# Ecoblock prototype, with recycled pet, styrofoam and ocoxal fibers

# Prototipo de ecoblock, con materiales reciclados de pet, unicel y fibras de ocoxal

CASTELÁN-URQUIZA, Demetrio†*

*Tecnológico Nacional de México/TES de Valle de Bravo, Programa de Arquitectura, Km. 30, Carretera Federal Monumento Valle de Bravo, San Antonio de la Laguna, 51200 Valle de Bravo, Méx.*

ID 1st Author: *Demetrio, Castelán-Urquiza* / **ORC ID**: 0000-0003-0250-7908, **CVU CONAHCYT ID**: 1166247

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D. Castelán

*demetrio.cu@vbravo.tecnm.mx

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**Abstract**

Eco-Blocks have become a low-cost construction material and a valid recycling method to reduce waste disposal in regions where industrial recycling is not yet available. Design and create a prototype of an ecological block using recycled materials such as PET, Styrofoam and natural ocoxal fibers, to increase the resistance to axial compression. The methodology was quasi-experimental, descriptive. Two prototypes of ecoblocks were designed, containing the same amount of materials such as cement, gravel, sand, varying the volume of the PET, Styrofoam and ocoxal fibers. Prototype 1 had the highest resistance to axial compression, achieving a result of 41.2708 kgf/cm$^2$, prototype 2 achieved a resistance of 32.8125 kgf/cm$^2$.

**Sustainable, Ocoxal, Compression**

**Resumen**

Los Eco-Blocks, se han convertido en un material de construcción de bajo costo y un método válido de reciclaje para reducir la disposición de basura en regiones donde el reciclaje industrial no está aún disponible. Diseñar y crear un prototipo de block ecológico utilizando materiales reciclados como el PET, el unicel y fibras naturales de ocoxal, para incrementar la resistencia a la compresión axial. La metodología fue cuasi experimental, descriptiva. Se diseñaron dos prototipos de ecoblocks, que contenían la misma cantidad de materiales como cemento, grava, arena, variando el volumen del pet, unicel y fibras de ocoxal. El prototipo 1 fue el que mayor resistencia a la compresión axial al lograr un resultado de 41.2708 kgf/cm$^2$, el prototipo 2 logró una resistencia de 32.8125 kgf/cm$^2$.

**Sostenible, Ocoxal, Compresión**

## Introduction

The project arises from the Interinstitutional Program for the Strengthening of Research and Postgraduate Studies in the Pacific (DELFÍN Program), during the stay of the XXVII Summer of Scientific and Technological Research in the Pacific, at the Tecnológico de Estudios Superiores de Valle de Bravo (TESVB). , in the Architecture Program, with students from the National Polytechnic Institute (IPN) at the high school level and a degree in Architecture and Civil Engineering, supported the design and construction of the ecological block prototype, with Materials and Technologies as their line of research. Alternatives for Bioclimatic Construction and Architecture.

The UN General Assembly adopted the 2030 Agenda for Sustainable Development, an action plan for people, planet and prosperity, which also intends to strengthen universal peace and access to justice. The member states of the United Nations recognize that the greatest challenge in the world today is the eradication of poverty and affirm that without achieving it there can be no sustainable development (UN, 2015). Within the 2030 Agenda for Sustainable Development, 17 objectives were established to achieve sustainable development, and in this specific case the aim is to collaborate in the development of objective 11: Sustainable cities and communities, which establishes: “Ensure that cities and human settlements are inclusive, safe, resilient and sustainable.”

Aczel, (2023), comments that sustainability has become one of the most powerful social movements of the last 40 years. However, many find it difficult to clearly articulate the meaning of sustainability due to its diverse applications. Sustainability in developed countries tends to focus on actions that generate small changes in existing behavioral patterns rather than fundamental social changes.

Cities around the world are developing strategies to deal with heat waves, extreme cold, floods, wildfires, hurricanes, earthquakes, droughts, pandemics and other disasters caused by climate change. To this end, a theory of resilience is being expanded and applied as a methodology to ensure social and spatial systems that respond to climate change while providing habitats and ecological spaces for more diverse human activities (Jun and Song, 2023).

