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Article

Reimagining construction with recycled polymer composites: Exploring usage in Portoviejo and Medellín's infrastructures

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Abstract: This research implements sustainable environmental practices by repurposing post-industrial plastic waste as an alternative material for non-conventional construction systems. Focusing on the development of a recycled polymer matrix, the study produces panels suitable for masonry applications based on tensile and compressive stress performance. The project, conducted in Portoviejo and Medellín, comprises three phases combining bibliographic and experimental research. Low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polypropylene (PP) were processed under controlled temperatures to form a composite matrix. This material demonstrates versatile applications upon cooling—including planks, blocks, caps, signage, and furniture (e.g., chairs). Key findings indicate optimal performance of the recycled thermoplastic polymer matrix at a 1:1:1 ratio of LDPE, HDPE, and PP, exhibiting 15% deformation. The proposed implementation features 50 × 10 × 7 cm panels designed with tongue-and-groove joints. When assembled into larger plates, these panels function effectively as masonry for housing construction, wall cladding, or lightweight fill material for slab relieving.

Keywords: recycled polymers; panels; circular economy; mechanical strength of materials

1. Introduction

The construction industry stands out as one of the main contributors to environmental pollution. Extensive energy consumption and the emission of significant levels of CO_2 are well-documented consequences of construction activities [1]. Furthermore, Wang et al. [2] highlight the detrimental environmental impact associated with certain materials applied within this sector.

The marked environmental impact of plastics is highlighted, from their extraction phase to their final disposal [3]. Furthermore, research carried out by Zheng and Suh [4] warns that, if these trends persist, by 2050 the accumulation of up to 12 million metric tons of plastic waste exclusively in landfills is expected, with a consequent estimated contribution of 16 million metric tons of greenhouse gases (GHG).

In its study, the Alianza Basura Cero-Ecuador [5] identifies Ecuador, Mexico, and El Salvador as the countries with the highest risk of plastic contamination due to their position as the main importers of this material in the region.

In the context of Ecuador, it is alarming to note that Ecuadorians throw away more than 531,461 tons of plastic annually [6]. Despite the fact that the country has one of the oldest alliances aimed at regulating single-use plastics, Plan V [6] reports that in 2018 Ecuadorians generated an average of 12,739.01 tons of waste daily. Of this total, plastic constitutes a worrying 11.43%, which is equivalent to an annual weight of 531,461 tons, comparable to the weight of more than 350,000 medium-sized vehicles.

According to the Alianza Basura Cero-Ecuador [5], between 2018 and 2022, the country imported approximately 27,338 tons of these materials from the United States alone, constituting 56% of total imports. Likewise, reports from Ecuavisa [7] mention that these waste materials are significantly contributing to climate change and even infiltrating our food chain.

In Colombia, the figures are equally alarming. Data from the Legal Clinic for the Environment and Public Health & Greenpeace Colombia [8] reveal that an average of 10.3 million tons of solid waste were generated daily that year. During that same period, Colombia produced more than 30,081 tons of this waste daily. Furthermore, it is estimated that an average Colombian household generates around 4.3 kg of solid waste per day.

This is why, at a global level, there are organizations that consider them key to progress and generate new lasting strategies to address socioeconomic and environmental challenges, promoting shared and sustainable development [5,9,10].

Likewise, regulations have been established in Ministerial Agreement No. 61 on the Integrated Management of Solid Waste by Ministry of the Environment [11], which recognizes the comprehensive management of solid waste as a national priority in Quito, Ecuador. On the other hand, in Colombia, decrees and pacts have been implemented with the aim of coordinating and executing actions throughout the plastic life cycle, focusing on the replacement of materials in construction [12].

To achieve a circular economy for plastics, the most important thing is to manage waste so that it can be recycled, not broken down. A recyclable product means that the material remains in the reuse cycle, allowing it to be transformed into new products with higher value and lower energy use [13].

