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Ferrous and Polyethylene Terephthalate Waste in the Production of Ecological Bricks: Characterization

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The final disposal of solid waste in Latin America is an invariable problem, which, coupled with the deficit of disposal infrastructure or eco-efficient transport systems, makes it difficult to comply with nationally determined contributions (SINIA, 2017, p8), given this problem, solid waste they must be converted into useful materials, or incorporated into energy recovery processes, a current trend is to find new uses for plastics in the construction industry, to incorporate recycled elements in the construction of homes, construction of walls, covering slabs, tracks, recreation areas, etc. The objective of the research was to use waste polyethylene terephthalate (PET) and ferrous metal shavings for the production of ecological bricks. In the experimental test, five different prototypes of bricks were made with different doses of PET and ferrous metal shavings to later determine the characteristics of these bricks by comparing them with the Peruvian Technical Standards NTP 399.604 and NTP 399.613, related to the resistance to compression, the warp and sizing; Bricks with a maximum load between 60,278 and 34,221 kg, compressive strength between 194 and 110.5 kg/cm ^{2} and warpage between 2 and 3 mm were obtained. According to the results, it was determined that the first brick prototype classifies as type V, the second, third, and fourth bricks classify as type III, the fifth classifies as type IV, with the fifth and first bricks being the best quality, classifying as a suitable brick to be used as a load-bearing brick in housing coverings and complies with the stipulations of the E.070 Masonry Technical Standard. Therefore, mass production of this type of brick taking advantage of plastic and metal waste constitutes an environmentally sustainable alternative in the management of plastic waste.

1. Introduction

It has been established that one million plastic bottles per minute are sold in the world, this level of generation coupled with the difficult degradation of plastics generates an impact of global considerations, on the other hand, 42% of plastics are considered a single use (food and beverage packaging, cutlery, bags, etc.) increasing the volume of discharges on the planet (National Geographic, 2023). During the pandemic, plastic pollution has become more noticeable, evidencing the impacts on the soil, water, and air through macro, micro, and nano plastics (Tan et al., 2022). Polyethylene terephthalate (PET) is an everyday element of global consumption, which has been found in landfills, oceans, deserts, the Arctic, and even in the highest peaks in the world, so its recycling and reuse is a factor key to solving this problem (Claudinho and Ariza, 2017). Taking into consideration the circular economy approach, sustainable construction is a milestone incorporated within sustainable societies, which is aligned with the objectives of sustainable development, health and well-being, industry, innovation and infrastructure, sustainable cities and communities, climate action, Submarine visa and life of terrestrial ecosystems evidence the advantage of replacement impact of materials (Sauerwein et al., 2019).
Between the years 1950 and 2015, the total amount of polyethylene terephthalate (PET) produced was around 8.3 billion metric tons, and only five hundred million metric tons were reprocessed (Geyer, Jambeck and Ley, 2017). that its abundance on the planet cries out to start replacing this material (PET) as a substitute for sand and other fines, it is also an economic advantage since conventional construction materials are more expensive than plastic waste material, demonstrating that is profitability (Ismail and AL- Hashmi, 2008). Recycled plastics of low-density polyethylene (PEBD), polyethylene terephthalate (PET) such as soft drink containers and other

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plastics (residues of printed films from candy wrappers), were conveniently ground and used as a replacement for aggregates to be mixed with cement. in the manufacture of bricks and cement plates in affordable or traditionally built homes. (Gaggino and Arguello, 2010). Other types of presentation of these polymeric residues can also be used, such as those found in tires, as indicated by Metzker et al. (2022) who using tires mixed with polyethylene terephthalate (PET) obtained bricks with improvements in compressive strength and durability, as well as low thermal conductivity, meeting the standards of the market. In this interest considering the advantage of waste use within the concept of circular economy. The manufacture of bricks has also been tested using steel mill sludge, arsenic-iron sludge and Pb/Zn foundry slag, partially replacing clay as raw material, with good characterization results, including resistance to compression (Kulkarni et al., 2019). Another waste used for the manufacture of bricks has been glass waste mixed with PET, where the change in the microstructure of the brick from porous to smooth was obtained; In addition, it allows good efficiency in the immobilization of metals if any (Mao et al., 2018). Along with the use of glass residues, the incorporation of galvanizing process sludge mixed with clay in the production of bricks has also been investigated; This composition gave the characteristic of lower water absorption, greater resistance to compression, and of course, the risk of leaching of heavy metals present in them is reduced (Mao et al., 2019).
In this context, the objective of the investigation was to use Polyethylene Terephthalate (PET) together with ferrous metal residues (shavings), to make handmade bricks that comply with the characteristics of construction regulations. The proposal seeks to reinforce other research with a similar objective in the use of plastic waste for its incorporation into the life cycle within the concept of circular economy and an improvement in the sustainable management of waste.