Rajagopal, (2023), in his research comments that creative entrepreneurs build and shape their business activities within their competencies and abilities consistent with their personalities. This synchronization in entrepreneurial mindset and competitiveness in entrepreneurial traits stimulates entrepreneurial growth within the industry. Creative entrepreneurs invest in value co-creation with their key partners to promote circular entrepreneurship in the agricultural and non-agricultural sectors to address key environmental challenges.

Ismail, (2023), comments in his research that less economically developed countries (LDCs) are struggling to meet the demand for affordable housing in their growing cities. There are several reasons for this, but an important limitation is the high cost of construction materials, these challenges with a set of strategies for the design and analysis of materially efficient concrete elements that can reduce the economic and environmental costs of urban construction.

Various authors have investigated ecoblocks such as their importance and different physical and mechanical characteristics, Ortiz-Castellanos et al. (2020), Núñez Crisanto (2021), Sánchez (2019), Puchoc Amaya and Lagua Pilla (2020), Maure et al . (2018), Hossain et al. (2021).

Chaka et al., (2023) investigated the use of natural false banana fibers and sisal fibers, in recycled plastics, resulted in the production of cheaper and more effective tile composites, and a reduction in environmental pollution.

Barragán-Alturo et al., (2017), analyzed how to reduce the costs caused by a conventional block when it is produced, through comparison with an eco-block made with PET bottles.

Sriprom et al., (2022), successfully developed a novel composite of reinforced recycled expanded polystyrene foam (r-EPS) and natural fiber. EPS was recycled by dissolution method using accessible commercial mixed organic solvent, while natural fibers, i.e., coconut shell fiber (coir) and banana stem fiber (BSF), were used as reinforcing materials.

Li, (2022), investigated plastic bottle bricks, the most popular type of ecobricks, are created by putting filled inorganic materials such as sand into polyethylene terephthalate (PET) plastic bottles.

Triyono et al., (2023), investigated the properties of the resulting solid polystyrene products from recycled polystyrene waste and determined the optimal temperature of the thermal extrusion treatment process to be carried out compared to the characteristics of the original polystyrene based on in the results of traction and impact tests.

Zakharov, (2023), investigated the use of polystyrene as an effective thermal insulating material in three-layer load-bearing and enclosing structures of reinforced concrete residential buildings.

Bedanta et al., (2022), analyzed polystyrene aggregate concrete was produced by partially replacing coarse aggregate in reference concrete mixes (normal weight) with an equal volume of chemically coated crushed polystyrene granules.

Currently, new ways of doing Architecture are changing so as not to sacrifice nature, beginning to not only see the comfort of users but also taking into account biodiversity; This leads architects to look for ways to be responsible with the environment and be able to adapt projects to the new trends that are innovating architecture. We can understand the environment as the union of natural, social and cultural values that exist in a given place and time, which influence the material and psychological life of man and the future of generations. That is, it is not only about the space in which the life of living beings develops. It also covers human beings, animals, plants, objects, water, soil, air and the relationships between them.

**Approach to the problem**

The environment is increasingly deteriorated by the human activities that take place daily. Which leads to a deterioration in the planet's ecosystems, as well as in the health of the living beings that occupy the earth. This is why concern about environmental problems is increasing and becoming widespread.

In addition to the above, in recent years the planet has experienced the scientific and technological advance of humanity, science has been able to provide us with new alternatives in different areas of daily life but it also brings with it certain negative consequences such as the pollution produced. due to the excessive use of materials that do not have biodegradable characteristics and that after their use end up in places that affect public health and biodiversity.

For this reason, many organizations have begun to take actions in order to implement sustainable alternatives that help conserve our planet. One of them is the well-known sustainable development. To achieve sustainable development, certain definitions must be taken into account, such as sustainability itself, which consists of a process that aims at the responsible use and exploitation of natural resources, avoiding their depletion. Sustainability is a process that can be applied within different areas of daily life, one of them is construction. Various options have been taken into account that could implement materials such as PET, where its use would focus on the area of recycling. PET recycling has multiple advantages that can be used in different materials or construction processes in the construction industry.

