "primary stage mechanical recycling" for the creation from a secondary raw material of a new product that offers the same properties as the original [1]. The procedure involved the grinding of HDPE into flakes [9] which were then converted into a homogeneous film or semi-finished product by means of a process of pressing and thermofusion. Finally, two tests were conducted to examine the thermal capacity of the material and to understand the mechanical behaviour of the final product, thus providing a quantitative evaluation of the progress of the prototype.

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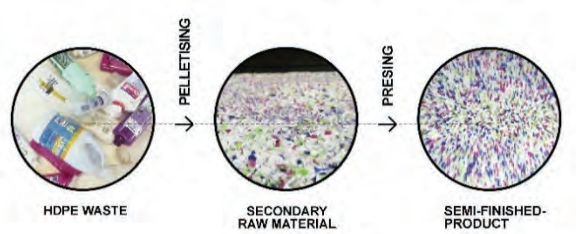

Figure 1: Semi-finished product manufacturing process.

3.1 Mechanical recycling

This procedure is used for the treatment of secondary raw materials such as plastic waste and, unlike other recycling processes, does not cause significant changes to the chemical structure of the material [9].

In the present study, the mechanical recycling process involved the following sequence of operations [9]:

Process: collection → identification → sorting → grinding → washing → drying → separating → agglomerating → pelletising

3.2 Thermopressing

This industrial process was used in the present study to manufacture a series of films according to different weight, heat, pressure and time configurations. A press was used to heat and compress the thermoplastic to form a film.

Figure 2: Three Semi-finished product or films.

The result was a series of semi-finished film products measuring 300 mm x 300 mm x 3 mm, each with a different pattern according to the type of plastic waste used.

In order to identify the recycled material with the most suitable characteristics, three types of plastic were used for the creation of the films: high-density polyethylene (HDPE); high-density polyethylene, 75% of which has been recycled previously; and low-density polyethylene (LDPE).

Table 1: Thermopressed film samples with different Weight (W), Time (T_i) and Temperature (T_e) configurations.

Sample	W (grams)	T_e (P)	T_i (sec)
HDPE	252.8	180	480
HDPE 75% recycled	276.8	180	480
LDPE	181.4	130	600

3.3 Thermoforming process

A mould is created from wood or plaster and is then used to shape the recycled plastic film.

The film is heated for a certain length of time by means of radiant heating elements, causing it to soften and settle over the mould. A vacuum is then created which forms the film closely around the shape of the mould. The film is then allowed to cool and harden [8].

Figure 3: A Film being thermoformed

Films measuring 488 mm x 283 mm x 3 mm were manufactured and the procedure consumed 1,840 watts per second over a period of 120 seconds, meaning a total of 220,800 joules per film.

3.4 Testing

Two tests were conducted to quantitatively assess the materials created. First, the "Determination of Steady-State Thermal Resistance" test (ASTM C518) was applied to films measuring 300 mm x 300 mm x 3 mm in order to establish their thermal transmission properties. Once the thermoforming process was complete, an experimental compression test was conducted in order to establish mechanical resistance data for the brick.

4.DESIGN AND MANUFACTURE OF THE BRICK

Creation of the brick involved a methodology designed to assess the characteristics of the secondary raw material. The approach brought together concepts of industrial design and experimental exploration of the component using thermal and mechanical tests. The design of the "form" of the architectural component is in accordance with the notion of technological determinism, which states that the formal characteristics of a product will be directly determined by the nature of the materials and the

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manufacturing process [7]. As such, the brick is designed through iterative prototype analysis based on the LEGO® concept of stackable, interlocking pieces and in accordance with masonry construction systems and the experimental study of thermoforming.

