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Original Article

Evaluation of High-Strength Plastics in Urban Furniture: A Comparison of Materials and their Use in Particular Public Spaces

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Abstract *- Street furniture in public spaces in high-risk areas meets two fundamental requirements for its designation: exposure to extreme climates and adverse weather conditions such as floods or landslides. Therefore, this article is based on an evaluation of the materials currently used in street furniture in high-risk areas, taking as a case study the informal settlement of the Sergio Toral Cooperative in Guayaquil. The overall objective of the study is to assess the current condition of the materials and propose solutions using high-density plastics to improve their long-term resistance and maintenance. In conclusion, it was determined that, with varying dosages of plastic alloys (1%, 2%, 3%, 4%, and 5%) and the addition of recycled HDPE plastic spheres, PVC fibers, and cement, the best results were obtained at the 3% and 4% dosages, particularly in sunlight, and with increased water absorption and dissipation. A hybrid material with absorbent and waterproofing properties was developed, resulting in a material more resistant to cracking and breakage, and with a 22% increase in its elastic properties.*

Keywords *- Street furniture, High-strength plastics, Sustainability, Material evaluation.*

1. Introduction

One of the world's biggest pollutants is plastic, a reality that has coexisted with humanity for over a century, currently accumulating 450 million tons. Many oceans and rivers are contaminated with between 5 and 50 billion microplastics [1], meaning there is at least one microplastic per cubic meter of water worldwide, which is then ingested by fish and humans [2]. In Ecuador, this level of waste increases considerably in aquatic environments and landfills, leading to extensive contamination in rivers and estuaries. This, combined with production from the construction and industrial sectors, has resulted in one of the highest rates of plastic pollution in Latin America.

The fate of polluting plastic materials in the Ecuadorian environment has not been precisely determined or addressed to establish sustainable consumption aimed at recycling and reusing plastic. Based on this premise, one of the most polluting industries in Ecuador is the construction industry, generating an alarming 25,200 tons of waste annually [3]. Given these figures, raising environmental awareness and reducing pollution by incorporating plastic into sustainable consumption would decrease pollution from contemporary construction in Ecuador.

The incorporation of recycled plastics in the construction industry is considered a local solution to excessive plastic consumption and waste in many countries [4]. However, in Ecuador, it can be considered an ecological contribution to the construction techniques and systems generally used in reinforced or mixed concrete structures. The plastics industry has been working on solutions for reuse, which has contributed to changing usage patterns [5]. In comparison, the plastics industry in Latin America and Central America has established research networks focused on the circular economy of plastics in the Caribbean, Central America, and South America, aiming for innovative solutions in construction technology. Mexico has been a pioneer, making significant contributions to processing and the sustainable integration of plastics into all aspects of traditional construction [6].

Programs in Latin America, such as Think Plastic Brazil, strengthen the internationalization of plastic solutions, promoting technology, design, and applications that impact not only the domestic plastics market but also related industries, such as construction [7]. Events such as conferences and seminars in Ecuador include congresses on “Sustainable Plastics: Innovations and Challenges,” which bring together experts to discuss technologies, processes, and plastic materials applied to sustainable construction and other productive sectors using high-strength plastics that compromise the material's properties for the sake of consumption [8].

High-strength plastics, such as HDPE or PVC, with a high degree of compression, offer improvements in various mechanical properties related to the material's original strength. Considerations regarding these properties are determined by the malleability of the elements during the mixing phase, where water retention can occur during the drying and curing phase [9]. Evaluating the physical and mechanical properties of materials through comparison is a valuable technique for providing quantifiable data on the various problems a material may present under conditions such as usage time and exposure, which accelerate or decelerate material degradation from the perspective of climatic effects and wear [10]. This material selection must be specific and critical for each project, demonstrating that material selection should encompass a thorough study of its properties.

The testing process to determine the physical and mechanical properties of the materials of interest and their applications constitutes the main part of the research. It was developed based on the Spanish standards UNE-EN-13279-2 and UNE-EN-520, in their general and specific experimentation phases [11]. These standards were taken as a frame of reference, meeting the highest standards for the systematic evaluation of properties such as mechanical characterization, durability, plate strength, thermal behavior, and permeability.

2. Materials and Methods

2.1. Plastic in the Construction

The construction industry has undergone significant changes since growing awareness of climate change and ongoing experimentation with materials have driven the use of plastic as part of its new, traditional building materials. Research such as that by Infante [12] and Rao [13] has had a major influence on the use of this material to help reduce plastic pollution [14]. One of the material's essential characteristics is its elasticity, which improves structural integrity, and some studies have shown that the use of plastic aggregates (such as PET) can improve the abrasion resistance of concrete [12].

Various plastics have been found in the literature to have been used as binders in concrete or plaster structures, or as the primary material for manufacturing panels or lightweight structures [15, 16]. Among the most used types of plastics in construction are HDPE and PVC. PVC is primarily a building material, with the construction industry responsible for around 60% of global demand. Versatile and lightweight, PVC is used to produce a wide range of construction fittings, including pipes, cables, flooring, windows, and roofing. Its forms as aggregates in construction are quite diverse, but according to previous research, the most malleable are in the form of chips or branches (See Figure 1) that adhere to concrete or the base mix [16].