Bioclimatic architecture in conjunction with sustainability seeks to create alternatives that lead us to the use of materials that, due to their excess production and single use, affect the environment, taking into account the climatic and physical conditions of the region, seeking solutions to factors that affect constructions such as humidity. Currently there are various alternatives in terms of construction processes which provide practical and viable solutions for the environment where they are applied, helping the environment, in addition to the construction advantages they have. One of these alternatives is the construction of blocks that seek to take advantage of various materials that are commonly wasted, including them in their composition so that they resist and comply with the specifications provided by the regulations. This alternative is known as ecoblock. Eco-Blocks have become a low-cost construction material and a valid recycling method to reduce waste disposal in regions where industrial recycling is not yet available.

Industrial processes are usually the largest polluters on the planet, either due to the emission of gases that are produced during the process or due to the waste they generate. Although the construction industry is the engine of economic development, it is also the main source of environmental pollution. One of the most polluting industries is block production, which uses a lot of coal and materials such as rubber to generate energy. According to the United Nations Environment Programme, the production of construction materials contributes up to 30% of global greenhouse gas emissions and consumes 40% of all energy.

In Mexico, as in other regions around the world, there are natural factors that affect construction in various ways, one of them and the most important is the climate, which is why various options have been implemented that take these conditions into account. One of them is bioclimatic architecture, which proposes solving problems such as humidity. This, together with sustainability, seeks to create alternatives that give us advantages when creating new construction materials and that at the same time meet the criteria that current regulations require for it to function correctly. An increase in the waste of materials such as plastic has also been observed. Alternatives have been thought of to take advantage of these products within different areas, thus promoting sustainable development, so that we can satisfy current needs, but at the same time conserve the future of generations that will share the same space that we currently enjoy.

The implementation of alternative technologies or ecotechnics are technological innovations that seek to guarantee the care and preservation of the environment through the design, creation and implementation of devices, to preserve and restore the balance between the environment and human activity. They focus on solving environmental problems that must necessarily be addressed. Taking these problems into account, this project proposes a block prototype that provides great help to the environment, trying to take care of the ecosystem by recycling polluting materials in a combination of organic materials from the region. This project seeks to design and manufacture a block based on cement, a crushed product of PET (polyethylene terephthalate), Styrofoam (expanded polystyrene) as well as natural fibers (ocoxal), the main purpose is to study various compositions, varying the percentages of the materials additional tests and perform different compression resistance tests and know their physical properties.

**Justification**

The purpose of this project is to make the most of materials such as PET, ocoxal and Styrofoam, materials that are normally destined for landfills and only a minimum percentage is recycled correctly. The proposal to create an ecoblock prototype is a great opportunity to solve the regional environmental problems that we face today.

On the other hand, the construction field needs innovative and sustainable products to face natural phenomena such as climate, earthquakes, among other factors. Therefore, elements are sought that have adequate resistance and that have the appropriate physical properties to satisfy the needs of the industry. With the creation of new construction methods, proposals for construction materials for sustainable housing are sought, which also meet the physical and mechanical characteristics necessary to support the necessary loads to which they will be subjected according to their structural use.

**Background**

Bioclimatic architecture can be defined as architecture that focuses on the design and construction of buildings taking into account the climatic conditions of the region or country in which it is being built, and also focuses on the use of available natural resources (sun , vegetation, rain, wind) to reduce as much as possible the environmental impact generated by construction and energy consumption. The objective of bioclimatic architecture is to design buildings that are capable of changing their environmental behavior according to the conditions of each season of the year. This in order to provide greater comfort to its occupants.

This type of architecture is based on the importance of providing the construction with thermal and acoustic comfort, as well as controlling CO2 levels.

Its main features are:

– The orientation: it is designed taking into account the position of the sun to make the most of sunlight.

– Sunlight and sun protection: at this point and depending on the region in which it is being built.

– Cross ventilation: with the aim of creating good ventilation in all areas of the building.

For the construction of a project, a wide variety of materials are taken into account; these are chosen according to the project requests, the conditions of the place, among other factors. Construction materials are used in large quantities, so the raw materials must be low-cost and easily acquired. One of their main characteristics is that they must last over time and environmental conditions. In addition, they must meet other requirements, such as mechanical resistance, fire resistance or ease of cleaning.