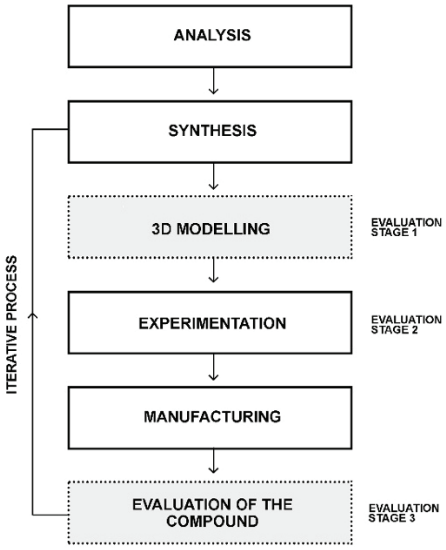

Figure 4: Methodological procedure

4.1 Analysis

A state-of-the-art conceptual analytical framework was applied to the various products available on the market and in order to determine the design possibilities according to the machines that would be used to manufacture the product. The thermopressing and thermoforming processes imply a number of considerations in terms of prototype design.

4.2 Synthesis

The information collected in the previous step was tabulated in order to establish the optimal dimensions, materials and shapes for manufacturing.

4.3 Design and 3D modelling

The prototype design was based on the dimensions of traditional clay bricks and the plastic assembly techniques seen in LEGO® pieces. Another key aspect of the prototype was the assembly of two separate parts to form the brick, thus allowing for material to be inserted into the void between the two.

Finally, a three-dimensional prototype was modelled using 3D design software.

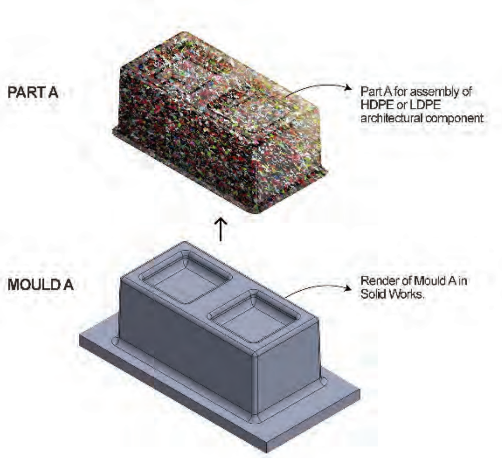

Figure 5: 3D modelling; mould A and part A

4.4 Experimentation

The HDPE and LDPE films were subjected to the Determination of Steady-State Thermal Resistance test according to standard ASTM C518. The test involves placing the film (B) between two parallel polystyrene plates (A and C), as shown in Fig. 6.

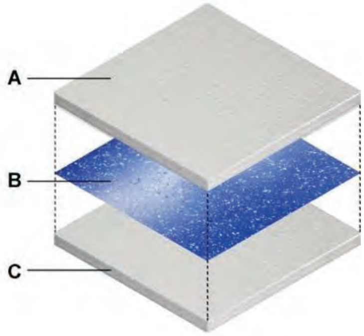

Figure 6: Configuration of plates and film according to standar ASTM C518

The following equation, based on Fourier's Law, was used to establish the value of B.

$$K_m = L_2 \ / \ (R_t - 2R_{poli}) \qquad (1)$$

K_m = thermal conductivity of manufactured HDPE film
L_2 = Thickness of the film
R_t = Total thermal resistance
R_{poli} = Polystyrene resistance

Table 2: Table of values for the Determination of Steady State Thermal Resistance test; where K_T = total thermal conductivity, K_m = thermal conductivity of the film, and R_T = total thermal resistance.

Sample	K_T (%)	K_m(w/mk)	R_T(%)
HDPE	36.78	0.103	1.09
75% recycled HDPE	35.62	0.135	1.08
LDPE	36.82	0.104	1.09

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4.5 Manufacturing

The first 1:1 scale prototype was formed using two machined MDF moulds (moulds A and B) and the films produced earlier.

Figure 7: Machined MDF moulds A and B

The final result was a brick constructed from the two thermoformed parts.

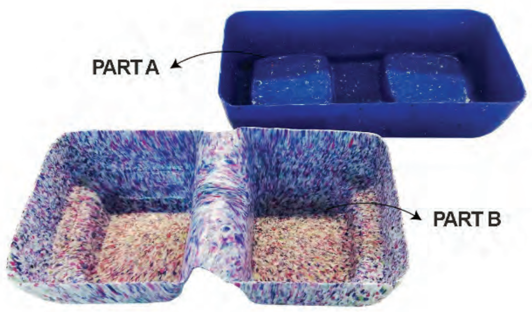

Figure 8: Parts A and B

4.6 Evaluation of the compound

The assessment of the component focuses on the thermal and mechanical characterization.

