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Waste Tetra Pak containers and its use in construction materials
Envases Tetra Pak y su uso en materiales de construcción

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Abstract

This reviewing work studies the incorporation of Tetra Pak packaging waste into construction materials. The results show a multifunctional use of such waste, since not only mechanical properties are improved (without the need to recycle or modify the packages), but also environmental pollution is reduced by not dumping them in landfills. In addition, a valuable alternative based on the use of gamma rays for the treatment and recycling of waste materials is studied, which presents important advantages over traditional methods as it does not generate by-products or harmful residues.

Keywords: Tetra Pak, multilayer packaging, building materials, gamma radiation, mechanical properties.

Resume

En este trabajo de revisión se estudiaron los efectos de añadir desechos de envases Tetra Pak en la elaboración de materiales utilizados en el área de la construcción. Los resultados demuestran que el uso de los desechos conlleva un carácter multifuncional, ya que no solo mejoran los valores de propiedades mecánicas sin la necesidad de realizar un proceso de reciclamiento o separación de sus componentes, sino que ayudan a reducir la cantidad de desechos arrojados al medio ambiente. Adicionalmente, se estudia el uso de la radiación gamma como metodología para el reciclamiento y modificación de materiales de desecho, entre ellos los envases Tetra Pak. Metodología que ofrecen considerables ventajas sobre los métodos convencionales de reciclamiento, entre estas la no generación de subproductos y/o residuos no deseados.

Palabras Clave: Tetra Pak, envases multicapa, materiales de construcción, radiación gamma, propiedades mecánicas.

1. Introduction

Worldwide, the preferred material for food packaging and preservation is Tetra Pak. It is composed of 75% cellulose, 20% low density polyethylene (LDPE), and the remaining 5% is aluminum (Salazar-Jurado *et al.*, 2021). It was created in 1940 by Swedish engineer Ruben Rausing as a material designed and intended to help solve food dosing and storage problems in those years (Robertson, 2021). In 2021, 190 billion units of Tetra Pak were placed in the global market, but only 26% were recycled. The recycling process is based on the mechanical operation of hydropulping (Nieves-Flores, 2015). However, due to the complexity and high operating costs presented by the process, the recycling rate in Mexico is 30%, which implies a real contamination problem because the rest of the non-recycled Tetra Pak ends up in local landfills. Hence the purpose of discovering new alternatives, without using a separation process, for example, incorporating them in composite materials.

1.1. Types of building materials

Globally, cement concrete is the most widely used building material, which is produced with cement as the matrix, mineral aggregates, and water. In some cases, the concrete matrix consists of a combination of binders such as white cement, gypsum, or other products (Smith and Javad, 2006; Askeland and Wright, 2016; Callister and Rethwisch, 2017). However, an alternative are polymer concretes, which unlike cement concrete use a thermosetting resin as a binder (referred to as continuous phase), and mineral aggregates (referred to as dispersed phase). These concretes have certain advantages over cement concrete, such as low installation cost and maintenance requirements (Dodiuk, 2021; Niaki & Ahangari, 2022). Both types of concretes are useful for building needs;

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however, their main drawback lies on a lack of ductility (Ohama, 2008).

Several construction materials, like panels and sheets, can also be manufactured by the thermo-pressing method, which involves first heating the polymer to its melting point and then transferring the melt to a mold or pressing machine. The mold defines the shape and dimensions of the final product. In addition, this method offers several advantages, such as the ability to create complex shapes, efficient production rates as well as the potential for recycling and reuse (Harper, 2010; Strong, 2000).

Wood-plastic composites (WPCs) are other useful construction material, composed of a thermoplastic as a matrix and cellulose as filler (Klyosov & Klesov, 2007). In WPCs, wood and natural fibers provide toughness, stiffness, and low density, while the thermoplastic holds the fibers together through adhesive and cohesive forces and protects them from the environment (Rowell, 2013). Recently, thermoplastic composites are sourced from recycled polymers, providing an opportunity for the circular economy (Platnieks et al., 2020).

1.2. Building materials containing recycled Tetra Pak

The construction industry requires a broad portfolio of products to meet the needs of society. Some products containing Tetra Pak are shown in Figure 1.