Bricks are currently considered a polluting material since, among other things, they require a lot of energy to manufacture, which is why they generate a significant environmental impact. On the other hand, this does not happen in those ecological bricks also called ecobricks. However, its use today is very rare, even though historically ancient civilizations have used sustainable materials in construction. Therefore, ecological bricks are those bricks manufactured from materials or through processes that do not have as significant an environmental impact as conventional bricks. Within ecological bricks, there are some that are more ecological than others according to their sustainability in various aspects. These bricks can offer us the same or greater resistance than conventional bricks and even offer the same advantages in comfort and safety, depending on the materials chosen for their construction.

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Due to the benefits that the ecoblock offers us, the natural resources found in the region were implemented, taking advantage of the existing polymers without affecting biodiversity, which is why ocoxal was implemented, a material discarded by the pine trees themselves and that if removed from its place of origin does not affect the region or its inhabitants.

**Theoretical framework**

PET is a plastic resistant to microbiological attack, due to this characteristic in PET there is no proliferation of bacteria, fungi or parasites related to putrefaction. Being non-biodegradable, it maintains its characteristics over time, which provides it with a long useful life (Muñoz, 2012).

UNICEL is a petroleum derivative, whose scientific name is expanded polystyrene. It is a plastic to which air is introduced into its mass, forming bubbles, a process known as foaming, so its composition is 5% raw material 5/7 and 95% air. It is identified by an equilateral triangle and the number 6 in the central part, in addition to the letters PS. It is important to clarify that this material is 100% recyclable.

In Mexico there are already alternatives and technologies for the proper management of this waste. Expanded polystyrene (EPS) geofoam is a lightweight material that has been used in engineering applications since at least the 1950s. Its density is about one-hundredth that of soil. It has good thermal insulation properties with stiffness and compressive strength comparable to those of medium clay. It is used to reduce settlement under embankments, dampen sound and vibrations, reduce lateral pressure on substructures, reduce stresses in buried rigid conduits and related applications. Expanded polystyrene waste in granular form is used as lightweight aggregates to produce lightweight structural concrete with unit weight varying from 1200 to 2000 kg/m³ (Bedanta et al., 2022).

OCOXAL is a very Mexican material, in fact the word “Ocoxal” comes from the Nahuatl “ocotl”: ocote and “Xalli”: sand, it can be said then that ocoxal means ocote sand. This material is also known as: acochal, ocojal, cochal, coxal, acoxal, cojal and is called “xibatji” in Mazahua. It comes from leaves or needles that come off some varieties of pine. The most suitable and used variety is white pine (Pinus montezumae Lamb.). However, red pine (Pinus patula) and straight pine (Pinus pseudostrobus Lindl.) are also used. They are collected from the ground, when they have completed their cycle once they have their characteristic brown color. Generally, dry pine leaves are collected between November and March (Artesanal, 2021).

**Hypothesis**

The ecoblock with recyclable materials such as PET and Styrofoam, together with the natural ocoxal fibers, will increase its resistance to compression stress, as well as provide acoustic and thermal properties.

**Objetives**

**General**

Design and create a prototype of an ecological block using recycled materials such as PET, Styrofoam and natural ocoxal fibers to improve and take advantage of its mechanical characteristics, complying with current regulations on the resistance of materials and being able to use it as an alternative construction material.

**Specific**

- Implement a way to recycle excessively used materials that have a late degradation time, such as PET and Styrofoam.

- Take advantage of the region's natural fibers such as ocoxal for the construction of an ecological block prototype
- Evaluate the materials that will be the components of the ecoblock in order to enhance the characteristics of the prototype and know the advantages that the additional materials give it.
- Design a prototype of an ecological block using recycled materials with the intention of improving their physical and mechanical properties, so that they can be used effectively in construction.

**Materials**

The materials that were used for the construction of the prototypes were from the region of the Municipality of Valle de Bravo, State of Mexico.

- Portland cement.
- Gravel.
- Sand.
- Water.
- PET.
- Unicel (extended polystyrene).
- Ocoxal.

**Tools**

- Weighing machine
- Test tube
- Flat shovel
- Trowel
- Vernier
- Plastic buckets

**Machinery**

- Vibro-Blocquera Machine
- Universal Machine

**Methodology**

The methodology is quasi-experimental since it will adhere to the Mexican standard NMX-C-441-ONNCCE-2013 (ONNCCE, 2013), Construction Industry - Masonry - Blocks, partitions or bricks and partitions for NON-structural use - Specifications and test methods; for the realization of variables of the ecoblock prototype. This Mexican standard establishes the specifications and test methods to be met by non-structural blocks, partitions or bricks and partitions.