The component was made up by the assembly of two pieces (A and B), which allowed to trap a layer of air as insulation. The result of the U-Values and thermal conductivity of the brick was compared with two similar masonry solutions presented on a study of new constructive technology with recycled plastic [13] showed on table 3. The U-Values were calculated according to the equation 2 of Chilean norm NCh853 [14].

$$U = \frac{1}{Rsi+Ri+Rg+Re+Rse} \quad (2)$$

U = Thermal transmittance
Rsi = Thermal resistance interior building
Ri = Thermal resistance interior layer
Rg = Thermal resistance air chamber
Re = Thermal resistance exterior layer
Rse = Thermal resistance exterior building

Table 3: Thermal transmittance comparison of plastic component manufactured and other construction systems based on plastic

Constructive Solution	U (W/(m².k))
HDPE component	2.21
75% recycled HDPE component	2.36
LDPE component	2.21
PET brick masonry*	1.25
Brick masonry with plastic papers*	1.51

*Data calculated from the research New constructive technology with recycled plastic [13].

An exploratory compression test was conducted using a maximum load of 200 kg to obtain an initial measurement of the mechanical resistance of the component. A second compression test was then conducted on the assembled brick.

Table 4: Compression test results; where A_b = gross contact area, R_C = compression strength, and D = deformation of the part

Sample	A_b (cm)	R_C(Kg/cm²)	D
HDPE (Part A)	30 X 15	0.4	No
HDPE (Part B)	28 x 13	0.5	No
HDPE 75% Recycled (Part A)	30 x 15	0.4	No
HDPE 75% Recycled (Part B)	28 x 13	0.5	No
LDPE (Part A)	30 x 15	0.4	Yes
LDPE (Part B)	28 x 13	0.5	Yes
HDPE (Part A and B)	8 x 8 x 2	1.4	No

Figure 9: Compression testing of Part B (HDPE)

5. Discussion

In order to establish a broader discussion framework, we focused on three issues addressed by the present study: manufacture of a semi-finished product or film, thermoforming process involving moulds and the thermal evaluation of the brick.

5.1 Manufacture of semi finished product or film

The manufacture of films by thermofusion involved an iterative series of experimental tests in which the parameters of temperature and weight were modified to produce a final semi-finished product. The process enabled us to check for a number of issues, including the presence of bubbles, fissures and orifices resulting from insufficient material or non-homogeneous plates.

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5.2 Thermoforming with moulds

The use of cheap and workable materials such as MDF allows for multiple iterations or adjustments to the mould design in order to achieve a final prototype. The present work involved a total of five iterations to achieve a final size and assembly of parts A and B.

5.3 Thermal evaluation of the brick

The results show worse thermal transmittance value for the brick presented in comparison to similar masonry recycled solutions. However the possibility to adapt and improve the thermal behaviour by incorporating insulation inside the brick chamber, according different climatic zone requirement, allow to provide a flexible and efficient solution for masonry made from recycled plastic.

6. CONCLUSION

The results of the present study provide the basis for a new methodological approach to the repurposing of high-density polyethylene.

Films were manufactured from mechanically recycled high- and low-density polyethylene, and the two materials presented similar thermal conductivity coefficients: 0.103 W/mK and 0.104 W/mK for the HDPE and LDPE films, respectively. These figures are comparable to the thermal conductivity of wood.

In relation to the thermal evaluation of the brick, values for thermal transmittance (U) of 2.21 and 2.36 W/m2k were obtained depending on the material used.

During compression testing, LDPE prototype parts A and B showed deformation under a load of 200 kg, thus enabling us to identify HDPE as the more suitable material for manufacture of the finished product.

Thermoforming using moulds made from materials such as MDF helps to minimise the costs involved in the exploration and design of components made from recycled plastic.

Assembly of parts A and B results in a single component which can be filled with a variety of materials to achieve different environmental functions, such as heat regulation or acoustic absorption, or to vary the weight of the component.

Figure 10: Part A and B assembled

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