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Hydraulic concrete design with addition of natural ocoxal fiber (pine needle)

Diseño de concreto hidráulico con adición de fibra natural de ocoxal (acícula de pino)

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Abstract

Conventional concrete has relatively low tensile capacity and ductility and is therefore susceptible to cracking. Determine the result of the addition of natural ocoxal fiber (pine needle) in hydraulic concrete to the axial compressive stress. The general method was scientific, the type of research was applied, the level was explanatory and the design was quasi-experimental. The population corresponded to three specimens of concrete cylinders with 10%, 15% and 20% addition of natural ocoxal fibers by volume. The axial compression strength test was only carried out 28 days after setting. Cylinder #1 containing 10% volume of ocoxal was the one that achieved the lowest result with an f'c= 101.50 kgf/cm^2, cylinder #2 with 15% volume of ocoxal achieved an f'c= 140.43 kgf /cm^2 and cylinder #3 with 20% volume of ocoxal achieved the highest f'c= 150.54 kgf/cm^2, the average of the three cylinders was f'c=130.8 kgf/cm^2.

Pine needle (ocoxal), Compressive stress, Concrete

Resumen

El hormigón convencional tiene una capacidad de tracción y ductilidad relativamente bajas y, por tanto, es susceptible a agrietarse. Determinar el resultado de la adición de fibra natural de ocoxal (acícula de pino) en el concreto hidráulico al esfuerzo de compresión axial. El método general fue el científico, el tipo de investigación fue aplicada, el nivel fue explicativo y el diseño fue cuasi experimental. La población correspondió a tres especímenes de cilindros de concreto con 10%, 15% y 20% de adición de fibras naturales de ocoxal en volumen. La prueba de resistencia a la compresión axial sólo se realizó a los 28 días de fraguado. El cilindro #1 que contiene el 10 % de volumen de ocoxal fue el que menor resultado alcanzó con un f´c= 101.50 kgf/cm^2, el cilindro #2 con un 15% de volumen de ocoxal logró un f´c= 140.43 kgf/cm^2 y el cilindro #3 con un 20% de volumen de ocoxal logró el mayor f´c= 150.54 kgf/cm^2, en promedio de los tres cilindros fue de f´c=130.8 kgf/cm^2.

Acícula de pino (ocoxal), Esfuerzo compresión, Concreto

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Introduction

The durability of a concrete infrastructure is defined by its ability to maintain reliable levels of serviceability and structural integrity under potentially harsh environmental exposure without the need for significant repair intervention throughout its design life.

Conventional concrete has relatively low tensile capacity and ductility and is therefore susceptible to cracking. Cracks are considered to be ways for harmful gases, liquids and solutes to enter the concrete, causing the early appearance of deterioration processes in the concrete or reinforcing steel (Paul et al., 2020).

Chen et al., (2023), conducted a literature review of natural fibers and their use in concrete, reaching the conclusion that to reduce the carbon footprint of traditional concrete materials, concrete with natural fibers is vital. . The findings indicate that natural fiber reduces the cracking rate of concrete, increasing tensile strength. Although fibers improve the distribution of stresses within the concrete, increasing its stability, reducing compressive strength, natural fiber concretes present considerable environmental benefits; The studies reviewed indicate effective economic and social sustainability, respectively.

Abdalla et al., (2023), states in their research that the use of fibers has increased enormously to create significantly robust structures. For sustainable and zero-waste development, manufactured fibers can be replaced with natural fibers without compromising requirements.

Hamada et al., (2023), comment that plant fibers play a crucial role in reinforcing the mechanical behavior of cement concrete, especially tensile and flexural strengths. The important disadvantages of natural fibers are the relatively high moisture absorption and hydrophilic behavior, which results in reduced bonding between the concrete matrix and the fibers and therefore affects the overall performance of the concrete material.

Ahmad et al., (2022), concluded in their research that jute fibers improved the aspect of strength and durability, but decreased the fluidity of concrete in a similar way to synthetic fibers. However, little research is available on the durability of jute fiber reinforced concrete. Furthermore, the optimal percentage of jute fiber in concrete is essential as the higher dosage negatively affects the strength and durability characteristics due to lack of fluidity.

Veigas et al., (2022), explored the use of sisal fiber. To address the potential degradability of this natural fiber, two different coatings were examined, i.e., polyester resin and bio-based shellac. To this end, several mixtures made with a variety of sisal fiber dosages, including coated and uncoated sisal fibers, were investigated. The study explored the mechanical properties of the developed mixtures through compression, tensile and flexural strength tests. From the results obtained, notable improvements were observed in the main resistance properties, compared to mixtures that did not contain fibers.