The classification of pure experiment is chosen because the results of this work will be based on the tests that will be carried out on the prototypes to be carried out. Thus, experimentation will be carried out controlling the quantity variables of materials (PET, Styrofoam and Ocoxal) in a control group. The classification of the standards of the Ministry of Communications and Transportation (SCT); of cement blocks, partitions and partitions described in N-CMT-2-01-002-02; the dimensions of the ecoblock prototype made from PET, Styrofoam and natural fibers from Ocoxal.

Length: 40cm;
Width: 12cm;
Height: 20cm.

Entering the following description: Solid cement block of Quality Grade “A”; Suitable for non-structural interior and exterior walls.

Likewise, the product must comply with the resistance values described in the Mexican standard NMX-C-441-ONNCCE-2013:

Medium Resistance: 35 kg/cm2;
Minimum resistance: 28 kg/cm2

**Results**

**Dosage (concrete block)**

The dosage was taken 1:5:2 (cement, sand, gravel), taking these data into account, the development of 4 prototypes was contemplated; 2 of these were made with ocoxal from which the leaf bearing was removed, the percentage added of this material to one of the prototypes was 0.54%, which is equivalent to 72 grams. For the other 2 prototypes, complete ocoxal was chosen; each of the prototypes in this section corresponds to a percentage of 0.8% equivalent to 106.6 grams of this material. For both sections, ¾" gravel was used; For a block, a gravel percentage of 24.962% (3,319.9 grams) is taken into account.

Finally, regarding PET, 214.5 grams were used for each of the prototypes, a percentage of 1.6%.

Unit quantities:

Cement = 1.66 kg + 10% waste = 1.826 kg
Sand = 8.31 kg + 2.286% waste = 8.5 kg
Gravel = 3.32 kg
Unicel = 0.02765 kg
Pet = 0.2145 kg

Percentages of each block

Cement = 12.5%
Sand = 62.5%
Gravel = 24.962%
Unicel = 0.208%
Pet = 1.6%

Of the 4 prototypes made, 2 of them have the following amounts of water and ocoxal, while the amounts of the other elements remained the same.

Prototype 1
Water = 4 liters.
Ocoxal = 213.2 gr.

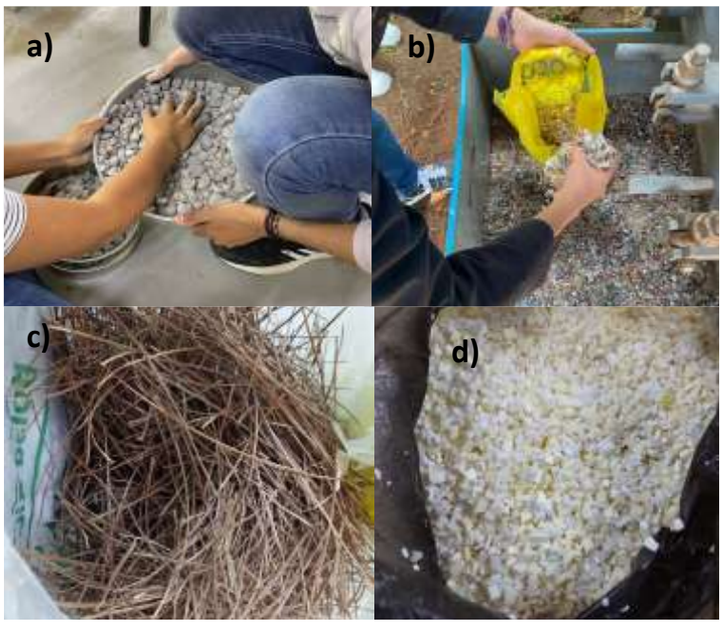
Prototype 2
Water = 5 liters.
Ocoxal = 144 gr.

**Experimental development**

The experimental process consists of several stages which allow the elaboration of the ecoblock prototypes, from the dosage of the materials for the mixtures, the weight of the materials, preparation of the mixtures, compaction and preparation in the vibroblock of the ecoblock and the tests. absorption and compression stresses.