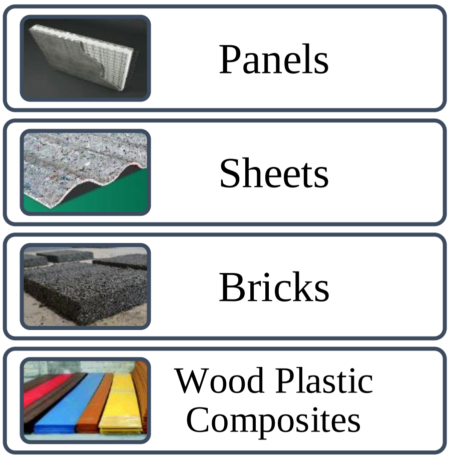

Figure 1. Building materials containing waste Tetra Pak.

1.3. Composition of Tetra Pak packaging containers

Tetra Pak packages have six layers, where each one has a special function, as shown in Table 1 (Dölle & Kavin-Chinnathambi-Jeeva, 2022).

Table 1. Layers of Tetra Pak containers

Layer Number	Material	Function
1	LDPE 1	Guarantees complete food´s protection
2	LDPE 2	Avoids the contact between aluminum and food
3	Aluminum	Blocks oxygen and light entry
4	LDPE 3	Helps to aluminum/cellulose adherence
5	Cellulose	Gives resistance and stability to the container
6	LDPE 4	Protects cellulose from external moisture

2. Composite materials containing waste Tetra Pak

In recent years, scientific communities around the world have been working with Tetra Pak package waste. Below is information gathered from scientific research concerning to waste Tetra Pak used in building materials.

Panels were made-using a sandwich type arrangement with an aluminum layer, followed by a Polyethylene/Aluminum/Cellulose (PAC) layer, and finally an aluminum layer. Also, panels using a Polyethylene/Aluminum (PA) layer, instead of the PAC layer (Koh-Dzul et al., 2023). The results show that Tetra Pak waste modifies the mechanical and thermal behavior. Both types of panels present similar values of stiffness and flexural strength; however, the panels with the PAC layer were stiffer, less ductile and with lower thermal conductivity than those with the PA layers.

Another type of panels, with density of 900 kg/m3 and sizes of 250x250x8mm, were fabricated from three waste polymer products, namely Tetra Pak (TP) cartons, food packaging films (FPEF) and polyethylene caramel wraps (CPEW). They were compressed at 3.5 MPa and 200°C for 10 min (Bekhta et al., 2016). The results show that panels with 60% TP, 10% FPEF and 30% CPEW had the highest modulus of rupture, namely 13 MPa, water adsorption of 10% and thickness swelling of 4%.

Better results were obtained for panels with 80% TP and 20% FPEF, which had 12 MPa modulus of rupture, the highest percentage of water adsorption, namely 23%, and thickness swelling of 12%. However, for high FPEF content (60%), the water adsorption decreased to 17% and thickness swelling to 6%; thus, water resistance mainly depends on the paper and paperboard content. In addition, panels with 20% or 30% CPEW, achieved better plasticization of the mixed particles as well as better bonding between molecules (Bekhta et al., 2016).

Panels containing three waste Tetra Pak sizes (as packaging; milled to 5x5 mm, and 1x25 cm) were manufactured by hot pressing method (Salamanca-Sarmiento & Vaca-Rodríguez, 2017). After testing, panels containing pieces of 1x25 cm, had the highest values of tensile strength, while those with packaging had the highest modulus of elasticity (41.27 MPa) and flexural strength (18.45 MPa). Decrease in the strength is due to the decrease of the particle size, thus it is advisable to use Tetra Pak in its original shape and size for applications of bigger volume.

Panels with a 1 gcm-3 density, included waste wool yarn and waste shredded Tetra Pak containers, were manufactured by hot pressing process (Hassanin & Candan, 2016). The results shown maximal modulus of rupture (22.67 MPa), for panels with 15% of waste wool yarn, and maximal internal bonding (0.7 MPa), when adding 10% of waste wool yarn. The minimal water adsorption (6.52%) was obtained after 24h. According to the results there is a possibility to use these composites as commercial construction panels.

Panels made from Tetra Pak and coated with beech veneer were evaluated against fungicides and insecticides. Panels had high resistance to fungi and higher antifungal and insecticidal properties. These panels can be used as a wood substrate in high humidity conditions. In addition, panels had lower production costs compared to commercial wood-based panels (Sen et al., 2010).