Boumaaza et al., (2022), comments that the results indicate that the treatment of the fibers improves adhesion in the mortar matrix systems of composite materials obtained. It increases its water absorption capacity and decreases its thermal conductivity, thus contributing to heat absorption and, above all, its durability.

Recently, the addition of various natural fibers to high-strength concrete has sparked great interest in the field of construction materials. This is because natural fibers are much cheaper and available locally, compared to synthetic fibers (Shah et al., 2022).

Jamshaid et al., (2022), states that the water absorption capacity of concrete reinforced with natural cellulosic fibers decreased substantially; however, it increased with the percentage of fiber loading. Natural fiber reinforced concrete can be used commercially for interior or exterior pavements and floor slabs as a sustainable building material for the future.

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Kurpińska et al., (2022), reviewed the properties of cement composites reinforced with short fibers, investigated the effect of natural fibers: cotton, sisal, jute, ramie, bamboo and synthetic fibers: polymer and polypropylene. It was observed that the fibers change the consistency of the mixture. In flexural strength testing of composites, a change in strength was noted. It had a positive effect on the compressive strength, in addition, the chemical composition, diameter and total length of the fibers of the element have an impact on the shrinkage of the composite. Fiber-containing composites showed higher water absorption compared to fiber-free samples. The exception is ramie fibers, which reduce water absorption.

Organic fibers such as coconut fiber, palm, kenaf, jute, sisal, banana, pine, sugar cane and bamboo, were studied by several researchers as construction materials that can be found in pulp cement, mortar and concrete. Results with low fiber were observed to be the most promising (Shadheer Ahamed et al., 2021).

Delgado Zambrano & Delgado Benavides, (2023), state that the use of natural fibers (banana, pineapple, coconut, sawdust and fique) as reinforcement in construction materials, specifically as a replacement for synthetic fibers in reinforced concrete, has been increasing in recent years due to its mechanical, economic and environmental benefits, opening a new field of research in the industry. In addition to these benefits, these fibers are biodegradable, abundant and can be classified as organic waste of industrial origin.

Awwad et al., (2011) indicated that the use of natural fibers (fibers from industrial hemp, palm and banana leaves) resulted in a reduction in the amount of coarse aggregate without affecting the flexural performance of the concrete. However, no clear trend was determined in the compressive strength test results of the cubes.

Steel, glass or polymer fibers are viable but expensive alternatives. Natural fibers may be a real possibility for developing countries, as they are available in large quantities and represent a continuous renewable source. The fiber is mainly affected by the alkalinity of the concrete matrix.

The durability of the composite will then depend on the protection that the fiber has and the impermeability characteristics of the matrix (Juárez Alvarado et al., 2004).

Chen, C., & Chen, R. (2023), investigated the use of magnesium oxide (MgO) in hydraulic concrete in the following projects in China: Baishan Hydropower Station unexpectedly discovered the beneficial effects of MgO; Dongfeng Hydropower Station actively used MgO as a blowing agent for the first time in the main project; Changshaba Hydropower Station used the blowing agent MgO in a full-arch dam for the first time; Huangjiazhai Hydropower Station exceeded 6% MgO content for the first time in concrete in normal state; and the Dahe deposit exceeded 6% MgO content in roller-compacted concrete for the first time.

Tian et al.,(2023), analyzed as an intrinsically self-sensing material, carbon fiber concrete has promising structural health monitoring applications. Investigating the long-term stability of carbon fiber concrete in terms of resistivity changes under the influence of factors such as aging effects and environmental conditions may help evaluate its viability for long-term monitoring applications.

Li et al., (2023), investigated the aggregate grading design of asphalt concrete. As fine aggregates and coarse aggregates perform different functions in an asphalt mixture, coarse aggregates (2.36–19 mm) and fine aggregates (0.075–2.36 mm) were considered differently for grading design. According to the interference theory, the optimal skeleton gradation of coarse aggregates was determined by step-by-step filling vibration compaction. For the gradation of fine aggregates, a mathematical model was obtained based on the fractal theory of gradation and the Dinger-Funk equation.

Emamjomeha et al., (2023), in their research the study was designed and implemented to evaluate the effects of silica fume, zeolite and blast furnace slag (BFS) on engineering cementitious composites and to compare the mechanical properties and the durability of polyvinyl alcohol-ECC (PVA-ECC) and polypropylene

Huaquisto et al., (2023), in their research evaluated the physical-mechanical behavior of hydraulic concrete with additions of fibers from PET plastic bottles and natural river aggregates. The concrete was evaluated in the fresh state using Slump and in the hardened state using density and compressive and flexural resistance, for which cylindrical and prismatic specimens were prepared with PET fibers in proportions of 2%, 4%, 6%. and 8% by weight of cement plus the standard concrete designed for 21 MPa. It was found that the slump and density of concrete decreased with the addition of PET fibers.