Fig. 1 PVC processed into chips less than 1/2 mm thick

High-Density Polyethylene (HDPE) is used in construction for pipes (potable water, wastewater, and irrigation), geomembranes (for waterproofing landfills and ponds), and coatings (roads, bridges). Its advantages include resistance to corrosion, chemicals, abrasion, and thermal changes, allowing for a long service life. The presentations as aggregates in construction are very diverse, but the most malleable according to previous research are in the form of spheres or formats less than 1 mm (See Figure 2) that adhere to the concrete or base mix more uniformly [11].

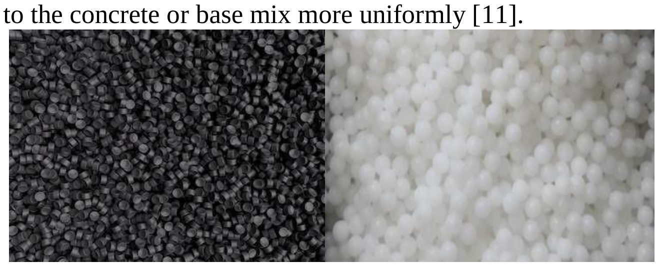


Fig. 2 HDPE processed into spheres and forms smaller than 1mm

It is undeniable that plastic is and will continue to be used in construction, although it does not always offer advantages to the material [17]. Its high degree of addition can lead to decreased workability and compressive strength if used in excessively high proportions. Considering these disadvantages, the issue is clear and demonstrates that the amount of aggregate must play a crucial role [18].

The practical formulation that the plastic fulfills is estimated through the maximum elasticity of a plastic, which is evaluated through concepts such as the elastic limit **(**σy), the Young's modulus (E), *and* (εy), which is the maximum elastic deformation.

To calculate the elastic limit, the following formula is used:

$$\sigma y = E \times \varepsilon y \quad [19]$$

The maximum elastic deformation is calculated using the formula:

$$\varepsilon = \Delta L / L0 \quad [20]$$

Where ΔL is the change in length, and $L0$ is the original length.

This formula will prevail in the final determination of the balanced elastic limit to obtain optimal elastic shaping with the concrete mix to achieve the ideal model of street furniture.

2.2. Choosing the Ideal Street Furniture Model

The ideal design of the furniture within the public space of this area is divided into 8 stages since public spaces, as such, serve 3 fundamental aspects of society, which make them interactive for communities; these aspects address interactive public spaces for sports, productive–economic, and entertainment (games).

The furniture's unique characteristic is its location, as much of it is exposed to the elements for 10 to 12 hours a day, with average temperatures of 27° Celsius. This causes the materials to retain heat for several hours, rendering them unusable and uncomfortable at times [16]. Furthermore, the materials used—low-carbon steel and reinforced concrete—have led to recurring deformations and breakages throughout the furniture. This trend of using steel in concrete structures has resulted in joints collapsing due to the degree of thermal expansion and poor heat transfer between the materials.

An additional constraint is the exposure to recurring winter periods throughout the year and low water tables, which means that most public spaces experience recurrent flooding at their base and up to 60 cm below the level of each piece of furniture. Therefore, the material must withstand high levels of absorption and saturation, and the ideal material composition must consider two overlapping climatic conditions: high temperatures and water saturation.

The layout of these eight interactive public spaces is represented in the following diagram of the furniture arrangement within the Sergio Toral Cooperative (See Figure 3).

Fig. 3 Location of urban furniture in the interactive public spaces of the Sergio Toral Cooperative

Note*: Planned design of an interactive public space as a territorial computer. (1) Safe and arboreal intervention. (2) Furniture and business area. (3) Furniture and sports area. (4) Local market development coupled with the ventures of the standardized local corridor. (5) Civic spaces and rest areas. (6) Security and interaction spaces. (7) Massive public space for interaction and entrepreneurship. (8) Pedestrian continuity and connectivity.

The street furniture in the study area exhibits considerable deterioration due to exposure to widespread flooding and settling, as it is in areas at risk of flooding and landslides. This has led to the deterioration of the eight mapped public spaces. The material structure of street furniture reflects a rudimentary evolution, resulting in damage that makes the equipment and furnishings in the study area unusable.

Materials such as wood and metal have been used continuously in street furniture, but without good results at the study site. Nevertheless, a comparison of the introduction of these materials is presented, focusing on their physical and mechanical properties.

Table 1. Comparison of alternative materials such as wood and metal

Property	Wood	Metal
Strength-to-weight	High	Very high
Predictability	Variable	Very predictable
Moisture sensitivity	High	Low
Fire resistance	Moderate (char layer)	Low (strength loss)
Sustainability	Renewable	High embodied energy
Maintenance	Moderate	Moderate–High

Studies demonstrate that the use of combined materials such as wood and steel improves resilience properties in areas of exposure, as Wu (2023) suggests in his research on combined material properties. He compared wood, which exhibits low resistance and is prone to cracking, with steel, a material that is less prone to elasticity and has a high degree of climate absorption. To combat the disadvantages of each material, he proposed a composite beam structure with a rectangular cross-section made of steel/pine [21]. The deformation under force, the transverse strain distribution law, and the damage mechanism of the combined beam were studied to optimize its design. The element adopted elastic properties by increasing its yield strength with the addition of steel, and by generating better thermal comfort using pine, thus improving the material's resistance.