Sheets with dimensions of 250x120x7 mm^3, were produced by thermos-pressed method, at 180°C and a maximal pressure of 10 MPa for 10 minutes. The sheets contained three sizes of Tetra Pak waste (4.6x11.85 mm; 10x15 mm, and 5x5 mm). The results show that the sheets with Tetra Pak of 5x5 mm had the highest tensile strength values (37.4 MPa), which was 55% higher with respect to those that using 10x15 mm sizes, and 94% higher than those using 4.6x11.85 mm (Macías-Gallego et al., 2020). These thermos-pressed materials could be applied for non-structural purposes in the building industry.

Sheets with 3 mm of thickness, elaborated with waste Tetra Pak and sheets of high-density polyethylene (HDPE) of different colors (yellow, white, gray, and single), were produced by hot pressing (Parada-Soria et al., 2012). The results showed that the degree of crystallinity and the mechanical modulus varies according to the HDPE type, and the adhesion decreased. The highest modulus of elasticity (490 MPa) was obtained for white HDPE and the highest tensile strength (19 MPa) for yellow HDPE. According to the results, it is suggested improvement on the processing parameters of the recycled HDPE, to generate composite materials with enhanced mechanical properties, suitable for structural applications.

Other 9 mm thick sheets were made with 14% resin, Tetra Pak, and sawdust by hot pressing at 150°C for 7 min (Sun & Zhang, 2013). The maximum modulus of rupture and modulus of elasticity were 23.1 MPa and 2917 MPa, respectively, while the thickness swelling decreased to 6.1%. These values are ranging between the requirements of commercial packaging materials.

Sheets were produced with 70% High Density Polyethylene and 30% waste Tetra Pak, by an extrusion process (at 25 rev/min), then by a hot press method at 190°C (Guillén-Mallette et al., 2021). The highest values were impact resistance of 32 J/m, tensile strength of 11 MPa, and flexural modulus of 314 MPa; which can be implemented for obtaining composite materials, by a rapid and effective implementation.

In the manufacture of bricks, three waste materials were used as fillers, namely paper, cardboard, and Tetra Pak packages. The wastepaper (from office papers, magazines, and newspapers), cardboard (from packaging boxes), and Tetra Pak were cut into strips of 4×18 mm. Then, they were mixed with water and natural gypsum in a ratio of 1:3 (v/v). The results show a maximum compressive strength value of 6.46 N/mm^2 for gypsum/Tetra Pak mixtures, and a minimum value of 4.48 N/mm2 for gypsum/magazine paper mixtures. Regarding the maximum values, these composite materials could be applied to interior walls of buildings (Foti et al., 2019).

Small bricks (3x3x1 mm), made with High Density Polyethylene and 40-70 wt% of Tetra Pak waste, were studied (Kuzmin et al., 2023). After 24h exposed to water at room temperature, the results show that the composites with 40% Tetra Pak had the lowest water absorption (0.6%), while those elaborated with 70% Tetra Pak had 5.9%. These results were due to the presence of cellulose in the Tetra Pak particles.

Other small bricks (20x20x18 mm), made from shredded Tetra Pak waste and 10% zinc borate, were immersed in reverse osmosis water for 14 days at room temperature (Yilgor et al., 2014). The results show that the brick gained 17% water absorption and 14% thickness swelling due to the presence of cellulose in the Tetra Pak containers.

In the case of wood-plastic composites (WPC), they were produced with 10-30% Tetra Pak waste, 57-60% low-density polyethylene (LDPE), 10-40% wood fibers and 3% MAPE (maleic anhydride grafted polyethylene) coupling agent. Results were analyzed according to the added Tetra Pak. For 20%, the tensile strength values increased by 26% (22.61MPa), which was attributed to the presence of aluminum, as it facilitates stress transfer between the polyethylene matrix and the wood fibers. The addition of 30% increased the modulus of elasticity, obtaining 1.67 GPa. However, Izod impact strength decreased by 5.1%, 33.33 J/M, as the Tetra Pak generated sites of stress concentration in the polyethylene matrix, allowing the formation of cracks (Ebadi et al., 2016).

In other study, wood plastic composites (WPC), with dimensions of 4x180x220 mm3, were elaborated with recycled polyethylene (rPE) as matrix, pine wood flour and milled Tetra Pak boxes, as fillers. These last ranged up to 40 %wt. The results show that, for boards with 40% of Tetra Pack particles, the flexural strength and modulus reached 19.8 and 406 MPa, respectively, but the flexural and tensile modulus decreased 17% and 15%, respectively, when comparing with those with 40% of pine wood flour. Thus, Tetra Pak boxes can be used as fillers in the manufacturing of WPC instead of pine wood flour (Cihad-Bal, 2022).