Theoretical framework

Cemex-Tolteca Extra brand CPC-30R Portland gray cement

Figure 1 shows CPC 30R Extra Cement is specially formulated to reduce the appearance of plastic shrinkage cracks in concrete exposed to extreme environmental conditions, improve the consistency of the mixture, produce a mixture that is easier to handle and avoid the process curing, a unique product on the market. CPC 30R Cement meets the specifications of the Mexican standard NMX-C-414-ONNCCE.

Figure 1 Bulk of extra gray Portland type cement, CPC-30R, CEMEX-Tolteca Brand
Source: Own elaboration

Applications

CPC 30R Extra Cement is special for exposed surfaces such as pavements and slabs, it is recommended for structural uses of reinforced or simple concrete (such as floors, castles, dalas, walls, footings, girders, columns) and/or masonry (branching, similar , repairs, pasting). It is compatible with conventional materials used in construction, achieving excellent results.

Characteristics

Mechanical specifications: Compressive strength at 28 days, test method NMX-C-061 = 30 N/mm2, minimum expected value.

General objective

Determine the result of the addition of natural ocoxal fiber (pine needle) in hydraulic concrete to the axial compressive stress.

General hypothesis

The addition of natural ocoxal fiber (pine needle) will increase the values of the mechanical properties to the axial compressive stress of the hydraulic concrete.

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.

- Cemex-Tolteca Extra brand CPC-30R Portland-type gray cement.
- Grave ¾´´.
- Sand.
- Water.
- Pine needle (ocoxal).
- Nopal mucilage.

Tools

- Weighing machine
- Shovel
- Trowel
- Vernier
- 19 liter plastic containers.
- Metal cylinders.

Machinery.

- Universal Machine Controls brand.

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Methodology to be developed

The general method was scientific, the type of research was applied, the level was explanatory and the design was quasi-experimental. The population corresponded to three specimens of concrete cylinders with 10%, 15% and 20% addition of natural ocoxal fibers. The axial compression strength test was only carried out 28 days after setting.

Regarding the treatment of the ocoxal fiber, the mucilage of nopal (nopal slime) was taken as a moisture waterproofing agent, cutting two nopales into small pieces, letting it rest in a 5 liter container with water. for 24 hours and extracting the nopal mucilage, straining it, to submerge the ocoxal just before mixing with the other aggregates.

The proposed dosage of the compressive strength of the hydraulic concrete was f´c= 250 kg/cm2, this dosage was based on self-construction construction procedures, which is indicated in the volume of 19 liter plastic containers, in the packages of extra gray portland type cement, CPC-30R, CEMEX-Tolteca brand.

Results

Design of the hydraulic concrete mix with the addition of natural ocoxal fiber.

For the preparation of concrete, the proportions of the different materials recommended in the bulk of gray cement, to obtain the resistance to axial compression stress f'c = 250 kgf/cm2, are shown in Table 1, the quantity of materials is indicated. in 19 liter containers. in proportion to a lump of cement.

Application (uses)	Cement (50 kg package)	Grave ¾" l (19 liter cans)	Sand (19 liter cans)	Water (19 liter cans)	Resistance f´c (kg/cm^2)
Walls and floors	1	8.5	8.0	3.0	100
Castles and dalas	1	6.5	5.5	2.5	150
Slabs and footings	1	6.0	4.0	2.0	200
Columns and special slabs	**1**	**5.0**	**3.5**	**1.5**	**250**
High resistance concrete	1	4.5	2.5	1.5	300

Table 1 Material proportions
Source: Own elaboration

Table 2 shows the dosages of the materials, the quantities in liters of cement, gravel, sand and water do not change, for the three cylinder specimens what varies is the percentage of natural ocoxal fiber.

#Cylinder	Cement (lts.)	Grave ¾" (lts.)	Sand (lts.)	Water (lts.)	Ocoxal (lts.) (%de 19 lts.)
1	3.1654	7.9154	5.5404	2.356	1.90 (10%)
2	3.1654	7.9154	5.5404	2.356	2.85 (15%)
3	3.1654	7.9154	5.5404	2.356	3.80 (20%)

Table 2 Proportions of materials to be used per cylinder specimen
Source: Own elaboration

Development of the preparation of the concrete mixture with the addition of natural ocoxal fibers

The natural pine needle fiber (ocoxal) was collected Figure 2 shows the drying and its composition can be seen.

Figure 2 Drying of natural ocoxal fiber
Source: Own elaboration

In Figure 3, the natural fiber was immersed to give it a waterproofing treatment with cactus mucilage in a container.

Figure 3 Washing of the natural fiber of (ocoxal)
Source: Own elaboration

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A hard, clean surface was used to mix, moistening it with water. Figure 4 shows the mixing of the materials.

