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Envases de bebidas Tetra Pak® como refuerzo en concreto polimérico

Waste Tetra Pak® beverage containers as reinforcement in polymer concrete

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Waste Tetra Pak® beverage containers as reinforcement in polymer concrete

Resumen

Los envases Tetra Pak® son ampliamente utilizados a nivel mundial gracias a su efectividad para la conservación de alimentos, lamentablemente solo una pequeña cantidad de estos se recicla, convirtiéndolo en un material altamente contaminante. El objetivo de este trabajo es utilizar el material Tetra Pak® post-uso como refuerzo en concreto polimérico elaborado con 20% resina poliéster y 80% mármol. Se utilizaron tres tamaños de partículas de Tetra Pak®, pequeño (1x0.5 mm), mediano (3x3 mm) y grande (5x5 mm), que sustituyeron al 1% de la concentración de mármol. Dichos concretos se evaluaron en pruebas mecánicas de compresión y flexión. Los resultados muestran mejoras en el módulo de elasticidad, en la resistencia y deformación a la flexión, 39%, 5% y 5%, respectivamente. Este trabajo muestra una alternativa novedosa y exitosa de reutilización de los envases de Tetra Pak® con el fin de reducir su impacto ambiental.

Palabras clave: tratamiento de desechos, tecnología de materiales, material compuesto.

Abstract

Due to their effectiveness in food preservation, Tetra Pak®is widely used around the world. Unfortunately, only a small part of these is recycled, making it a highly polluting material. The objective of this work lies on using waste Tetra Pak® beverage containers as reinforcement in polymeric concrete manufactured with 20% polyester resin and 80% marble. Three sizes of Tetra Pak® particles were used, small (1x0.5 mm); medium (3x3 mm) and large (5x5 mm), which replaced 1% of marble´s concentration. Concretes were evaluated in both compression and flexural tests. Results show improvements in the elastic modulus, in the flexural resistance and in the strain at yield point, 39%, 5% and 5%, respectively. This work shows a novel and successful alternative for reusing Tetra Pak® packages aiming to reduce its environmental impact.

Keywords: waste treatment, materials engineering, composite materials.

Introduction

Current situation

Food packaging has become crucial for humanity, to be capable of sustainably meeting their nutritional needs. Better and avant-garde alternatives for food preservation are demanded due to the continuous growth of the global population, the severe effects of climate change and the enormous migration, over the world, caused by armed conflicts. The reason for using a packaging method it is because it protects food from any physical, chemical, and biological contamination when is on storage or on its journey to its final destiny (Ncube et al., 2021) (Alias et al., 2022) (Yan et al., 2022). In Mexico, there are many different materials intended to assist with this purpose; table 1 provides some examples of such materials commonly used.

Table 1.
Materials used for food packaging in the local market.

Material	Product
Tetra Pak®	Liquids and vegetables containers
Low density polyethylene, LDPE	General wrapping
High density polyethylene, HDPE	Trays for microwave
Polyethylene terephthalate, PET	General bottles
Polylactic acid, PLA and expanded polystyrene, EPS	Disposable containers
Cardboard	General boxes
Aluminium	Soda and beer cans
Steel	Fish and vegetables cans

Note. Authors´ own elaboration.

Having said that, not all these materials are eco-friendly, and even worse, the use of many of them generates extreme pollution on earth and sea because they have no second use (Alabi et al., 2019) (Chen et al., 2021) (Ponnusamy & Mani, 2022).

Keeping in mind the negative environmental of these packaging materials, this work focuses on the case of Tetra Pak® with the objective of finding a new and novel alternative of use to help reduce its carbon-footprint in Mexico using it as reinforcement in a polymer concrete made with polyester resin and marble.

