

Original Article

Evaluation of the Potential of Natural Additives based on Oje, Croton Lechleri, and Copaiba for Waterproof Concrete Compared to Commercial Products

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Abstract - Construction on saturated and sloping terrain presents challenges for the stability and durability of concrete due to water infiltration, loss of strength, and accelerated deterioration. This research evaluated the performance of natural Amazonian additives such as bloodwood resin, oje, and copaiba in the formulation of waterproof concrete, comparing them with Sika-1 and Sika Bitumen in mixtures of 210 kg/cm². An experimental methodology was applied, varying the proportions of additives (1% to 6% relative to the weight of the cement), and compression, indirect tensile, absorption, porosity, and penetration tests were performed according to ASTM standards. The results showed that an optimal dose of 3% bloodwood, oje and copaiba resin improved mechanical strength (up to 229.96 kg/cm² in compression and 28.03 kg/cm² in traction), reducing absorption (1.55% to 1.66%), porosity (4.2%) and penetration (13.8 mm), with performance similar to or superior to commercial additives. Higher doses did not generate improvements and increased porosity. The cost of concrete with 3% resins was S/ 490.88 /m³, cheaper than Sika-1 (S/ 532.71) and competitive with Sika Bitumen (S/ 475.45). Therefore, the use of Amazonian resins in appropriate proportions is an efficient and sustainable alternative for improving the impermeability and durability of concrete in humid environments, providing technical, economic, and environmental value.

Keywords - Concrete, Natural additives, Resin, Mechanical strength, Impermeability.

1. Introduction

In Peru, many cities have experienced rapid growth towards peripheral areas and areas with steep slopes due to the scarcity of flat land suitable for housing construction [1, 2]. This phenomenon is particularly noticeable in Amazonian regions such as San Ramón, located in the central jungle of Peru, characterised by intense and frequent rainfall throughout most of the year [3, 4]. In this context, numerous homes built mainly with conventional concrete face serious problems resulting from direct and prolonged exposure to water and humidity. Due to the inherent permeability of traditional concrete, water can easily penetrate, creating adverse conditions that compromise the stability, strength, and durability of structures [5, 6]. Constant exposure to moisture causes significant internal damage to conventional concrete, such as early cracking, accelerated corrosion of reinforcement, and progressive deterioration of the material. This problem is significantly intensified in homes located on slopes, where water accumulation and continuous seepage can lead to critical processes such as differential settlement, surface detachment of concrete, erosion of the surrounding terrain, and potential structural collapse [7, 8]. Such effects have been

observed in different areas of the Peruvian Amazon. At the Regional Hospital in Iquitos, serious problems with water seepage through the concrete have caused recurrent internal flooding, leading to severe dampness, mould growth, and health risks for patients and medical staff [9]. Similarly, at the Regional Hospital of Pucallpa in Ucayali, massive leaks through deteriorated roofs and walls caused flooding in various areas, jeopardising the structural safety of the building, damaging medical equipment, and forcing the temporary suspension of services [10]. In urban areas such as Iquitos, private homes have also been severely affected due to poor waterproofing of roofs and walls, resulting in structural deterioration, mould proliferation and disease vectors such as dengue fever due to the accumulation of stagnant water [11, 12]. Given this problem, it is essential to implement construction solutions that significantly increase the resistance of concrete to water penetration and damage [13]. In this regard, the incorporation of natural additives emerges as an innovative, ecological, and effective alternative capable of optimizing waterproofing properties and improving the durability of concrete, as demonstrated by recent studies evaluating the use of plant extracts, lignocellulosic fibers, and



natural resins as concrete modifiers, showing remarkable improvements in reducing porosity and water absorption [14]. However, most of these studies have focused primarily on mechanical properties, such as compressive strength, neglecting the systematic study of waterproofing and durability properties under prolonged water exposure [15]. This limitation represents the main research gap, as to date there are not enough experimental studies that comprehensively quantify the real effect of natural additives on critical parameters such as water absorption, capillary porosity, and resistance to moisture penetration under extreme exposure conditions. Consequently, the novelty of the present work lies in the comparative evaluation of three Amazonian natural resins: croton lechleri, ojé, and copaiba, used as natural waterproofing additives in concrete with a design strength of $f_c = 210 \text{ kg/cm}^2$. Through this approach, the individual influence of each resin on the permeability, durability, and structural behavior of the material under persistent humidity conditions is analyzed. This proposes an ecological, low-cost, and regionally available alternative, contrasting with previous studies focused on chemical or synthetic additives. Therefore, the main objective of this research is to identify the optimal dosage of each natural resin that maximizes the waterproofing capacity of concrete and extends its structural service life in buildings exposed to extreme humidity, thereby contributing to the development of robust experimental criteria for the design of sustainable and durable concretes.

2. Literature Review

This section of the literature review presents and analyzes the most common types of damage recorded in unwaterproofed concrete structures, based on real problems observed in different regions of the country, which supports the need to investigate more efficient and sustainable alternatives for protecting structures.