Wood plastic composites (WPC) were made with 10% polypropylene, 50% wood derived fillers (WDF) and 40% milled Tetra Pak containers (TC). The WDF consisted of wood flour, sawdust, and recycled newspapers. Other fillers were used instead of Tetra Pak, such as hard wood fiber (HW) and veneer polishing dust (VD), to compare the mechanical properties (Viksne et al., 2010). The results show that the composites with WDF and Tetra Pak had the highest flexural strength (75 MPa) and impact strength (9.8 kJ/m^2). Contrary, the lowest value was obtained for WPC with 50% HW. Nevertheless, highest values for flexural modulus belonged to WPC with 50% HW, while the lowest values for WPC with Tetra Pak. These results are due to the cellulose in Tetra Pak containers, since they are more flexible comparing to the HW and VD fillers. Thus, the modulus of elasticity of the polypropylene/Tetra Pak composite decrease. In addition, water absorption after 400 h of the WPC with Tetra Pak was 50% higher than those for WPC with HW.

In other study, wood plastic composites with waste Tetra Pak containers had results of 10.2% for water absorption and 7.2% for swelling (Gao et al., 2011).

Regarding the previous information, mechanical behavior and water absorption are two fundamental properties for composites which involve waste Tetra Pak and have building applications. Tables 2-4 show the values for mechanical properties and water absorption of composites previously cited.

Table 2 and 3 do not depict a well-defined range of values between them, and this is because not all composites neither belong to the same type of composite nor are made with the same raw materials. but what it needs to be highlighted, it is the fact that these values are higher than their reference material without Tetra Pak.

Table 2: Tensile and flexural strength of composites with Tetra Pak.

Composite	Tensile strength (MPa)	Flexural strength (MPa)	Reference
Sheet of Tetra Pak	37.40	-	Macías, 2020
WPC of Tetra Pak/LDPE/wood fibers	22.61	-	Ebadi, 2016
Sheet of Tetra Pak/Colored HDPE	19.00	-	Parada, 2012
Sheet of Tetra Pak/HDPE	11.00	-	Guillén, 2021
WPC of Tetra Pak/WDF/PP	-	68.86	Viksne, 2010
WPC of Tetra Pak/PE	-	19.80	Cihad-Bal, 2022
Panel of Tetra Pak	-	18.45	Salamanca, 2017
Sheet of Tetra Pak/Sawdut	-	23.10	Sun, 2013
Panel of Tetra Pak/Wool yarn	-	22.67	Hassanin, 2016
Panel of Tetra Pak/FPEF/CPEW	-	13.00	Bekhta, 2016

Table 3: Modulus of elasticity of composites with Tetra Pak.

Composite	Modulus of elasticity (MPa)	Reference
Sheet of Tetra Pak/sawdut	2917.00	Sun, 2013
Sheet of Tetra Pak/Coloured HDPE	490.00	Parada, 2012
WPC of Tetra Pak/PE	406.00	Cihad-Bal, 2022
Sheet of Tetra Pak/HDPE	314.00	Guillén-Mallette, 2021
Panel of Tetra Pak	41.27	Salamanca, 2017

According to table 2-4, Tetra Pak might be considered as a multifunctional mixable comoponent for construction materials because, in fact, it can be added to the majority of materials commonly used for building. Furthermore, it was clearly exposed that Tetra Pak also can be blended in different percentages to the composites while maintaining its current improvements.

Table 4: Impact strength and water adsorption of composites with Tetra Pak.

Composite	Impact strength (MPa)	Water absorption (%)	Reference
WPC of Tetra Pak/WDF/PP	75	4.5	Viksne, 2010
WPC of Tetra Pak/LDPE/Wood fibers	33.33	-	Ebadi, 2016
Panel of Tetra Pak/FPEF/CPEW	-	17	Bekhta, 2016
Brick of Tetra Pak/Zinc borate	-	17	Yilgor, 2014
WPC of Tetra Pak	-	10.2	Gao, 2011
Panel of Tetra Pak/Wool yarn	-	6.52	Hassanin, 2016
Brick of Tetra Pak/HDPE	-	5.9	Kuzmin, 2023

Table 4 presents the optimal water absorption´s values for each specimen, and as in table 2 and 3, does not depict a defined interval for the percentage of adsorbed water. This table is not meant to be useless, on the contrary, it gives a nearby idea of the values than can be reached by the different types of studied composites if they are taken as first model for manufacturing processes.

