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Analysis of the behavior for polyethylene terephthalate (PET) in compression efforts for use in the masonry

Análisis del comportamiento del tereftalato de polietileno (PET) en esfuerzos de compresión para su uso en la mampostería

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Abstract

This article focuses on analysis and a study on the mechanical behavior of recycled plastic materials to manufacture bricks. The current proposal provides a viable alternative for the manufacture of bricks under its regulations, standards and care for the environment. Standardized tests for the study and analysis of the behavior of polyethylene terephthalate (PET) in compressive stresses also is showing. SolidWorks finite element analysis is used to validate the regulations of the bricks, where the results obtained show the values within the norm. The implementation of models is presented through simulations of the proposed brick based on these materials within the masonry. Finally, a methodology for the treatment of PET and its transformation process for the manufacture of partitions with polyethylene terephthalate is proposed. In addition, a methodology for the treatment of PET and its transformation process for the manufacture of partitions with polyethylene terephthalate is proposed.

Polyethylene terephthalate (PET), Compressive stresses and masonry

Resumen

En este artículo se realiza un estudio y análisis sobre el comportamiento mecánico de los materiales plásticos reciclados para ser considerados como posible materia prima para fabricar ladrillos. La propuesta actual proporciona una alternativa viable para la fabricación de ladrillos bajo sus normatividades, estándares y al cuidado del medio ambiente. También se enumeran las pruebas estandarizadas para el estudio y análisis del comportamiento del tereftalato de polietileno (PET) en esfuerzos de compresión, así como su aplicación por medio del elemento finito con ayuda del software SolidWorks, para validar si los resultados obtenidos de las variables evaluadas muestran el valor mínimo que debe de cumplir la norma. Se presenta la implementación de modelos por medio de simulaciones del ladrillo propuesto en base de dichos materiales dentro de la mampostería. Finalmente, se propone una metodología para el tratamiento del PET y su proceso de transformación para la manufactura de tabiques con tereftalato de polietileno.

Tereftalato de polietileno (PET), Esfuerzos de compresión y mampostería

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Introduction

The issue of pollution by plastics has increased due to the lack of awareness and responsibility towards the environment when they are discarded, which are made of materials that are resistant to degradation, in any geographical space; avoiding the application of reprocessing to give them another favourable use.

Consequently, this waste invades natural landscapes, causing harmful impacts on the living beings that inhabit them, such as the release of substances that nature cannot assimilate. The combustion of this waste generates toxic gases, and thus more pollution [1].

The search for alternatives to contribute to the care of the environment has been an issue highlighted in social and industrial spheres to implement an environmental culture, making solid urban waste, especially plastics, become new sustainable materials that serve as raw materials to manufacture more environmentally friendly products for the field of housing construction due to the high population growth. In view of this, it is evident to promote technology towards the design of solid and infrastructural objects such as building bricks where the main recyclable plastic waste is required as raw material, considering the analysis of their selection by means of the mechanical properties they possess.

Masonry

The term masonry refers to a construction of bricks placed in mortar to be laid in rows or courses, and if these are laid on top of each other they form a brick wall [2].

Within construction, brick is the most commonly used element as it is a masonry of small dimensions to be placed manually to build larger elements such as walls [3].

One of the most important materials for ceramic bricks is clay due to the following characteristics [4]:

- Ease of use in simple and structural constructions.
- Good compressive strength.
- Multiple shapes with different levels of quality.

A. Characteristics of bricks

In the following, the quality requirements for bricks and ceramic blocks to be considered as masonry elements will be mentioned:

Manufacturing	With machine
Subtypes	Solid (compact throughout).
Quality grades	A
Structural requirements	Suitable for load-bearing masonry under advanced stresses.
Functional requirements	Suitable for exterior or interior use in single or double-sided apparent walls.
Minimum simple compressive strength (MPa)	20
Nominal dimensions of ceramic bricks and blocks in cm (length, width and height/profile)	20 X 20 *5
Dimensions of machine-made ceramic bricks and blocks in cm (length, width and height/perpallet)	19 X 19 X 4.5