Figure 4 Mixing of concrete aggregates
Source: Own elaboration

Figure 5 shows when the mixture of cement with sand, gravel and water free of impurities was made to make the hydraulic concrete cylinders.

Figure 5 Preparation of the concrete mix
Source: Own elaboration

Figure 6 shows the metal cylinders filled with fresh concrete added with natural ocoxal fibers. The mixture was vibrated to dislodge the air trapped in the concrete in the metal molds and after 24 hours. They were cured by immersing them in water.

Figure 6 Preparation of concrete cylinders
Source: Own elaboration

Axial compression test results

After making the cylinders and curing them for 28 days, the axial compression test was carried out in the universal machine, on the three specimens of the hydraulic concrete cylinders. Table 3 shows the results of the compressive stress, having As a result, cylinder #1 containing 10% volume of ocoxal was the one that achieved the lowest result with an f'c= 101.50 kgf/cm^2, cylinder #2 with 15% volume of ocoxal achieved an f'c= 140.43 kgf/cm^2 and cylinder #3 with 20% volume of ocoxal achieved the highest f'c= 150.54 kgf/cm^2, the average of the three cylinders was f'c=130.8 kgf/cm^2.

#Cylinder	Axial load (kgf)	Cylinder area (cm^2)	Compressive stress f´c (kgf/cm^2)
1	17,937.00	176.71	101.50
2	24,816.50	176.71	140.43
3	26,601.73	176.71	150.54
Average	23,118.41	176.71	130.80

Table 3 Axial compression test results
Source: Own elaboration

In graph 1 it can be inferred that the greater the volume in liters. of the percentage of 10%, 15% and 20% of natural ocoxal fibers, the highest result obtained was 20% with a resistance to axial compression stress of f'c=150.54 kgf/cm^2, compared to the f'c design, 100 kgf/cm^2 were missing to reach the design resistance, which was f´c= 250 kgf/cm^2.

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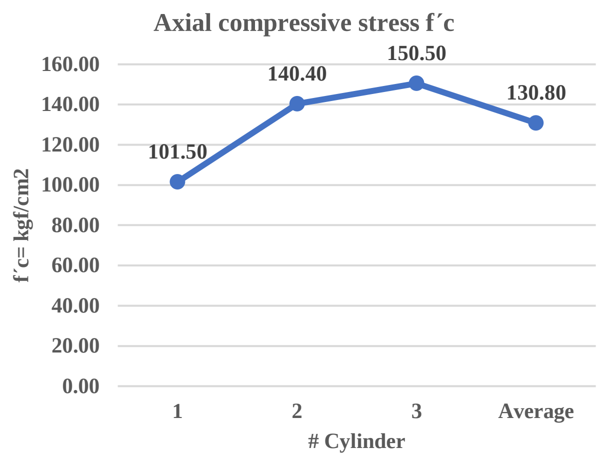

Graphic 1 Axial compression stress of the three cylinders
Source: Own elaboration

Conclusions

Natural fibers are easily accessible and can be biodegraded, ocoxal (pine needle) is found in large quantities and its use is only to make regional crafts, in the municipality of Valle de Bravo, State of Mexico, Mexico.

By adding the natural fiber treated with cactus mucilage to waterproof it and not degrade it due to the cement matrix present in the concrete, it was possible to achieve axial compression stress values below the design resistance, which was f'c=250. kgf/cm^2, achieving a maximum value of 150.54 Kgf/cm^2, which contains 20% of 19 liters of natural ocoxal fiber.

The results indicate that the higher the percentage of natural ocoxal fiber in the three specimens, the greater the resistance to axial compression stress was achieved. This is due to the design of the empirical concrete, since this is what the table found in the packages indicates. of cement and is what supports the empirical design of hydraulic concrete, taking as reference the resistance to axial compression stress f'c=kgf/cm^2 for the different uses and applications of hydraulic concrete.

This type of cement is used in self-construction and the dosage of concrete is in volume of 19 liter plastic containers. which implies low quality control in the production of hydraulic concrete, compared to concrete made in a plant.

The average resistance of the three specimens is 130.80 kgf/cm^2, which is greater than 50% of the design resistance f'c= 250 kgf/cm^2, so it is inferred that by adding a high percentage of fibers Natural ocoxal increases the resistance of the concrete to the axial compression stress of hydraulic concrete, but does not reach the expected resistance.

The use of hydraulic concrete is proposed for columns and special slabs with a f´c= 250 kgf/cm^2, due to the results obtained its use could be applied to non-structural floor or pavement pavements, castles, dalas and poor concretes (low endurance). The research focused on the design of hydraulic concrete with the addition of natural ocoxal fibers to know the resistance to axial compression stress, which implies in future research to calculate the bending stress of hydraulic concrete.

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