These residues can be used to build homes in different countries, in the production of blocks or roofs, constituting an alternative with sustainable properties, and achieving Leadership in Energy and Environmental Design (LEED) certifications. The LEED certificate is a certification system for sustainable buildings, developed by the U.S. Green Building Council [14], which evaluates the energy efficiency, resource use, and indoor environmental quality of projects.

Polyethylene terephthalate (PET) containers are also applied under this modality in countries such as Colombia and Ecuador [1] and are widely used in the food and beverage industry due to their resistance, lightness, and recyclability [15].

The company ByFusion, founded by New Zealander Peter Lewis, designed a machine that recycles ocean plastic into bricks. These bricks are used to build housing for low-income communities in Hawaii. The manufacturing process for these blocks, called RePlast, is almost completely carbon-neutral and non-toxic. The result is blocks composed of 100% recycled plastic, generating 95% fewer gas emissions compared to traditional building materials.

This research focuses on developing a recycled polymer matrix for the manufacture of slabs for use in masonry construction. The proposal examines the tensile and compressive properties of the composite material currently under study in the cities of Portoviejo and Medellín. Based on the characterization of recycled industrial thermoplastic polymers, the objective is to establish the optimal dosage and evaluate their physical and mechanical properties through tensile, flexural, and compression tests. Thus, its application in an innovative masonry construction process is proposed. This research responds to an environmental responsibility in the construction sector by reincorporating industrial polymer waste into a new use cycle, reducing waste generation, and contributing to climate change mitigation.

Currently, the cities of Portoviejo and Medellin are leading the development of these materials, with Medellín standing out as an example of sustainable construction and the use of eco-friendly materials. Due to its focus on environmentally conscious building practices, Medellin is regarded as a benchmark city for comparing and relating the properties and applications of both materials in the field of sustainability.

2. Methodology

Through this research, we sought to analyze a composite material of recycled industrial thermoplastic polymers, carrying out physical and mechanical tests and experiments with the aim of making its use viable in the manufacture of panels for construction.

As a first step, information was collected using a qualitative methodology in a desk-based setting. This consisted of semi-structured interviews with two experts in the field in both cities, with the aim of understanding the processes and dosages required to create objects with these materials.

The manufacturing method used in Portoviejo and Medellín, known as extrusion-pressure or injection, allows for the production of elements from recycled industrial plastic waste. This method offers environmental advantages by allowing the temperature of the material to be regulated, avoiding incineration and greenhouse gas (GHG) emissions.