2. Methodology

The methodology used consisted of three stages described in Figure 1:

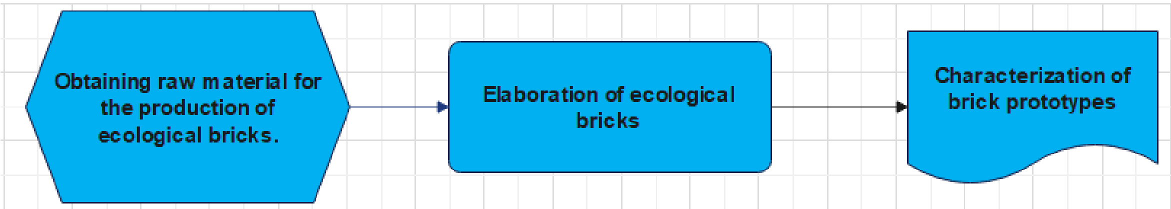

Figure 1: Elaboration stages of ecological brick.

2.1 Obtaining the raw material for making bricks

The PET material was obtained from discarded bottles near the Puente Piedra, Lima district. The ferrous waste (iron shavings) was obtained from the metal lathe workshops located in the district of Carabayllo. PET waste as well as ferrous was physically pre-treated to remove dirt and adhered. See Figure 1. The PET was processed to flakes of approximately 2 cm and similarly, the iron shavings were processed in a metal mill to a size of 0.25 cm.

Figure 2a: PET

Figure 2b: Iron shavings

2.2 Preparation of the bricks

A mahogany wood mold (Swietenia macrophylla) with dimensions of 23 cm long, 13 cm wide, and 9 cm high, according to NTP 331.019 (INDECOPI, 2008).
In the elaboration of the brick prototypes, 5 combinations of different doses of raw materials were formed (See Table 1) to give rise to the bricks coded as L-1, L-2, L-3, L-4, and L- 5 of each prototype. Subsequently, these were melted in an artisan furnace of liquefied petroleum gas (LPG).

Table 1: Composition of the bricks

Brick prototype	Raw material composition			
	Weight (g)		Percentage (%)	
	PET	Ferrous metal shavings	PET	Ferrous metal shavings
L-1	3000	500	85.7	14.3
L-2	3250	220	93.7	6.3
L-3	2350	340	87.4	12.6
L-4	3500	300	92.1	7.9
L-5	3600	300	92.3	7.7

After the bricks were cast, the mold was removed, and they were subsequently dried in the environment for 3 hours, finally remaining as shown in Figure 3.

Figure 3: Prototypes of bricks

2.3 Characterization of brick prototypes

The brick prototypes were characterized around their sizing following the test method of the reference standard of NTP 399.604, 2002 revised in 2015; the maximum load and compressive strength according to the test method of NTP 399.604 (INDECOPI, 2002) using the PROETI uniaxial testing machine; and the warp concavity according to NTP 399.613:2017 (INDECOPI, 2005) and the E.070.2006 standard (MVCS, 2006). These tests were carried out at the Materials Testing Laboratory of the National Engineering University (with ISO 90001 certification).

3. Results

3.1 dimension variation

Considering the standard mold and the dimensional variation of the elaborated brick prototypes (see Table 2), these were compared with the norm and classified by type according to technical norm E.070 Masonry of the Ministry of Housing of Peru (2006), the results They showed that the elaborated bricks were classified in type IV and V.

Table 2: Dimensional variation of the bricks

Brick prototype	Length (mm)	Width (mm)	height (mm)	Class (E 070)
L-1	23.9	13.0	8.7	V
L-2	24.0	12.9	8.6	V
L-3	23.9	13.0	6.7	IV.
L-4	24.0	13.1	7.7	IV.
L-5	24.1	13.1	7.9	IV.
Average	23.9	13.0	8.7	IV.

3.2 compressive strength

The compressive strength test of the brick prototypes presented in Table 3 shows that the maximum load and best performing compressive strength was coded as L-1, with 194 kg/cm^2, with a composition of 3,000 g of PET and 500 g of iron filings; This result may be due to its apparent specific mass and the composition of the matter (Mymrin et al., 2021), as well as the behavior of PET, when the amount of this residue increases, this supports the resistance but in % of low composition (Gareca et al., 2020). On the contrary, the brick with the greatest amount of iron shavings (L-2) presented a lower maximum load and lower resistance to compression, so it is established that the presence of iron residues decreases the maximum load and resistance to compression., consequently, it is of lower quality (Gamboa, 2017), similarly, Metzker et al. (2022) found that the use of PET (at 1.5%) improves resistance to comprehension in the elaboration of bricks. On the other hand, García (2008) made concrete mixtures by adding 12% and 14% steel chips to replace the fine aggregate, their results were homogeneous in the compression resistance measurement process since they did not present porosity and showed malleability at the time of casting, the best results obtained were those with the lowest percentage of chips added concerning the fine aggregate. Similarly, Akinyele et al. (2020) mixed PET with laterite (clay with the presence of iron and magnesium) and concluded that less than 5% PET can be used in bricks fired under controlled conditions with compressive strength results below 52.51 kg/cm^2. On the other hand, Del Rey Castillo et al., (2020) studied the inclusion of an artificial aggregate made from plastic waste to develop lightweight concrete with relatively good compressive strength results of 203.4 kg/cm^2 (20 MPa), a slightly higher result than the ecological brick. The compression was calculated taking into account the maximum load on the gross area of each prototype.