Table 1 Requirements and characteristics of bricks according to N-CMT-2-01-001/02
Source: [5]

The mechanical properties of 20*20*5 cm clay brick are as follows [6]:

Properties	Clay brick
Dimensions (cm)	20 X 20 X 5
Water absorption (%)	23
Bulk density (kg/m3)	1,330
Modulus of elasticity (MPa)	5,300
Poisson's Coefficient	0.17
Shear modulus of elasticity (MPa)	-
Compressive strength (MPa)	5.3
Tensile strength (MPa)	0.53
Loading force (MPa)	-
Coefficient of thermal expansion (m/m/°C)	0.6×10^{-5}
Coefficient of friction of mortar joints (m/m/°C)	-
Tensile bond strength of mortar joints (MPa)	-
Adhesive shear strength (cohesion) of mortar joints (MPa)	-

Table 2 Mechanical properties of clay brick

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The compression test of the bricks should be in the range of 2000 to 5000 psi (15 to 35 MPa), if it is below this range the brick is of poor quality [7].

B. Environmental impact

Brick production benefits the profitability of the ceramic and construction industry, as well as satisfying the need for housing for the population; to some extent it reflects an environmental problem from the high energy consumption for its production to the emissions of toxic gases from its chimneys, causing an increase in the rate of pollution and detrimental damage to the health of workers. Given this, waste plastics can be proposed as a new solution to brick formation with the following advantages [8]:

- Not requiring the use of large-scale materials or facilities.
- Avoiding the felling of trees for firewood to run the kilns.
- Minimising air pollution.
- Increased production of green housing.

Evolution of polymers in the context of recycling

Classifications of recycled polymers are based on the thermal property that characterises their behaviour and processability; for example, thermoplastics have linear or branched structures where they facilitate conversion into fluids if heated to certain temperatures, representing high malleability into the desired shape upon cooling. Thermoplastics are considered to be the most widely applied and commercially used category of synthetic polymers; among them are: polyethylenes, polypropylenes, polyvinyl chloride, polycarbonates, polyurethanes, among others [9].

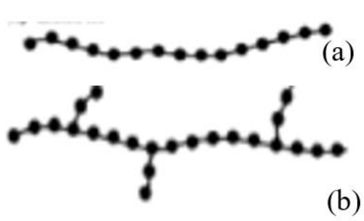

Figure 1 Molecular structure of thermoplastic polymers (a) linear such as acrylics, nylons, polyethylene and polyvinyl chloride (b) branched such as polyethylene
Source: [10]

The first step in recycling plastic waste from the urban environment is the "collection" of plastic waste through the various containers to landfill sites for sorting and cleaning. One of the best ways of collecting and separating plastics in recycling centres is to visualise the numerical code that the product has, as this allows the type of polymer the container is made of to be identified; they are even guided by the colour of the plastic [11]:

1	**PET**	Polyethylene terephthalate: Soft drink bottles and microwaveable ready meals trays.
2	**PHPE**	High density polyethylene: Milk bottles and dishwashing liquid.
3	**PVC**	Polyvinyl chloride: Food trays, plastic film and water bottles.
4	**LDPE**	Low density polyethylene: Plastic bags.
5	**PP**	Polypropylene: margarine containers.
6	**PS**	Polystyrene: Yoghurt containers, food trays, fast food containers, household appliance packaging.
7	**Others**	All other plastics: Melanin, used in household appliances.

Table 3 Code number to identify plastics
Source: [12]

Standardisation of recyclable plastics

In order to determine the minimum requirements for new materials made of polymers, they will have to undergo and comply with several standardised tests, among them the American Society for Testing and Materials (ASTM).

ASTM D695 determines the compressive strength of polymer-based materials. Within this standard, the dimensions 4 x 4 x 8 (cm) will be considered for PET thermoplastic [13].