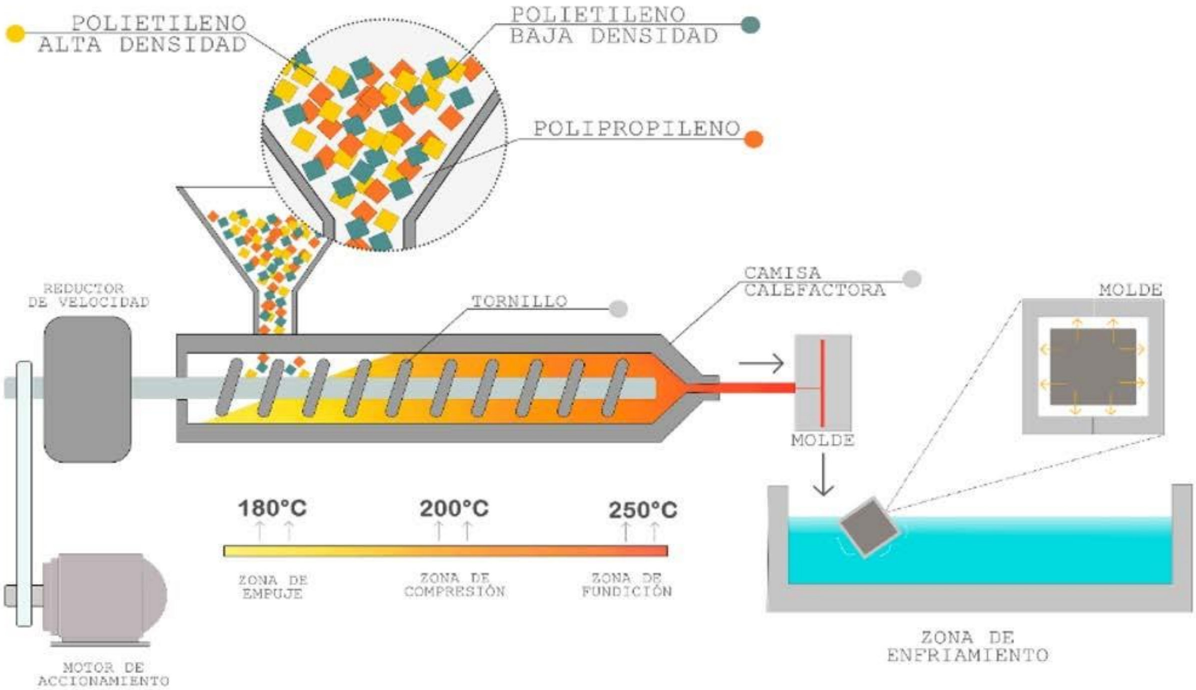

Figure 1. Plastic extrusion-pressure (injection) process.

Recycled industrial thermoplastic pellets are introduced into the hopper, shown in **Figure 1**, and the plastic is melted by various propellers located inside the heating jacket. These propellers are arranged from widest to thinnest, with controlled temperatures ranging from 180 ℃ to 200 ℃ to 250 ℃, allowing the material to homogenize and plasticize properly for subsequent injection into the mold.

In addition, an experimental approach was applied in specialized factories, where samples were made with a 1:1:1 dosage in kg of low-density polyethylene (LDPE), high-density polyethylene (HDPE) and polypropylene (PP) in both cities. To perform bending resistance tests, samples were made in the form of beams with measurements of 50 cm × 4.0 cm × 4.0 cm, which were subjected to KN loads, and cubes were cut with equal dimensions on all sides, 5.00 cm × 5.00 cm × 5.00 cm, to perform compression tests. The result is observed in **Figure 2**:

Figure 2. Samples obtained.

Finally, the physical and mechanical strengths were checked in both cities by applying the aforementioned dosages. This was done through laboratory tests with specialized instruments such as a hydraulic machine and a universal machine UH F500 Kn X, under the ASTM D790 and ASTM D638 standards, shown in **Figure 3**:

Figure 3. Universal machine UH F500 Kn X.

Additionally, a practical-experimental investigation was carried out to determine the appropriate type of assembly for the proposed panel.

3. Results

For a better understanding of the results, the trials carried out in the city of Portoviejo were called Experiment 1, while those carried out in the city of Medellín were named Experiment 2.

3.1. Comparative analysis of samples

A comparative morphological analysis was carried out on the samples obtained. **Figure 4** shows the result of Experiment 1 (A), which shows a black scale color and a non-uniform color composition. The particles are mostly visible and elongated, maintaining the colors of the waste type entered into the mixture. Voids of around 4 mm are seen, which is attributed to the lack of drying of the raw material before being entered into the injector. In turn, Experiment 2 (B) shows grayish-green tones due to the pigment entered; in addition, due to its high compaction, it does not present visible waste particles; therefore, it maintains a much smoother texture where the depth of the external voids is at least 3 mm.