Table 3: Maximum load and compressive strength

Brick prototype	Gross area (cm^2)	Maximum load (kg)	Compressive strength (kg/cm^2)
L-1	310.7	60,278	194.0
L-2	309.6	34,221	110.5
L-3	310.7	39,608	127.5
L-4	314.4	38,057	121.0
L-5	315.7	52,514	166.3

3.3 Determination of the Warpage of the prototypes

Warpage is the degree of concavity or convexity of a masonry unit that masonry units may have, the level of warpage causes construction problems, compromising flexural and compression resistance (Parro, 2015). The whitewash test of the brick prototypes made with PET and iron shavings (waste) and by the NTP for the case of handmade bricks, yielded the values presented in Table 4 as results; Therefore, the values found in the range of 2 and 3 mm classify bricks of type V and IV respectively. It is indicated that bricks with a maximum warpage of 3 mm are accepted and to be used in masonry construction the joints to be used will be 1 to 1.5 cm.

Table 4: Warpage of bricks

Brick prototype	Warp Concavity (mm)	Class (E.070)
L-1	3	IV
L-2	3	IV
L-3	3	IV
L-4	2	V
L-5	3	IV

The PET waste and iron waste bricks did meet the main characteristics that classify them as construction units of type V and IV for construction activities in masonry, in the construction of homes as indicated by Wahane et al., 2022), according to It can be seen in Fig. 4, where the L-1 prototype exceeds, the level established for the V-type brick.

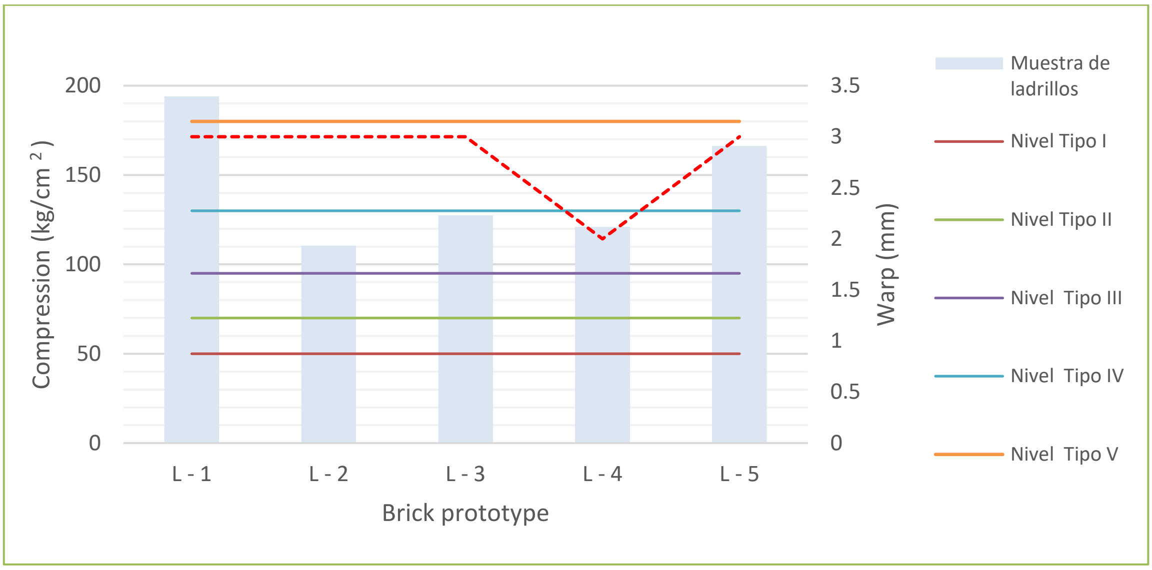

Figure 3: Comparison of the compressive strength of the brick prototypes

4. Conclusion

Having carried out sizing, warping, compressive strength and maximum load tests, it can be stated that using Terephthalate polyethylene and ferrous metal shavings it is possible to produce ecological bricks. Terephthalate residues and iron residues (shavings) as raw material, these components gave it good load and resistance to compression, fulfilling the conditions to be used as masonry units such as is established by national technical standards. Likewise, it is an alternative for the use of waste of this type to improve the reduction of plastics within sustainable environmental management and the framework of the circular economy.

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