State of art

Recycling rates for the materials listed in table 1 shows a rate of 90% for aluminium and steel, while it is 60% for cardboard, PET and LDPE; however, it is only 40% for Tetra Pak®, HDPE, PLA and EPS (Salazar-Jurado et al., 2021) (Dölle & Kavin-Chinnathambi-Jeeva, 2022). This low recycling rate causes environmental pollution, as non-recycled packaging materials are just wasted and deposited in landfills. In Mexico, since 2019, 46,000 million Tetra Pak® containers have been recycled per year, surprisingly; it only represents 30% of its consumption. New alternatives are being studied in an attempt to help people to reduce Tetra Pak®´s carbon footprint. A case in point is the circular economy model in building materials (Haigh, 2023) (Papamichael et al., 2023).

Tetra Pak® packaging containers and their composition

Tetra Pak® was created in 1940 by Swedish engineer Ruben Rausing as a material designed and intended to solve food dosing and storage problems (Robertson, 2021). It is composed of 75% cellulose, 20% low density polyethylene (LDPE) and 5% aluminum. On its composition, it has six layers (Figure 1), each with its own function (Buonocore & De Luca, P., 2022), namely:

1st layer: Polyethylene (PE) – Ensures complete food protection.

2nd layer: Polyethylene – Prevents food from coming into contact with aluminum.

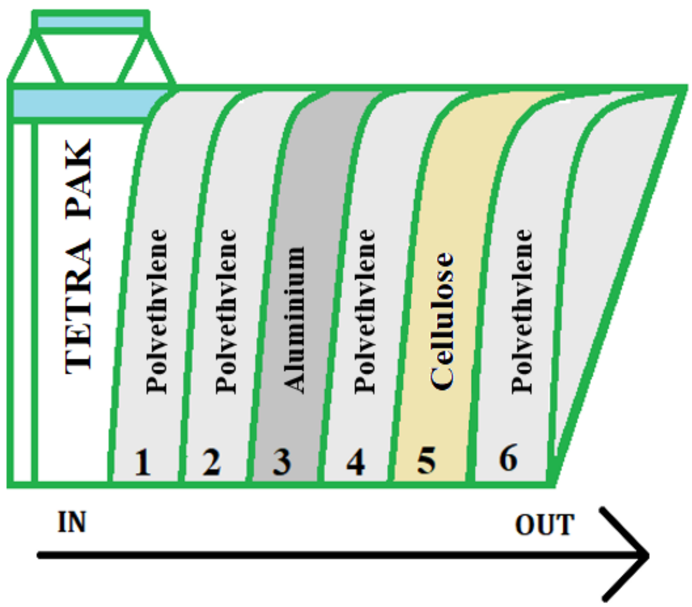
3rd layer: Aluminum (A) – Prevents the entry of oxygen, light, and loss of aroma.

4th layer: Polyethylene – Provides adhesion by fixing the cellulose and aluminium layers.

5th layer: Cellulose (C) – Provides strength and stability.

6th layer: Polyethylene – Protects the package from external humidity.

Figure 1.
Composition of Tetra Pak® containers.



Note. Authors´own elaboration from Dölle& Kavin-Chinnathambi-Jeeva (2022).

In the aseptic packaging market, Tetra Pak®, was worth $15 billion in 2020, with an expected annual growth of 9.8% from 2021 to 2028. Therefore, this material will become the preferred material for transporting preserving liquids and solid foods, compared to the materials shown in table 1. (Dölle, K., & Kavin-Chinnathambi-Jeeva, 2022).

Tetra Pak® recycling

Tetra Pak®´s package recycling aims to separate the three components: carton, polyethylene, and aluminum. Hydro pulping and pyrolysis are the most commonly used processes for recycling, but they are expensive and not cost-effective for small and medium-sized companies (Robertson, 2021).

Hydro pulping process consists of separating the cardboard, polyethylene and aluminum, by means of water flow and mechanical grinding. In this method, the cardboard absorbs water and pulp is formed, which is separated from polyethylene and aluminum (known as polyaluminum) (Posada & Pazmiño, 2016).