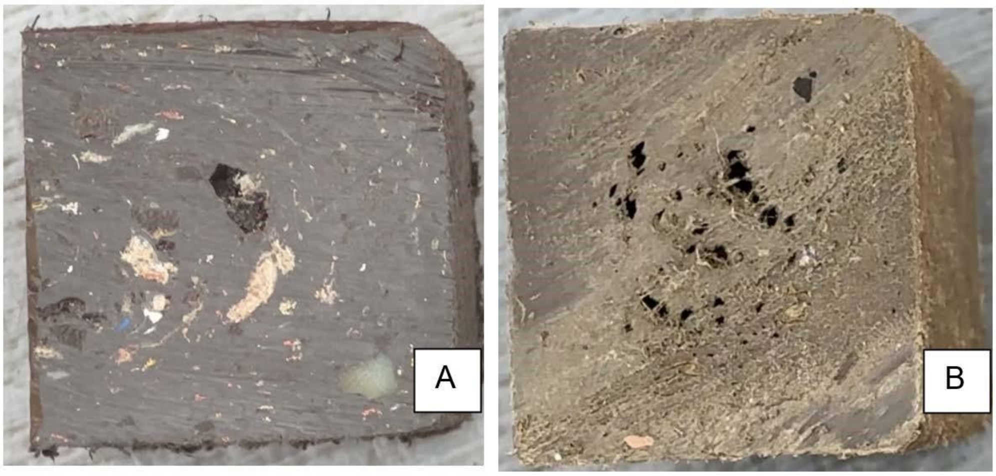

Figure 4. Morphological comparison of the samples obtained.

Note: A: Experiment 1; B: Experiment 2.

3.2. Essays experiment 1

For the bending tests, the specimens were subjected to a span of 45 cm, yielding the results for Experiment 1 shown in **Table 1**:

Table 1. Flexural tests on the samples from experiment 1.

Name	Max. _Force	Max. _Flexion	Max. _Displacement	Max. _Deformation
Parameters	Calc. at entire areas	Calc. at entire areas	Calc. at entire areas	Calc. at entire areas
Unit	KN	N/mm^2	mm	%
1_1	3.84792	20.3594	52.8696	15.8609
2_2	3.95471	20.9244	52.9587	15.8876
Media	3.90131	20.6419	52.9141	15.8742

The sample presented a fracture after approximately 1 h and 30 min, as shown in **Figure 5**. The flexural strength test reached a value of 20 N/mm^2, highlighting its remarkable deformation capacity, with a 15% elongation. This confirms its ductility, in contrast to concrete, which does not exhibit these characteristics under similar testing conditions.

Figure 5. Results of the bending test of experiment 1.

To perform the compression test, the samples were subjected to forces at a speed of 0.8 mm/min. The results are shown in **Table 2**.

Table 2. Compression tests of the samples from experiment 1.

Name	Max. _Force	Max. _Compression	Max. _Displacement	Max. _Deformation	M. elastic force 5–40 kN
Parameters	Calc. at entire areas	Calc. at entire areas	Calc. at entire areas	Calc. at entire areas	Force 5–40 kN
Unit	KN	N/mm^2	mm	%	N/mm^2
1_1	64.7719	35.8648	20.9106	49.7872	73.5345
1_2	64.2481	35.5747	20.8904	49.5481	73.0246
Media	64.5100	35.7197	20.9005	49.6676	73.2795

A maximum force of 64.77 kN was obtained with a strain of 49.78%, although it should be noted that this data does not reflect the full deformation of the sample. The results of this test are shown in **Figure 6**.

Figure 6. Compression test results of experiment 1.

3.3. Essays experiment 2

Table 3 shows the results obtained in material strength tests, specifically in terms of maximum force, maximum deflection, maximum displacement, and maximum deformation.

Table 3. Flexural tests on the samples from experiment 2.

Name	Max. _Force	Max. _Flexion	Max. _Displacement	Max. _Deformation
Parameters	Calc. at entire areas	Calc. at entire areas	Calc. at entire areas	Calc. at entire areas
Unit	KN	N/mm^2	mm	%
1_1	4.53886	24.0152	54.5676	16.9719
2_2	4.58483	24.2584	54.9889	17.0154
Media	4.56184	24.1368	54.7782	16.9936

Source: Tests carried out in the laboratories of the ECOPLAST 2K Company, in Medellin.

Yield strength represents the range in which the plastic material operates without difficulty, maintaining its shape and structure under load. The material then enters the yield strength range, where it is subjected to stresses of up to 10 MPa, testing its deformation capacity before reaching its limit. Finally, the material's breaking point is observed to be 24 N/mm^2, as illustrated in **Figure 7**.

Figure 7. Results of the bending test of experiment 2.