Seeking alternative solutions based on the vulnerability of exposed materials while enhancing their qualities has shaped a framework of theoretical solutions based on the introduction and innovation of technology to expand the range of resistance of physical and mechanical properties in areas exposed to risk [22].

Previous studies in areas exposed to extreme climates have demonstrated that the correct selection of materials through a study of the site conditions can contribute to the sustainable development of materials and their exposure [23]. Lapidus (2025) in his studies of the resistance of infrastructures and buildings include various approaches for the reconstruction of buildings and residential structures in the Arctic zone through a risk-based approach and its changing conditions, thus generating a concept of material resilience through the study of climatic and geological peculiarities of the Arctic zone, as well as modern risk analysis methods can be transmitted in the application of modeling and prediction methods to assess the impact of various factors on the stability and durability of materials in buildings [24].

Another study analyzing the material's properties and behavior in building and furniture coatings has been part of da Silva Andrade's (2024) ongoing research, generating an evaluative process for the medium- and long-term behavior of paint coatings exposed to the elements and, therefore, influencing the hygrothermal behavior of buildings [25].

Characterizing and evaluating coating materials is fundamental, seeking suitability in their selection, especially regarding the effects of humidity and temperature on wear. Through experimentation, a range of coatings with plastic additives has been developed that improve performance under controlled climatic variations and can be effectively used in high-risk areas. These previous studies establish a direct correlation between the material and the environment where it is applied, a crucial parameter for extending the life cycle of materials and reducing structural problems.

3. Methodology

An exploratory study will be conducted on recycled plastic materials to address the problems associated with the production of street furniture in public spaces on the Ecuadorian coast of Guayaquil. This area was chosen as a reference point due to the climatic conditions that generate high resistance to the summer and winter seasons of this equatorial region.

The public spaces of the Sergio Toral neighborhood were selected as a reference sample, where physical and chemical pathologies are present in the street furniture of the interactive public spaces. Therefore, the exploratory study was guided by a comparison of laboratory-tested materials that improve the characteristics of the materials used in the construction of this furniture, such as precast concrete panels, which are the element where these pathologies appear.

The samples were selected according to the materials used in the urban furniture of the site (reinforced concrete 70% and concrete+metal 30%), which structures all of the samples; therefore, the selection of the hybrid material was categorized from the introduction of HDPE because of its better malleability and workability with concrete as determined by the UNE-EN-520 standard. The tests will be categorized into samples to obtain dosage results with plastic aggregates mixed with traditional concrete base materials. All samples will be subjected to the testing plan configured in the following dosage and testing scheme:

Table 2. Characterization of the different dosages used (Concrete + HPDE)

Binder/water ratio		Recycled plastic content	
0,65		0% (REF)	
Dosifications	**Concrete (gr.)**	**Water (gr.)**	**HDPE (gr.)**
E0,65 – REF	1000	650	-
E0,65 – 1% HDPE	990	643,5	16,5
E0,65 – 2% HDPE	980	637	33
E0,65 – 3% HDPE	970	630,5	49,5
E0,65 – 4% HDPE	960	624	66
E0,65 – 5% HDPE	950	617,5	82,5

Note: For thermal conductivity plates, multiply the dosage quantities by two. 1000 g Concrete / 650 g Water. **Total:** 6 dosages. Variations: 1% - 2% - 3% - 4% - 5% of the total mix. (*) Another option is to use recycled and non-recycled polyethylene, preparing fewer dosages for each type of concrete, using only percentages (1%, 3%, 5%).

Experimental Test Plan:
a) Mechanical Characterization – 4*4*16 cm mold (3 specimens) (1)

Weight (apparent density). MOEus, Shore C surface hardness, flexural, and compressive strength. Scanning Electron Microscopy (SEM) (CONCRETE with non-recycled HDPE and recycled Plastics - PVC)

b) Durability – Two 4*4*16 cm molds (6 specimens) (2)

Wet-dry cycles (20 cycles) -2 reference specimens and 2 test specimens. Cycles: Initial and final weight, surface hardness, flexural and compressive strength. (2.1). Capillarity – 2 specimens. Initial weight, height measured per minute for 10 minutes, and final weight + Thermography. (2.2). Without cycles: Surface hardness, flexural strength, and compressive strength. (2.3)

c) Actual study with plates – 40*30*2cm. (1 plate) (3)

Simple flexural strength. Indentation diameter (impact)

d) Thermal behavior – 24*24*3cm mold (1 test tube) (4)

Thermal conductivity coefficient – Physics Laboratory. Using the same test tube – total water absorption.