Figure 1 shows the selection of the different materials used to make the ecoblock, coarse aggregate materials (3/4" gravel), sand, crushed pet flakes and Styrofoam (expanded polystyrene).

**Figure 1** Materials collection process: a) aggregate materials, b) Pet, c) Ocoxal, c) Unicel (expanded polystyrene)




*Source: Own Elaboration*

Figure 2 shows how the different materials were weighed on the scale for the dosages of the two ecoblock prototypes.

**Figure 2** Materials weighing process

*Source: Own Elaboration*

**Preparation of mixtures of ecoblock prototypes.**

The surface where the mixture was made was moistened so that it did not absorb water from the mixture. Gravel, sand and cement were added first, and then a homogeneous mixture was made to add the PET materials, Styrofoam and the natural ocoxal fibers. the amount of water calculated for each ecoblock, in Figure 3, the preparation of the mixture of the first prototype is shown and in Figure 4, the preparation of the mixture of the second prototype.

**Figure 3** Mixing process for the first prototype

*Source: Own Elaboration*

**Figure 4** Mixing process for the second prototype

*Source: Own Elaboration*

After preparing the mixture for each ecoblock prototype, the mixture was poured into the molds of the vibro-block maker for compaction as shown in Figure 5.

**Figure 5** Production process of the two ecoblock prototypes in the vibroblock machine

*Source: Own Elaboration*

In Figure 6, the first prototype that contains the ocoxal fiber without leaf bearing is presented. The physical characteristics of the prototype can be observed, which shows pores and rough surfaces.

**Figure 6**. Ecoblock with ocoxal leaf bearing.

*Source: Own Elaboration*

In Figure 7, the second prototype that contains the ocoxal fiber with leaf bearing is presented. The physical characteristics of the prototype can be observed, which shows few pores and uniform surfaces.

**Figure 7** Ecoblock with ocoxal leaf bearing

*Source: Own Elaboration*

In Figure 8, you can see how the different prototypes of ecoblocks were weighed on the scale, the first being denser than the second prototype.

**Figure 8**. Ecoblock weight measurement process.


*Source: Own Elaboration*

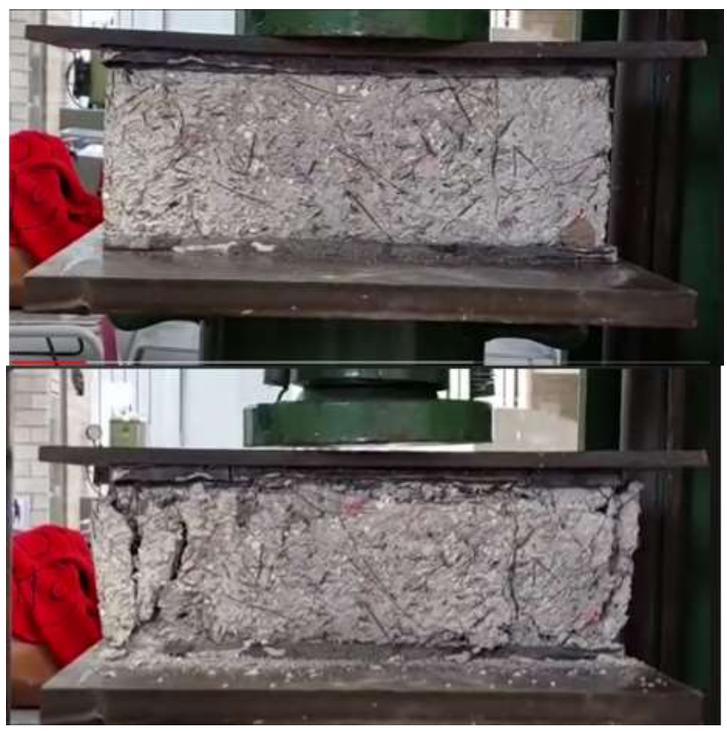
Figure 9 shows the application of water to cure the ecoblocks, for their subsequent compression stress test.

**Figure 9** Application of water with a spray bottle for curing the ecoblocks

*Source: Own Elaboration*

Figure 10 shows the axial compression stress test to which the prototypes of the ecoblocks were subjected in the universal machine, showing the detachment of the material from the ecoblock.