One of the implementation models for the production of environmentally friendly bricks using recyclable plastics is based on the following flow chart [14]:

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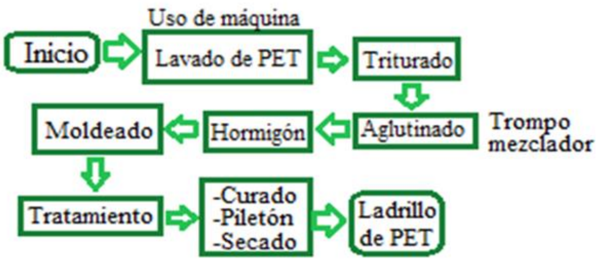

Figure 2 Process flow diagram for the production of environmentally friendly PET bricks

Methodology

The finite element method (FEM) is a numerical method that solves a system of partial derivative equations for the approximate resolution of continuous problems where the boundary equations, initial conditions, are established based on the discretisation of the problem domain in subdomains (elements), these are interconnected by a series of points (nodes). Therefore, it is translated as a system with different degrees of freedom whose behaviour is modelled from a system of linear equations; among them are:

- Stiffness matrix: it establishes the deformation relationship that defines the behaviour of an element subjected to a stress analysis. Its development is considered in terms of energy by the function:

$$U_e = \frac{1}{2}\int \sigma^T \epsilon A dx \qquad (1)$$

- Stresses and deformation: When a body is deformed, the action of external force causing deformation at each point of the body generates a displacement; if this body is three-dimensional it is governed by the expression:

$$s = ui + vj + wk \qquad (2)$$

Where u, v, w; are displacements in the x, y, z directions.

The type of AutoFEM module to be used will be static analysis to perform stress state modelling for mechanical structures and strength testing [15].

Results

For the validation of the proposed process for the production of PET bricks, two simulations using SolidWorks finite element will be carried out for the following two cases:

1. Clay brick.

2. PET brick.

In both cases, their behaviour in compression will be analysed under the following considerations:

1. The standardised dimensions of PET and its mechanical properties are standardised from the SolidWorks database.

2. For the clay brick, the data in Table 2 will be used to determine the load forces (minimum and maximum) in relation to the area of the clay brick; these forces will be used for the PET brick according to its standardised dimensions by:

$$\sigma = \frac{F}{A} \text{ en } \left[\frac{N}{mm^2}\right] \qquad (3)$$

Minimum Compression Limit (MPa)	15
Maximum Compressive Limit (MPa)	35
Nominal dimensions of the clay brick in mm (length, width and height or camber)	200x200x50
Area (mm^2)	40000
Minimum compressive strength (N)	6E+05
Maximum compressive strength (N)	1.40E+06

Table 4 Parameters of the clay brick to be used
Source: [16]

Figures 3 and 4 show the successive form tension behaviour of the clay brick and the PET brick.

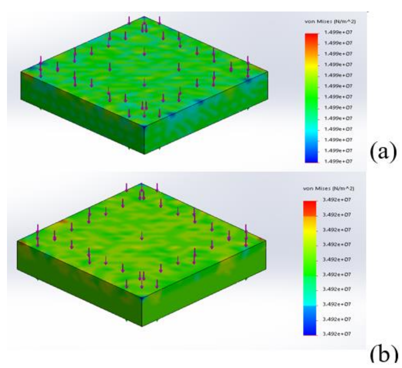

Figure 3 Tensile stress (Pa) (a) minimum (b) maximum for the clay brick
Source: Own elaboration

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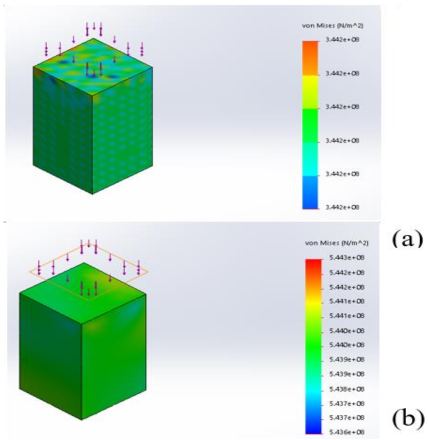


Figure 4 Tensile stress (Pa) (a) minimum (b) maximum for the PET brick
Source: Own elaboration

Figures 5 and 6 show successively the minimum and maximum displacement behaviour of the clay brick and the PET brick.