4. Results and Discussion

4.1. Comparative Study of Materials

From a comparative analysis of materials found in the street furniture, the following categorization was established: at least 70% of the furniture is made of concrete, and the remaining 30% uses mixed materials such as concrete and low-carbon steel. This initial categorization was evaluated based on the monitoring of the eight interactive public spaces. As a second categorization, the initial and final strength of the concrete was measured using an Ultrasonic Pulse Hammer (UPV). This was done on two samples taken during the winter months of 2023-2024 and the summer months of 2023-2025 to determine its final strength (See Figure 4). For this purpose, concrete debris piled in a 4*4*16 cm test specimen was used as the standard sample.

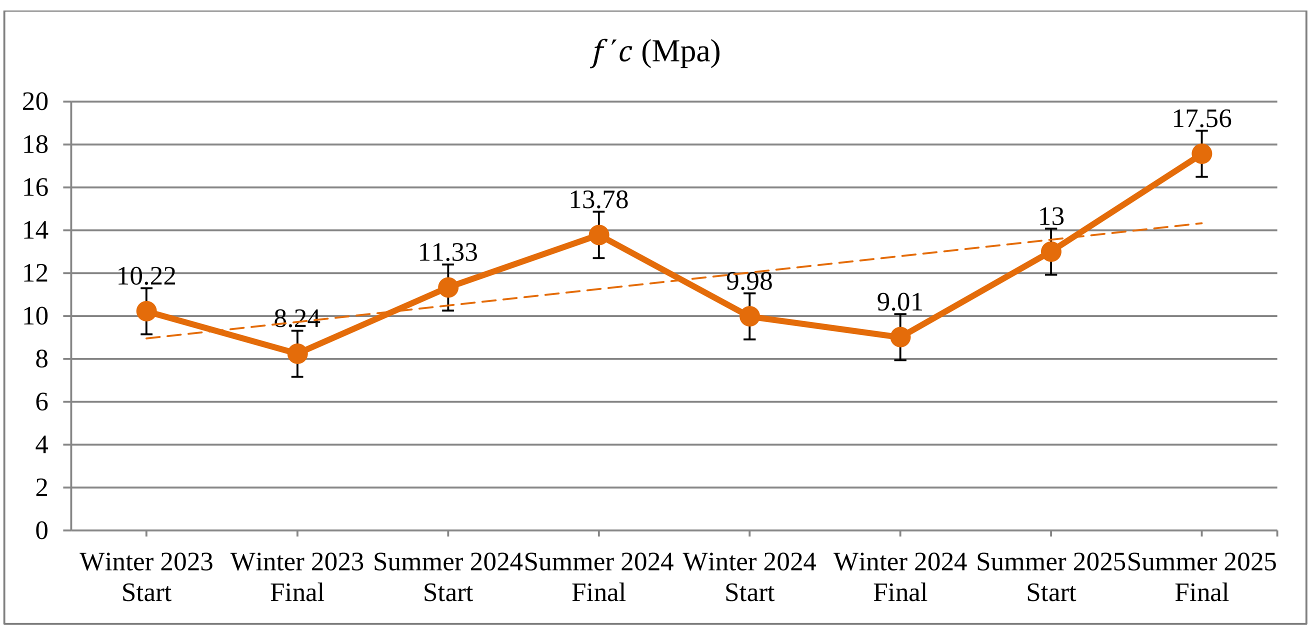
Fig. 4 Ultrasonic testing (UPV) for measuring the resistance of concrete specimens

The $f´c$ strength assessments estimated that the sample values are below 13 MPa in the initial summer period and generate a hardening of 15% at 27 and 45 days, reaching a peak hardening of 17.56 MPa at 6 months of the highest heat season. While the assessments in the winter period initially remain at 12.3 MPa, as the degree of saturation penetrates the concrete mix, significant spalling and porosity swelling exceeding 16.20% are evident, with pores larger than 2 and 5 mm per cm².