Pyrolysis process involves heat and temperature in an anaerobic chamber where cardboard (cellulose) and polyethylene degrade in a temperature range of 368-490°C, while aluminum is melted at 660°C. It is worth mentioning that, when operating in a continuous system, cellulose and polyethylene are commonly used as feed fuels for the operation (Huo, 2021).

Waste Tetra Pak® used in building materials

The scientific community has been working in the field of building/composite materials reusing Tetra Pak® waste and studying its effect on mechanical properties. The goal is to avoid the use or hydropulping nor pyrolysis processes. Thus, several opportunities are being developed to reuse or reincorporate Tetra Pak® waste in composite materials, as mentioned in the following research.

Hamouda et al. (2019) mixed Tetra Pak® packaging particles with 5-20% waste wool yarns using a hot-pressing method. The results show a 9.2% of improvement in modulus of rupture (15.1 ± 1.01 MPa), for the composite with 85% of Tetra Pak®, as well as 18.7% improvement in tensile strength (5.5 ± 0.5 MPa) with 95% of Tetra Pak®, compared to the control specimen, without Tetra Pak®.

Murathan et al. (2007) used waste Tetra Pak® particles of 2x2 mm size. The authors heated to 70°C, and then mixed it with polyvinyl acetate (PVA)-(G) (37-50% by weight), and urea-formaldehyde (U-F) (37-43% by weight). The best composite, satisfactory manufactured, obtained a density of 0.46 g/cm3 and had an improvement in shore hardness of 23% when 43% of Tetra Pak® was added to the material.

In other study, several cellulosic wastes were separately mixed with gypsum. Among them were office paper, magazines, newspapers, cartons, paper cartons and Tetra Pak® cartons. The results showed that the highest compressive resistance of 6.46 N/mm^2 belonged to the composites made with Tetra Pak® particles (size 4x18 mm), and a density of 1.29 g/cm3. This strength was 44% higher than that of the composite with magazine paper, which presented the lowest value (Foti et al., 2019).

Macías-Gallego et al. (2020) used a hot-pressing method to elaborate Tetra Pak® sheets with dimensions of 250x120x7 mm. The results showed that sheets made with 5x5 mm Tetra Pak® particles had the highest tensile strength values (37.4 MPa), which were 55% higher than sheets with 10x15 mm particles and 94% higher than those containing 4.6x11.85 mm particles. In another study, panels containing waste Tetra Pak® were used in three sizes: as packaging; milled to 5x5 mm^2 and cut in 1x25 cm^2. The results showed that panels with 1x25 cm^2 Tetra Pak® particles had the highest tensile strength values, while those with Tetra Pak® packaging had the highest elasticity modulus (41.27 MPa) and flexural strength (18.45 MPa) (Salamanca-Sarmiento & Vaca-Rodríguez, 2017).

Ebadi et al. (2016) manufactured Wood Plastic Composites (WPC) with 10-30% waste Tetra Pak®, 57-60% low density polyethylene (LDPE), 10-40% wood fibers and 3% of MAPE (maleic anhydride grafted polyethylene) as coupling agent. The most relevant performance was obtained for composites with 20% Tetra Pak®, as the tensile strength increased by 26% (22.61 MPa), which was attributed to the aluminum favouring stress transfer between polyethylene and wood fibers

Another type of WPC with dimensions of 4x180x220 mm, were made with recycled polyethylene (rPE) as matrix, and pine wood flour or shredded Tetra Pak® cartons as fillers. Composites with 40% Tetra Pak® particles showed a 43% improvement in flexural strength and 38% improvement in tensile strength, but the flexural and tensile moduli decreased by 17% and 15%, respectively. Thus, shredded Tetra Pak® is a better option than pine wood flour for obtaining higher mechanical properties in WPCs (Bal, 2022).

Koh-Dzul et al. (2023) fabricated sandwich construction panels with: a) an aluminum layer, followed by a Tetra Pak layer, and finally an aluminum layer, b) an aluminum layer, followed by a polyethylene/aluminum (P/A) layer, and finally an aluminum layer. Both types of panels had similar flexural strength values, but the panels with Tetra Pak layer are stiffer, less ductile and with lower thermal conductivity than those with P/A layers.