4. Discussion

In the background analysis of the study, Sangucho et al. [16] conducted an analysis at the Central University of Ecuador on the physical and mechanical properties of recycled plastics produced in the country as a construction material. They examined plastic lumber samples from Ecuaplastic, a company that reuses polypropylene from snack bags using the injection method. They found that the material's flexural strength is 17.02 MPa under ASTM D6109 and its compressive strength (ASTM D6108) is 22.43 MPa.

Likewise, the research by Ruiz et al. [17] carried out a comparative study of plastic wood with other alternatives of the same type, where the results were favorable for plastic waste, obtaining a Flexion of 17.53 MPa, unlike a plywood board that obtained the minimum requirements in bending of 19.51 MPa and compression of 6.51 MPa.

Analyzing the above results, the material is suitable for use in construction due to its favorable results, such as its high plasticity, which means it can almost completely recover its original shape after being subjected to great stress. This gives the material greater strength and durability, as well as greater ease of molding it according to construction needs.

However, authors such as Chen et al. [18] have determined that both the physical and mechanical results of these samples can vary depending on the intrinsic properties of the recycled material. Factors such as contamination, the degree of degradation, and prior processing could significantly influence the final properties of the material.

The panels in this case feature notable features that promote savings and efficiency in the use of materials, as well as optimization of labor time and movement. Because they do not require mortar or nails, their installation is faster and more economical, taking advantage of a tongue-and-groove assembly system. This type of joint allows for quick and easy assembly, also facilitating panel alignment and stability.

The tongue-and-groove panel structure, reinforced with profiles of the same material, provides adequate space for the installation of various interior service networks. This includes electrical, drinking water, drainage, telephone, computer network, and cable television systems, among others. Furthermore, the panels are designed to accommodate thermal and acoustic insulation, contributing to improved thermal and acoustic comfort conditions in the built spaces. This system not only guarantees a cleaner and more organized construction but also allows for greater energy and acoustic efficiency in the building.

Post-industrial plastics stand out as the most commonly used materials among those interviewed due to their ease of handling, cleanliness, and cost-effectiveness. They allow for an endless recycling cycle, as the waste generated during their use can be reused in new production processes. Furthermore, post-industrial waste within a polymer matrix is an innovative option for construction, thanks to its high flexibility and adaptability. These characteristics not only allow for more efficient and conscious construction but also contribute to a more environmentally friendly approach by reducing the consumption of materials that would normally become waste.

Although the manufacturing of these components presents certain drawbacks, such as requiring large-scale machinery and continuous operation generating greenhouse gases (GHG) for extended periods, the investigated material offers significant advantages. Its ease of implementation contributes to substantial reductions in labor costs and material expenses.

Furthermore, the physical and mechanical characteristics of these plastics, such as their flexibility, are superior to those of traditional alternatives like concrete, providing structural and construction advantages. Their versatility in applications, thanks to their tongue-and-groove system, reduces waste in the construction process compared to traditional materials. By following the logic of the circular economy, waste from other material processes is used as a primary source, ensuring a constant and sustainable supply.

5. Conclusion

Although the results did not show significant variations in the fundamental properties of the recycled industrial thermoplastic polymer composite materials from Portoviejo and Medellin, small differences were observed that could be attributed to various factors, such as climatic differences and the time dedicated to the drying process in each city, which affects the microstructure related to the amount of internal voids as well as its colorimetry, as well as the final behavior of the material and its results in terms of flexural strength, where in the city of Portoviejo 20,642 N/mm^2 were obtained, while in Medellin 24,137 N/mm^2, which would be equivalent to around a 17% difference.

Despite this aspect, it is important to note that none of these factors significantly affect the critical properties of the recycled material, such as its strength, plasticity, and elasticity. These results highlight the potential of recycled plastic material as a viable and sustainable alternative worldwide, regardless of climatic conditions or variations in local manufacturing processes.

The use of these plastics in the form of panels for construction processes has demonstrated high flexural strength, especially in a 1:1:1 ratio. Their rapid production allows for large quantities of material to be obtained in a short time, which is advantageous for the construction industry.

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