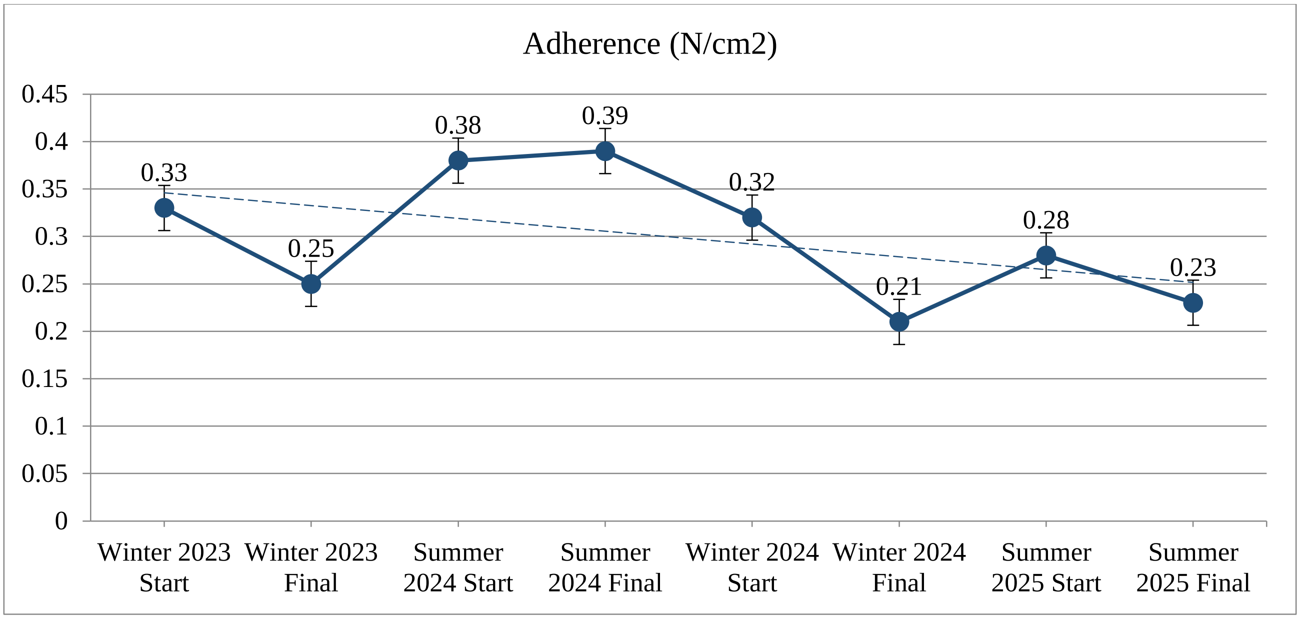
This leads to spalling of the concrete at its edges and important joints. The final sample at the peak of the winter season reduces the $f´c$ resistance of the concrete to 8.24 MPa, a non-load-bearing mixture that creates a danger when supporting dynamic and constant loads. Two additional measurements were analyzed: the level of concrete adhesion, measured by shear and tensile strength tests using an LCB shear test on layers of the specimen, and the level of workability of the concrete through the slump test (or Abram's cone test), which evaluates the consistency and fluidity of fresh concrete using a typical sample of each $f´c$ strength.

Table 3. Comparison of concrete strengths in winter cycles 2023-2024 and summer cycles 2023-2025

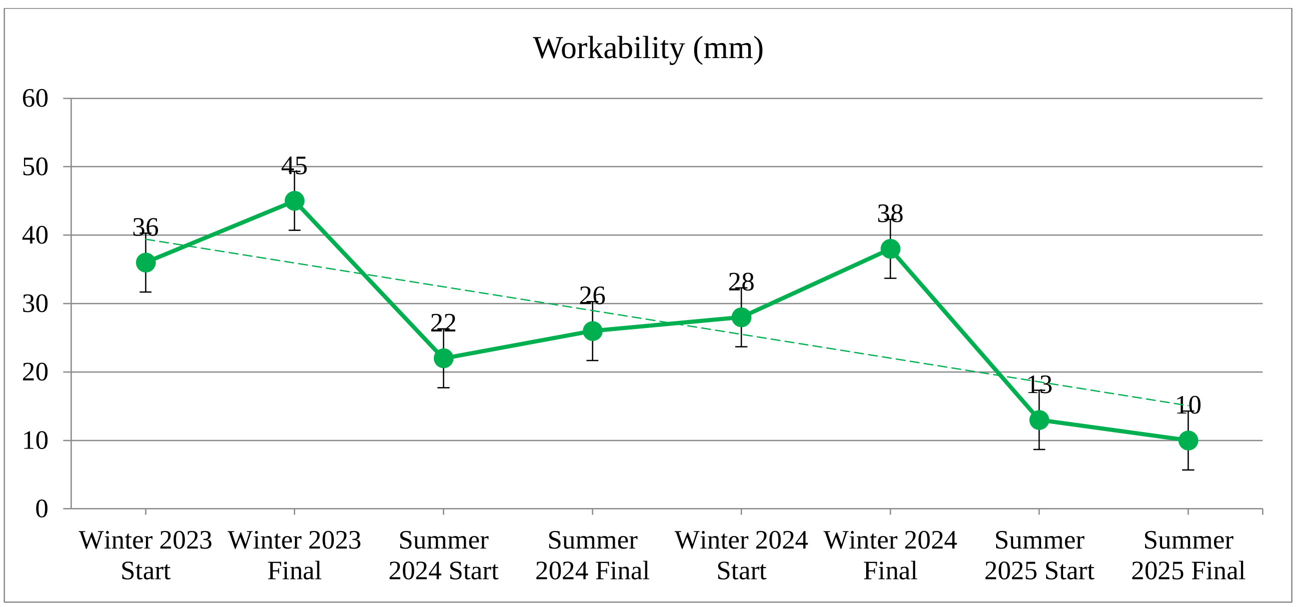
Sample Concrete Periods	$f´c$ (Mpa)	Adherence (N/cm2)	Workability (mm)
Winter 2023 Start	10,22	0,33	36
Winter 2023 Final	8,24	0,25	45
Summer 2024 Start	11,33	0,38	22
Summer 2024 Final	13,78	0,39	26
Winter 2024 Start	9,98	0,32	28
Winter 2024 Final	9,01	0,21	38
Summer 2025 Start	13,00	0,28	13
Summer 2025 Final	17,56	0,23	10