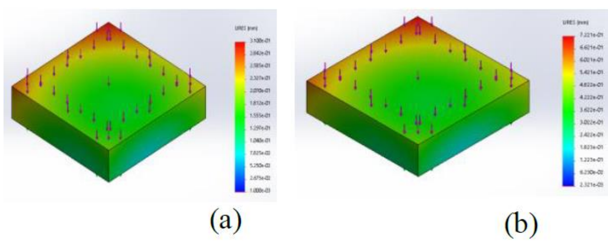


Figure 5 Displacement (mm) (a) minimum (b) maximum for the clay brick
Source: Own elaboration

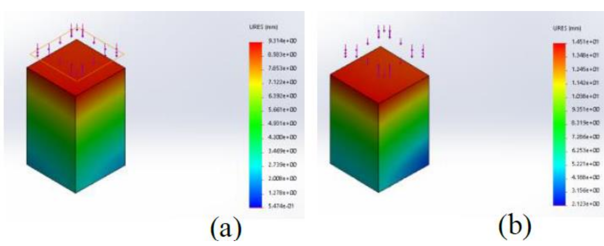


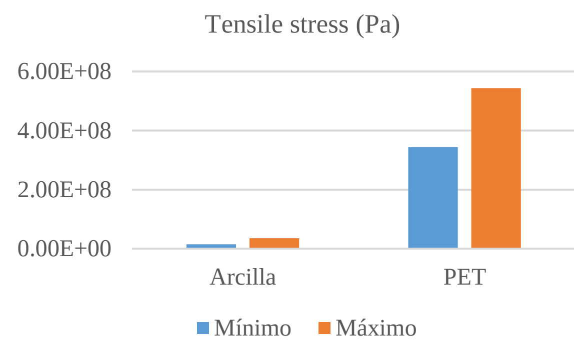
Figure 6 Displacement (mm) (a) minimum (b) maximum for the PET brick
Source: Own elaboration

Based on the results obtained for the tensile stress, it is shown that under a minimum compressive strength of 6E+05 N, the clay brick has a lower value than the PET brick (1.499e+07<3.442e+08Pa).

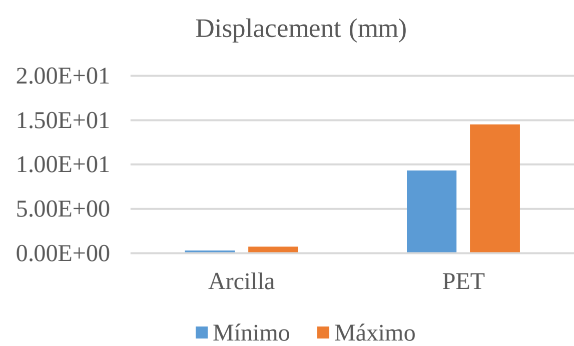
In the case of a maximum compressive strength of 1.40E+06 N, the clay brick has a lower value than the PET brick (3.492e+07<5.443e+08 Pa).

Within the displacement analysis, the same compressive strength limits of 6E+05N and 1.40E+06 N were used, of which reflected that the minimum displacement of clay is less than that of PET (3.100e-01<9.314e+00 mm) while the maximum displacement of clay will be less than that of PET (7.221e-01<1.451e+01 mm).

Graphics 1 and 2 reflect the results obtained from the finite element method in figures 3, 4, 5 and 6.



Graphic 1 Tensile stress difference (Pa) between the clay brick and the PET brick
Source: Own elaboration



Graphic 2 Difference in displacement (Pa) between the clay brick and the PET brick
Source: Own elaboration

Conclusions

Within the mechanical analysis, the PET brick has better mechanical behaviour in compression than a clay brick, even though its dimensions are smaller than those of conventional bricks, making this material a possible input for the manufacture of bricks, and thus build quality internal dividing walls, as long as a good process of transformation of PET bricks is carried out and these are approved by the standardised tests.

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To have a better validation of the mechanical behaviour for future works, flexural and water absorption tests can be used.

Given that PET is one of the most widely used waste plastics because it is recyclable, it is determined that this possible application can favour the care of the environment.

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