Objetive

This work focuses on the use of waste Tetra Pak® containers as reinforcement in polymer concrete, managing to reduce its negative environmental impact, and succeeding in incorporating it into a circular economy model for construction materials.

Materials and method

Participants

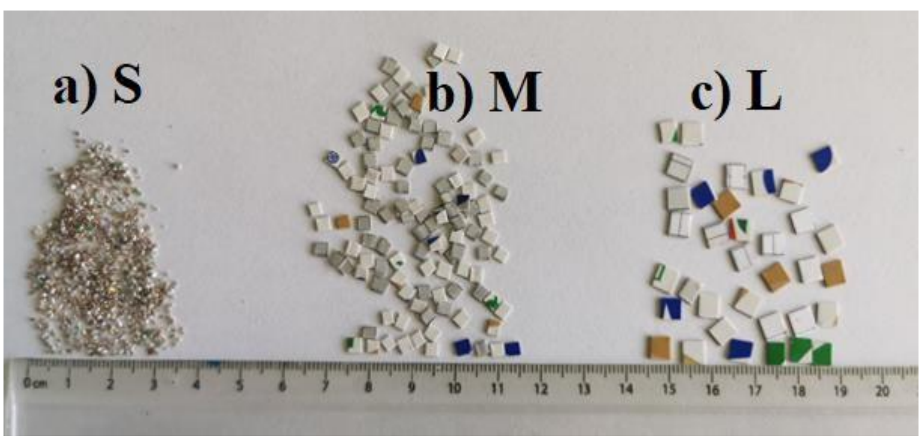
The main raw materials used in this paper were: unsaturated polyester resin, marble, and milk waste Tetra Pak® containers.

Unsaturated terephthalic polyester resin (UPR), was supplied by Reichhold Química de México, marketed under the name Polylite® 32335-10. For the polymerization of UPR, methyl ethyl ketone peroxide (MEKP) was used, which was added in a proportion of 2g/100g of resin according to the manufacturer.

Marble was purchased from Prodimar® (Toluca City, Mexico), which had an average diameter of 0.3 mm.

Milk waste Tetra Pak® beverage cartons were washed with abundant water to remove impurities, and then dried for 24 h at room temperature; finally, they were cut into three different sizes (figure 2), using scissors to avoid possible deformations as occurs in a milling machine. The three sizes were: 1x0.5 mm denoted with the "S", corresponding to small size; 3x3 mm denoted with the letter "M", related to the medium size, and 5x5 mm denoted with the letter "L", according to the large size.

Figure 2.
Tetra Pak® particles with a) 1x0.5 mm, b) 3x3 mm, and c) 5x5mm sizes.

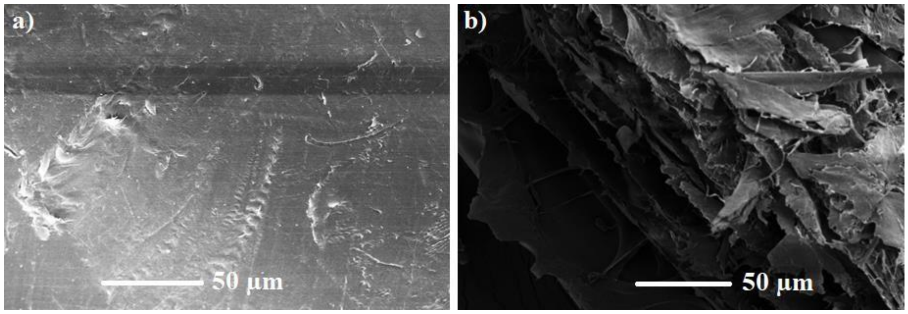


Note. Authors´ own elaboration.