(a)



(b)



(c)

Fig. 5 Comparison of concrete strengths in winter cycles 2023-2024 and summer cycles 2023-2025

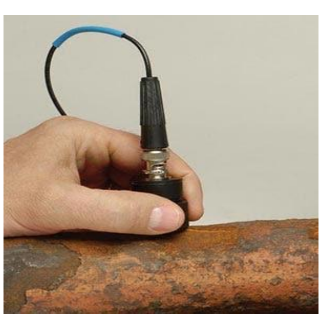


Fig. 6 Ultrasonic test (UPV-27 MG meter adaptation) to measure the resistance of steel samples

The low-carbon steel used in the construction of the furniture was analyzed using a similar test, adapting the equipment to indirect ultrasound measurement (See Figure 6).

To determine the strength of the steel, a comparative table of different types of steel and their standard strengths in Pounds per Square Inch (PSI) was used, which resulted in strengths well below the Spanish standard UNE-EN 1090 and the Ecuadorian Standard NEC for steel structures (See Figure 7).

Table 4. Tensile and yield strength of various metals, along with hardness and density values

Types of Metals	Tensile Strength (PSI)	Yield Strength (PSI)	Hardness Rockwell	Density (Kg/m3)
Stainless Steel 304	90000	40000	88	8000
Aluminum 6061-T6	45000	40000	60	2720
Aluminio 5052-H32	33000	28000	60	2680
Aluminum 3003	22000	21000	25	2730
Steel A36	80000	36000	64	7800
Stell Grade 50	65000	50000	68	7500
Low carbon steel (0.15%)	**18000**	**12500**	**10**	**4500**

Note*: For the measurement of these results, mechanical experimentation instruments were used to establish a comparison with standard measurements of other metals used in the Ecuadorian construction industry.

The pipe taps taken from the furniture for the samples (See Figure 6) showed that the steel in all samples exhibited partial or total layered corrosion.

Within this assessment, using data from researchers such as Rasti [26], which employs the International Standard ISO 2063, the classification of the degree of corrosion in an environment can be based on categories such as C1 (very low) to C5 (very high) and CX (extreme). Therefore, this table was used to categorize the corrosion level of the metal parts, with an additional measurement quantified in the sample years of 2023 and 2025, measuring the corrosion rate of the metal in units of microns per year (µm/yr).

Table 5. Comparison of corrosion degree in steel samples

Sample concrete periods	Level of corrosion	% Corrosion
Winter 2023 Start	C3	3,96
Winter 2023 Final	C5	5,25
Summer 2024 Start	C5	5
Summer 2024 Final	C5	5,35
Winter 2024 Start	C4	4,46
Winter 2024 Final	C4	4,98
Summer 2025 Start	C5	5,2
Summer 2025 Final	C5	5,89

The level of corrosion in the samples is categorized as very high (C5) in the testing process. This level of corrosion resulted in a 5.25% increase in material thickness, measured using ultrasound, demonstrating that constant exposure to heat and water caused the piece to expand in continuous cycles of deformation and corrosion [27].

4.2. Test Plan and Ideal Sample

The results were analyzed in 4*4*16 cm test specimens using a loose solids thermometer to determine the amount of recycled plastic aggregate in the mixture. The mix proportions were determined according to the parameters of the Spanish standard UNE-EN 13108-20 for aggregate mixtures, with a mixing ratio of 30% mix/60% mix/60% remainder/30% mix/30% remainder/30% mix.

Workability was determined using the parameters of the Spanish standard UNE-EN 13279-2 to measure the amount of total unmixed solids before pouring into the test specimens. Ranges of 1 to 5% aggregate were used in each dosage of PVC and HDPE to avoid a range greater than 10% aggregate, since the concrete used in furniture structures does not exceed a resistance of 17.52 MPa and therefore placing a greater amount of aggregate could weaken the workability and malleability of the mixture, which would significantly reduce the desired percentage of elasticity of the material type [28].

The test plan sought to characterize the best results in concrete by introducing PVC chips and HDPE spheres with thicknesses less than 1 mm into the mixture. It is demonstrated that each of the configurations was systematically fulfilled in the test plan detailed below:

Table 6. Mechanical characterization of the material with PVC + HDPE aggregate (a)

Test:	**Mechanical Characterization**					
Type of sample:	**PVC + HDPE + Concrete + Water**					
Dosages	**Test**	**Shore D Hardness Average**	**Flexion (Mpa)**	**Compression (Mpa) Average**	**Weight**	**Ultrasound**
E0,65 - REF	P1	60,40	3,5110	9,1210	291,50	69,10
		74,80				
	P2	74,00	5,0570	9,7180	288,40	70,40
		71,60				
	P3	45,80	2,7700	2,8120	220,70	81,00
		33,00				
E0,65 - 1%	P1	74,00	3,8475	10,0195	287,50	70,40