**Figure 10** Axial compression test on the universal prototype machine.



*Source: Own Elaboration*

**Results of prototype I - (With leaf bearing)**

For this prototype, the ocoxal was cleaned with chlorine and water, allowed to dry and then mixed with the other elements. For this section, a dosage of 1:5:2 was used, with an addition of 4 liters of water.

A resistant block was obtained with the ocoxal fibers scattered throughout the block, some of them appear outside of it, the leaf bearing caused them to remain united in the same place. However, this in turn caused some small gaps to occur in the block.

**Prototype II Results - (No Leaf Bearing)**

For the second prototype, the leaf bearing was removed from the sheet, cleaned with bleach and water, and allowed to dry for about 24 hours. For this section, the same dosage of materials was used, but with an addition of 5 liters of water.

A firm and heavy block with relief was obtained due to the amount of water used. When removing the leaf bearing, the ocoxal spread throughout the block, which caused it to present fewer voids than the other section.

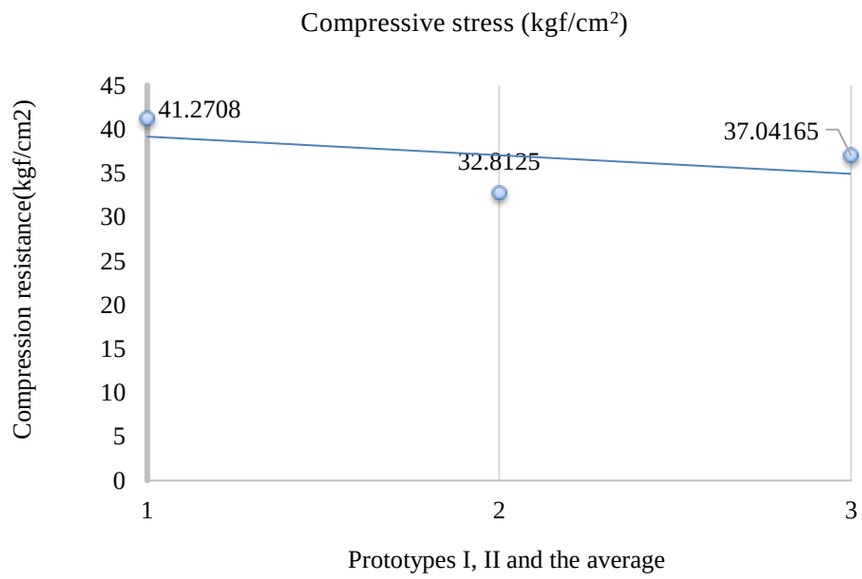
**General results:**

Absorption test:

Prototype I = change from a weight from 15 kg to 18 kg, having a weight greater than the initial one of 3 kg, Prototype II = change from a weight from 15 kg to 17 kg, having an increase of 2 kg.

Graph 1 shows the results of the compressive strength test of Prototype I = resistance of 41.2708 kgf/cm2, Prototype II = resistance of 32.8125 kgf/cm2 and the Average of the two prototypes = 37.0416 kgf/cm2, with these data it can be inferred that only prototype 1 is the one that achieved a resistance greater than that referred to in the NMX-C-441-ONNCCE-2013 standard: Average Resistance: 35 kg/cm2; Minimum resistance: 28 kg/cm2.

**Graph 1** Axial compression test on the universal prototype machine.




*Source: Own Elaboration*

**Conclusions**

According to current regulations, prototype 1 of the ecoblock met the resistance greater than 35 kgf/cm2, since it is more homogeneous, and contains less natural ocoxal fiber and water, which increased its compressive stress, this was a characteristic for which it met the test. These ecoblock designs are not for structural use since by adding recycled materials such as PET and Styrofoam, as well as natural ocoxal fibers, their compression resistance is reduced, causing them to fracture when used in confined load-bearing walls (structural).

Its application and use is recommended on non-structural walls that do not support loads, such as dividing walls (diaphragm walls), for low-rise architectural projects. The research only focused on the design and construction of ecoblock prototypes with the addition of materials such as PET, Styrofoam and natural ocoxal fibers, which in future research can vary the percentage of materials to increase their resistance to compressive stress.

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