Figure 3 shows SEM (Scanning electron microscope) images of Tetra Pak® particles. According to the six layers of Tetra Pak® packages (PE/PE/A/PE/C/PE). Figure 3a shows the aluminun/polyethylene surface, while figure 3b shows the morphology of the layers.

Figure 3.

SEM images of Tetra Pak® surfaces: a) aluminium/PE, and b) inner layers.



Note. Authors´own elaboration.

Method

Polymer concrete specimens

Three types of polymer concrete specimens were produced: 1) polymer concrete made with polyester resin and marble particles, which was referred to as "control" concrete; 2) polymer concrete with addition of a Tetra Pak® particle size (S, M or L), and 3) polymer concrete with a combination of different Tetra Pak® particle sizes.

Polymer concrete production

"Control" concrete was produced by mixing 80% wt. marble particles and 20% wt. polyester resin.

Concrete with Tetra Pak® particles contained 1% by weight of them, which replaced marble. The compositions of these 1% Tetra Pak® particles in each concrete specimen are shown in table 2. The number after each particle size (S, M or L) represents the content of the Tetra Pak® particles, e.g., the concrete specimen designed S50/M33/L17 had 0.5% small particles, 0.33% medium particles and 0.17% large particles.

Six specimens of each formulation were produced giving a total of 66 specimens for the whole experimentation. Furthermore, curing of the concrete specimens was carried out at 25.0 ±3.0°C for 24 h.

Figure 4 shows some cured concrete corresponding to the formulations in table 2.

Table 2.

Composition of the 1% Tetra Pak® particles in polymer concretes.

Particles' combination	Tetra Pak® (%)		
	S	M	L
Control	0	0	0
S100	1.0	0	0
M100	0	1.0	0
L100	0	0	1.0
S33/M33/L33	0.33	0.33	0.33
S50/M33/L17	0.50	0.33	0.17
S50/M17/L33	0.50	0.17	0.33
S33/M50/L17	0.33	0.50	0.17
S33/M17/L50	0.33	0.17	0.50
S17/M50/L33	0.17	0.50	0.33
S17/M33/L50	0.17	0.33	0.50

Note. Authors´ own elaboration.

Figure 4.

Polymer concrete specimens.

Note. Authors´ own elaboration.

Experimental tests

Mechanical tests

After the curing process, the concrete specimens were subjected to compression and three-point flexural tests on a Controls TM Universal Testing Machine, with a load cell capacity of 30 tons. The compression test was performed according to ASTM D695 and the flexural test according to ASTM D7264. The test parameters are shown in table 3. The load-displacement curves and the maximum load for flexural collapse were recorded.

Table 3.

Parameters for compression and flexural tests.

Parameter	Compression	Flexural
Strength rate, kgf/s	30	25
Strain velocity, mm/min	0.3	0.3
Upper limit of force, ton	25	25
Upper position limit, mm	4.5	4.5

Note. Authors´ own elaboration.