		69,40				
	P2	71,60 74,60	3,4899	10,6475	285,70	68,60
	P3	70,40 76,00	4,7297	6,8875	288,70	69,40
E0,65 - 2%	P1	75,40 70,60	4,1260	11,3730	287,80	69,00
	P2	76,00 73,80	3,2410	10,6950	283,50	69,50
	P3	71,20 76,00	4,0350	10,9030	283,50	69,00
E0,65 - 3%	P1	82,20 79,60	4,1460	6,4200	298,40	68,80
	P2	82,00 82,60	4,0000	10,5090	282,50	67,50
	P3	82,60 82,20	3,4590	10,4615	281,40	67,50
E0,65 - 4%	P1	84,60 81,40	4,2190	9,1880	278,00	67,80
	P2	81,40 83,60	4,5880	8,4645	290,50	68,10
	P3	83,00 81,60	4,6210	8,9015	282,30	66,70
E0,65 - 5%	P1	79,60 80,20	3,4115	8,9900	279,70	69,20
	P2	84,00 79,80	3,3344	8,3950	281,20	69,20
	P3	82,60 81,20	3,3029	9,4105	280,70	67,70

Table 7. Durability (Water/stove cycles) of the material with PVC + HDPE aggregate (b1)

Test:	**Durability (Water/stove cycles)**						
Type of sample:	**PVC + HDPE + Concrete + Water**						
Dosages	**Test**	**Cycles (x2)**					
		Dry Weight	**Submerged Weight**	**% Weight gain**	**Dry Weight**	**Submerged Weight**	**% Weight gain**
E0,65 - REF	P1	238,40	298,88	20,24%	217,20	220,60	1,54%
	P2	261,10	316,01	17,38%	198,93	201,80	1,42%
E0,65 - 1%	P1	321,70	371,46	13,40%	281,85	286,20	1,52%
	P2	341,30	387,53	11,93%	286,38	289,50	1,08%
E0,65 - 2%	P1	292,20	367,97	20,59%	278,68	288,00	3,24%
	P2	326,30	380,93	14,34%	280,90	290,40	3,27%
E0,65 - 3%	P1	297,42	387,89	23,32%	255,78	271,52	5,80%
	P2	286,82	378,00	24,12%	217,98	226,80	3,89%

E0,65 - 4%	P1	290,78	400,03	27,31%	232,62	240,02	3,08%
	P2	276,03	376,00	26,59%	248,43	251,92	1,39%
E0,65 - 5%	P1	283,82	399,20	28,90%	198,67	199,60	0,46%
	P2	279,07	388,44	28,16%	237,21	240,83	1,50%

Table 8. Durability (capilarity) of the material with PVC + HDPE aggregate (b2)

Test:	**Durability (Capillarity)**				
Type of sample:	**PVC + HDPE + Concrete + Water**				
Dosages	**Test**	**Cycles (x1)**		**% Weight gain**	**Heights reached**
		Dry Weight	**Weight after test**		
E0,65 - REF	P3	215,70	280,50	23,10%	3,33
	P4	231,60	287,90	19,56%	3,19
E0,65 - 1%	P5	284,84	314,87	9,54%	2,17
	P6	290,41	323,33	10,18%	2,00
E0,65 - 2%	P3	294,05	322,05	8,69%	2,20
	P4	296,66	318,77	6,94%	1,83
E0,65 - 3%	P3	282,56	312,97	9,72%	2,14
	P4	281,97	312,19	9,68%	1,85
E0,65 - 4%	P3	281,29	310,38	9,37%	1,80
	P4	295,15	325,02	9,19%	2,00
E0,65 - 5%	P3	279,19	312,04	10,53%	1,96
	P4	278,84	308,52	9,62%	2,02

Table 9. Durability (humidity / dry cycles) of the material with PVC + HDPE aggregate (b3)

Test:	Durability (Humidity/Dry Cycles)			
Type of sample:	PVC + HDPE + Concrete + Water			
Dosages	**Test**	**Cycles (x2)**		
		Initial Dry Weight	**Final Wet Weight**	**% Weight gain**
E0,65 - REF	P5	293,11	385,50	23,97%
	P6	238,17	354,10	32,74%
E0,65 - 1%	P3	285,16	375,70	24,10%
	P4	288,51	375,50	23,17%
E0,65 - 2%	P5	290,84	380,30	23,52%
	P6	288,65	375,50	23,13%

E0,65 - 3%	P5	302,76	375,00	19,26%
	P6	280,90	388,20	27,64%
E0,65 - 4%	P5	284,31	333,55	14,76%
	P6	283,15	320,11	11,55%
E0,65 - 5%	P5	279,00	380,23	26,62%
	P6	279,51	400,01	30,12%

Table 10. Flexural strength of the material with PVC + HDPE aggregate (c)

Test:	**Flexural strength**			
Type of sample:	**PVC + HDPE + Concrete + Water**			
Dosages	**Test**	**Footprint Diameter Average**	**Flexion (kN)**	**Weight**
E0,65 - REF	P1	8,00	0,1700	2052,60
E0,65 - 1%	P1	7,80	0,0800	2084,30
E0,65 - 2%	P1	7,52	0,1900	1972,17
E0,65 - 3%	P1	8,04	0,1600	2039,09
E0,65 - 4%	P1	7,46	0,2000	2024,62
E0,65 - 5%	P1	7,76	0,0900	2008,58