3. Gamma rays in building materials

Gamma radiation is electromagnetic energy emitted by an atomic nucleus when it passes from a higher to a lower energy state. Gamma rays are packets of energy called photons. Unlike alpha and beta particles, which have energy and mass, gamma rays are pure energy (Brock, 2021). When gamma rays act on polymers, they produce cross-linking and degradation of their chains; while in polymer concrete, they produce modifications in both the polymer resin matrix and the mineral aggregates (Drobny, 2021).

Martínez-López et al. (2015), elaborated polymer concrete with 20 wt% polyester resin and 80 wt% silica sand. The latest was partially replaced up to 6% by ground Tetra Pak waste with particle sizes of 0.85, 1.40 and 2.36 mm. After, polymer concrete specimens were exposed to gamma radiation doses of 100 and 200 kGy, at a dose rate of 3.5 kGy/h, in air at room temperature. The results show a compressive strength of 90 MPa for concrete without Tetra Pak particles. However, the values of this property gradually decrease with increasing waste particles. They decrease up to 28% less (65 MPa).

As for particle size, small variations in values were found. Therefore, the particle size does not have a great influence on the compressive strength. As for the effects of gamma irradiation, these affect polyester resin, polyethylene and cellulose of the Tetra Pak packages. For higher particle concentrations, more interactions are between the resin matrix and the Tetra Pak particles. In addition, such particles are more crystalline due to the radiation doses and generate pores in the polymer concrete, which acting as faults do not allowing efficient loads transfer, resulting in low compressive strength (Martínez-López et al., 2015).

The flexural strength values of polymer concrete decrease up to 21% with increasing particle concentration. However, gamma irradiation improves the flexural strength value by 13%. But, at higher particle concentrations, this progressively decrease up to 12% less than the control concrete value (Martínez-López et al., 2015).

Concretes made with unsaturated polyester resin and 40-60% polymer fibers were irradiated at doses of 2.5-12.5 kGy at a rate of 6 kGy/h. The results show that in non-irradiated concretes the tensile strength increases up to 49 MPa with the addition of 59% fibers, an improvement of 40%; while the flexural strength increases up to 88.2 MPa, after the addition of 53% fibers, Impact strength also found its maximum at a value of 17.9 kJ/m^2.Thus, the strength increases as a function of the fiber content, which actively participates in the transfer of localized stresses and strains. In the case of irradiated concretes, a 29% improvement in tensile strength was obtained for the specimen with 50% fibers at a dose of 7.5 kGy, being 37.05 MPa, while flexural strength increased by 14%, being 60.1 MPa. Both increases are due to chain breakage in the polyester resin and fibers. After, small molecules are formed by cross-linking of the polymer chains (Khan-Rezaul, 2014).

Composites were fabricated with low density polyethylene pellets (LDPE) and 10-60% pineapple leaf fibers (PALF). The results show that the highest impact strength (33.42 kJ/m2) was obtained with 50% PALF. With this fiber concentration, composites were elaborated to be exposed to doses of 2.5-10 kGy. The results show maximum values at 7.5 kGy dose, namely tensile strength increased by 35%, tensile modulus by 16%, flexural strength by 17%, flexural modulus by 21% and impact strength by 36%. Whereas the maximum deformation at fracture, 44.4%, was obtained at doses of 10 kGy (Rahman, 2019).

4. Conclusions

Tetra Pak's waste packages can offer novel scientific applications in construction materials such as panels, sheets, bricks, and polymer concrete, because of their mechanical properties were noticeably improved.

Considering that Tetra Pak packages are made of cellulose (75%), polyethylene (20%), and aluminum (5%), it is cellulose, and its hydrophilic behaviour, which plays a critical factor to consider when new building composites are required for their use in humid environments. Therefore, water absorption must be considered like a crucial factor for the design of all these innovative materials. In this sense, the behavior of composites in humid environments needs to be also studied.

Talking about gamma rays, it should be noted that they can be considered a cutting-edge and promising alternative for modifying the physicochemical properties of materials with the notable advantage of not generating unwanted residues.

This paper has presented a glance of few scientific works which aimed to re-use and recycle Tetra Pak´s containers introducing them in composite materials that are used in the building sector, enabling science to keep developing and studying Tetra Pak's effects over this sort of composites.

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