Results and discussion

Mechanical properties

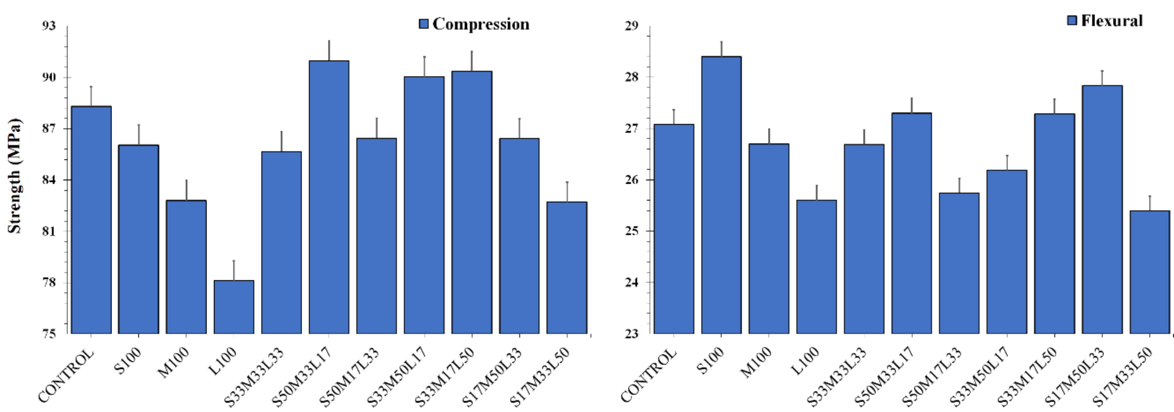
Compressive and flexural strength

Figure 5 shows the compressive and flexural strength results of the concrete specimens. In the case of compression tests, the resistance value of the control concrete is 88.3 MPa. The values for all concretes with individual Tetra Pak® particles are lower than those of the control concrete. Furthermore, the resistance values decrease as the particle size increases. On the contrary, concrete with S50/M33/L17 particle combination had the highest value of 91.0 MPa, which is 3% higher than the control concrete.

Regarding flexural strength, the control concrete had a value of 27.0 MPa, while the concretes with individual Tetra Pak® particles had greater resistance than those of the control concrete, but the values decrease as the size of the particle increases. Concrete with 1.0% small particles had highest value (28.4 MPa), which is 5% higher than the control concrete. In the case of concrete with particles size combinations, the highest value (27.8 MPa), was obtained for the addition of the S17/M50/L33 particles combination. These slight increases are the result of an improvement in stress transfer between the polyester resin and the marble and Tetra Pak® particles.

Figure 5.

Compressive and flexural strength.



Note. authors´ own elaboration.

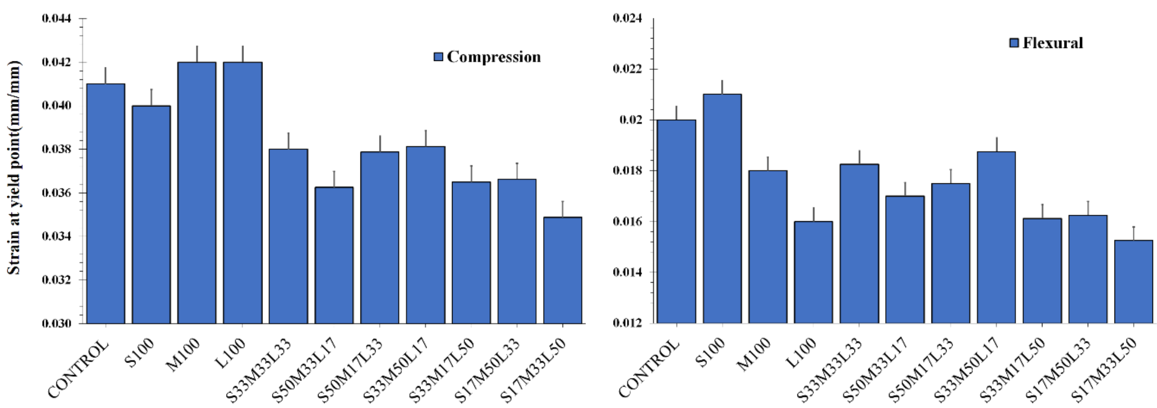
Compressive and flexural strain at yield point

Figure 6 shows the results of compression and flexural deformation at yield point. Regarding compression deformation, the control concrete had a value of 0.041 mm/mm. Concretes with a single Tetra Pak® particle size had similar values to the control concrete. However, concretes with Tetra Pak® particle size combinations were 15% lower than control concrete, with a strain of 0.035 mm/mm. Therefore, the concrete becomes stiffer, as there is more stress transfer between Tetra Pak particles of different sizes and matrix.

For the flexural tests, the control concrete had a deformation of 0.02 mm/mm, while the concretes with small Tetra Pak® (S) particles showed an improvement of 5% with respect to the control concrete. Furthermore, with large particle sizes the deformation values were lower, for example the values obtained for the particle combinations S33/M17/L50 and S17/M33/L50.