Table 11. Thermal behavior of the material with PVC + HDPE aggregate (d)

Test:	Thermal behavior				
Type of sample:	PVC + HDPE + Concrete + Water				
Dosages	**Test**	**Starting Weight**	**λ (W/mK)**	**Weight 2 h submerged**	**Total absorption**
E0,65 - REF	P1	293,11	0,058	368,15	75,04
E0,65 - 1%	P1	288,56	0,069	362,43	73,87
E0,65 - 2%	P1	301,22	0,064	378,33	77,11
E0,65 - 3%	P1	326,44	0,046	377,36	50,92
E0,65 - 4%	P1	330,2	0,075	414,73	84,53
E0,65 - 5%	P1	354,2	0,066	430,71	76,51

Major result   Minor result

The ideal sample is formed from the best results of the mix design, determined by dosages of between 3 and 4% of the aggregate percentages for each material (PVC and HDPE shavings in spheres less than 1 mm thick). These dosages, as determined by mechanical, thermal, and absorption tests, have demonstrated optimal workability and adhesion for climate and site adaptation, in accordance with the material specifications. The final test will measure the maximum elasticity of the concrete, the results of which are shown in the following formula.

(a) Concrete with a compressive strength of 17.52 MPa with 4% PVC and HDPE aggregate

$$Ec=4700\sqrt{17{,}52}\ \text{MPa}\approx 4700\times 4.19\approx 19693\ \text{MPa}$$

Studies show that the use of plastic aggregate can lead to an experimental elastic modulus different from that calculated using the standard formula. This results in an equation adjusted with the factor of:

$$Ec=3350f'c\sqrt{}$$

Obtaining a lower resistance, but a high elasticity index.

$$Ec=3350\sqrt{17{,}52}\ \text{MPa}\approx 3350\times 4.19\approx 14037\ \text{MPa}$$

(b) Concrete with a strength of 17.52 MPa with 3% PVC and HDPE aggregate

$$Ec=4700\sqrt{17{,}52}\ \text{MPa}\approx 4700\times 4.19\approx 19693\ \text{MPa}$$

Studies show that the use of plastic aggregate can lead to an experimental elastic modulus different from that calculated using the standard formula. This results in an equation adjusted with the factor of:

$Ec = 3950 f'c\sqrt{}$

Obtaining a lower resistance, but a high elasticity index.

$Ec = 3950\sqrt{17{,}52}\ \text{MPa} \approx 3950 \times 4.19 \approx 16551\ \text{MPa}$

5. Conclusion

In conclusion, the percentage of compressive strength decreases between 16,4 to 29%, which is considered normal within the context of materials where the stress-strain relationship is approximately linear, up to approximately 40-45% of their compressive strength ($f'c$) [29]. The results show a continuous elasticity level 22% better than traditional concrete, demonstrating that the properties of this hybrid material have significantly improved its resistance and tolerance to varying climates, making it more comfortable and functional for both the environment and the user. The modulus is closely related to the bond energies of the atoms. Bonding forces and the modulus of elasticity are greater in materials with a high melting point [30], obtained by the sample according to the specifications of the mixture used to obtain the sample.

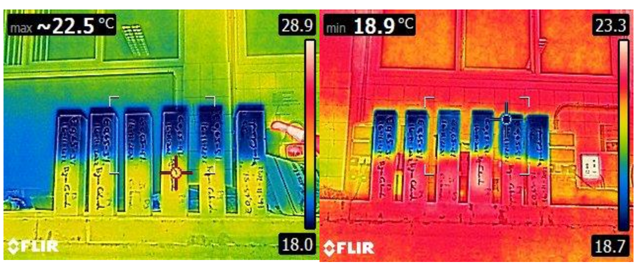


Fig. 7 Ideal sample subjected to a photometric camera to determine the degree of elastic deformation

A higher temperature in the material increases atomic vibration but does not generate excessive elastic expansion or deformation. Conversely, low temperatures do not decompose or internally affect the average elasticity of the material (See Figure 7). For metal parts, it is recommended to use A36-type steel with a carbon content of at least 0.30% and an anti-corrosive coating to extend its lifespan and prevent extensive corrosion. It is also recommended to use plastic connectors at joints to improve coverage and the overall fit of the furniture.

The tangible design of the furniture will incorporate HDPE material, resulting in a more flexible design that can include a foundation module with a 4% PVC aggregate in the base mix. This will generate a higher absorption level up to the immersion depth, which, according to the preliminary review, is 60 cm. Therefore, the HDPE and PVC content must be strictly limited to 3%. The scalability of the furniture module will include scalable aggregate immersions and flexible PVC joining pieces to improve material adhesion under immersion and excessive sun exposure. Future research aims to improve the material's elasticity to create more dynamic and innovative furniture and to incorporate greater amounts of recycled plastic to reduce local plastic pollution, resulting in designs made entirely from plastic waste.

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