Figure 6.

Compressive and flexural strain.



Note. authors´ own elaboration.

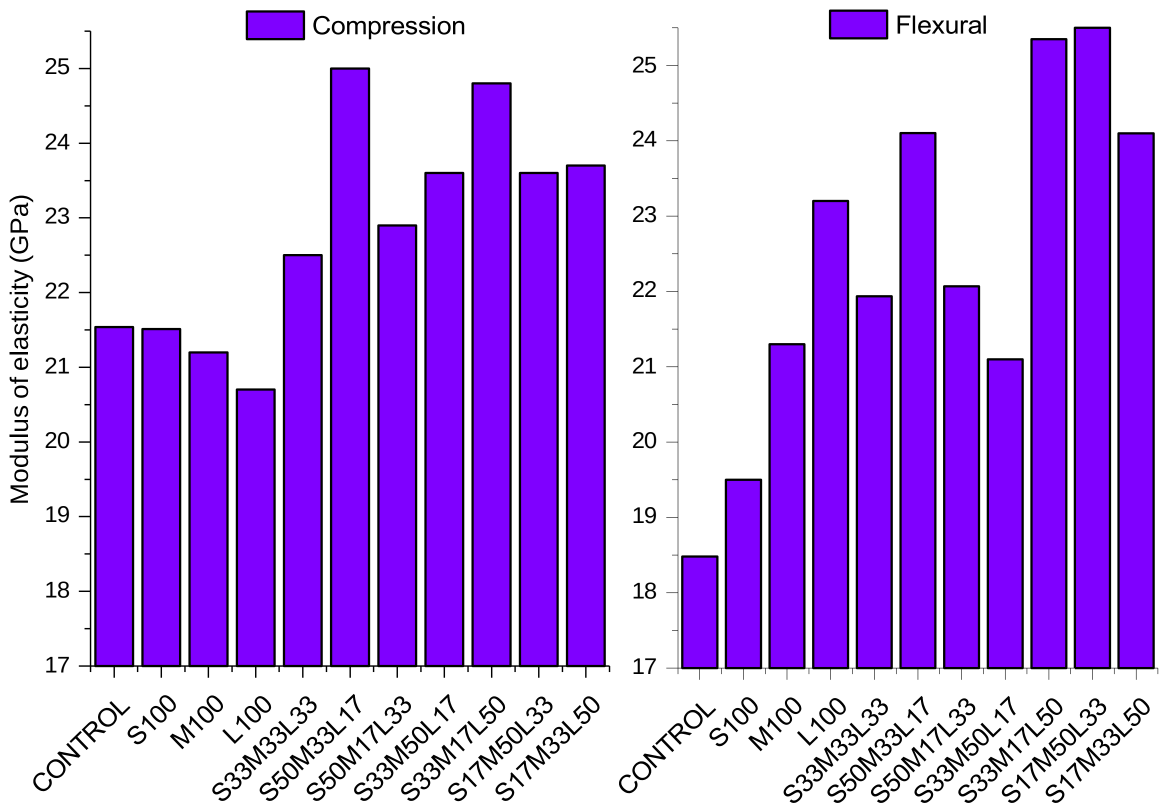
Compressive and flexural modulus of elasticity

The modulus of elasticity in compression for the control concrete was 21.5 GPa (figure 7). For concrete with a single Tetra Pak® particle size, the values decrease as the particle size increases, that is, with large particles (L) the concrete loses rigidity, and more deformation is obtained. However, for concrete with combination of particle sizes, there was an increase of 16% with the combination of S50/M33/L17 particles, which corroborates that the high content of small particles (S) allows for less deformation.

The results for the flexural modulus show a value of 18.5 GPa for the control concrete, while the concrete with large particles had the highest value (23.2 GPa), which means an improvement of 25% with respect to the control concrete. In the case of concrete with a combination of particle size, the highest value (25.7 GPa) was obtained for the combination of S17/M50/L33 particles, which means an improvement of 39%. Then, the high content of medium size particles (M), allows greater rigidity in the concrete.

Figure 7.

Compressive and flexural modulus of elasticity.



Note. Authors´ own elaboration.

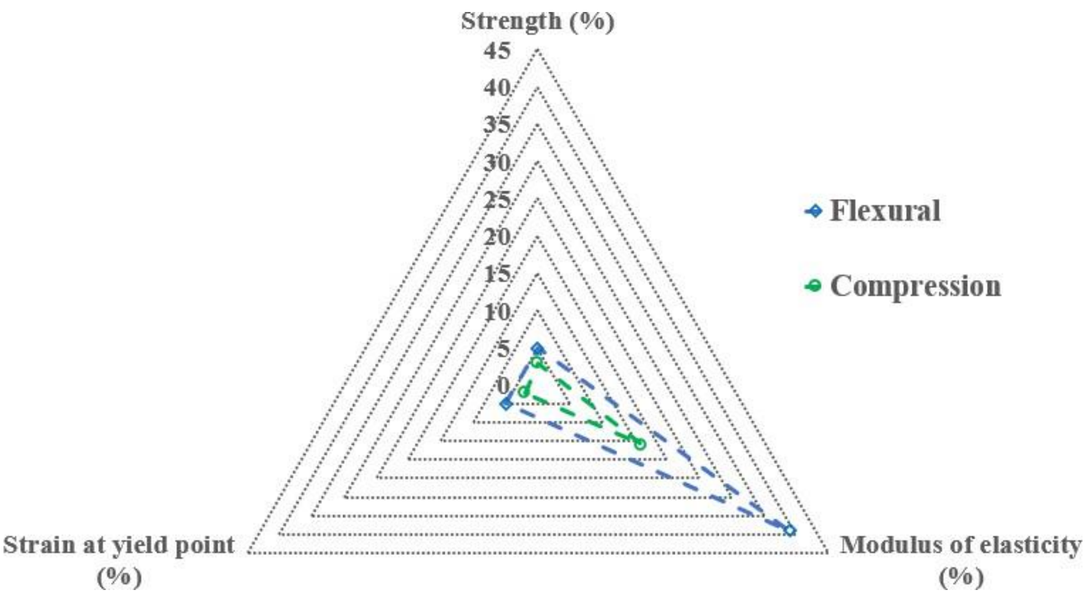
Discussion

According to the results section, it is clearly observed that, indeed tetra Pak® disposable containers managed to improve mechanical properties of the polymer concrete. Figure 8 shows the general mechanical behaviour of the material in which it is observed that not only strain at yield point was enhanced but also the strength and even better modulus of elasticity. It can be said that flexural test was the one that took the greatest advantage of Tetra Pak® material because under this mechanical test the plastic behaviour of the particles helps to retard fracture.

What is more, to have succeeded in upgrading mechanical values is highly rewardable since Tetra Pak® is not manufactured for these purposes.

Figure 8.

Results of compressive and flexural tests.



Note. Authors´ own elaboration.

Conclusions

The use of Tetra Pak® particles from discarded beverage containers as fillers in polymer concrete, produced with polyester resin and marble particles, can improve their mechanical properties. The most notable improvements occurred in the flexural elasticity modulus, for concrete with a particle sizes combination, obtaining values up to 39% higher, as well as 16% improvement in compression. These increases are due to better stress transfer between the components, polyester resin, marble and Tetra Pak® particles.

Minor improvements were obtained for compressive and flexural strength, 3% and 5% respectively, what is more, strain at yield point reached a 5% of enhancenment for flexural test; however, detrimental values were obtained for the deformation of polymer concretes in both mechanical tests, since the values decreased up to 15% less than for the control concrete.

The improvements represent a novel alternative to successfully reuse Tetra Pak® containers, and contribute to reducing their high pollution impact on the environment.

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