- a) The Iquitos Hospital, located in a region with high rainfall, has experienced significant leaks since its recent construction. In Figure 1, item A shows damp patches and deterioration in the concrete walls and floors, as well as leaks in sanitary connections, evidencing the lack of adequate waterproofing. This deficiency favours water ingress, corrosion of reinforcement and deterioration of the material, compromising the durability of the infrastructure and the health of its occupants [9].
- b) The Regional Hospital of Pucallpa, in the Ucayali region, was severely affected by the heavy rains of November 2022, which highlighted the waterproofing deficiencies in its infrastructure. In Figure 1, item B shows massive leaks, detachment of the roof covering, damp patches and water accumulation on floors and walls, reflecting the advanced deterioration of the concrete due to the continuous action of water. This lack of adequate waterproofing facilitates infiltration, accelerates the corrosion of reinforcements and the degradation of materials, compromising the safety, durability and

functionality of the hospital, as well as the health of patients and staff [10].

- c) In the city of Iquitos, located in the Peruvian Amazon, heavy rains often cause severe flooding in streets and homes, as shown in Figure 1, item C. The accumulation of water at critical levels exposes buildings to prolonged periods of moisture and hydrostatic pressure, aggravating damage to concrete walls and foundations that do not have adequate waterproofing systems. This situation increases the risk of leaks, structural weakening, and accelerated deterioration of materials, affecting the safety and living conditions of the population [11, 12].



Fig. 1 Damage recorded to unwaterproofed structures

This section presents a literature review on the use of tree resins in building materials, beginning with research on pine, eucalyptus and willow resins, the results of which highlight improvements in the mechanical, thermal and waterproofing properties of concrete and other materials. It then delves into the contributions of bloodwood, ojé resin and copaiba, highlighting their chemical characteristics, ability to form protective barriers and their potential as natural additives to optimise the durability and performance of concrete in humid environments.

2.1. Pine Resin

In Turkey, researchers at the Diyarbakir Vocational School of Technical Sciences developed an eco-friendly lightweight concrete using recycled Expanded Glass Aggregate (EGA) and pine resin, demonstrating that the incorporation of this resin in proportions of 0.5% and 1% improves porosity and thermal insulation, keeping water absorption below critical levels, which makes its use viable in applications such as mortars, panels, bricks, and floors [16]. Similarly, at Malatya Turgut Ozal University and Firat University, a lightweight building material was developed based on cement, pumice and 1% pine resin, observing that increasing the amount of resin and pumice decreases density, thermal conductivity and compressive strength, while increasing porosity and water absorption, making it suitable

for interior and roofing applications due to its low [17]. On the other hand, in the same country, the combined effect of fly ash and pine resin in concrete with expanded clay aggregates was studied, finding that the use of 1% pine resin and industrial by-products allows the development of concrete with low density, lower thermal conductivity and acceptable strength, suitable for partition walls and non-structural roofs [18].

In South Korea, researchers at Chonnam National University analysed the adhesion of eco-friendly adhesives formulated with pine resin and wax on concrete surfaces. They prepared adhesives with different resin-to-wax ratios, with the pine resin ranging from 60% to 100%, while the wax was incorporated in proportions of 0%, 20%, 40% and 60% relative to the adhesive mixture. These adhesives were applied to concrete specimens manufactured with different formwork to modify the surface roughness. The results showed that the bond strength increased with increasing wax proportion and concrete roughness, reaching maximum values of 1.41 MPa with adhesives containing 60% pine resin and 40% wax on rough surfaces, far exceeding the values obtained on smooth concrete (0.99 MPa). Thus, the technical feasibility of pine resin and wax-based adhesives was proven, with the 60:40 formulation being recommended as the most efficient for ecological applications in concrete joints [19].

In Italy, the Polytechnic University of Milan developed redispersible polymer additives (RDPPs) with high renewable content from lauryl acrylate (core) and isobornyl methacrylate (coating, derived from pine resin). The RDPPs were incorporated into the concrete at doses of 5% and 15% relative to the weight of the cement mixture. The additive with 75% renewable content (lauryl acrylate–pine resin ratio) performed best, achieving a more homogeneous and compact concrete surface, suggesting great potential as a waterproofing agent. In addition, when the biodegradable lactic acid-based additive was used, the porosity of the concrete increased, which may be useful for aerating applications. The authors highlight that the 15% dose of pine resin-based RDPPs offered the best results for waterproofing, although they suggest further studies to optimise the balance between impermeability and mechanical properties [20].

2.2. Eucalyptus Resin

In Peru, the National University of San Agustín evaluated the use of eucalyptus resin obtained by steam distillation, incorporating it as an additive in soils intended for pavement base and subbase layers. The optimal proportion of resin used was 2% of the dry weight of the soil, comparing treated and untreated samples. The results showed that, with the resin, the maximum dry density of the granular soil increased from 2.023 g/cm³ to 2.107 g/cm³, and permeability was reduced from 5.19E-07 to 2.83E-07 cm/s. The CBR (California Bearing Ratio) of the treated mixture remained at adequate values (from 46.9 to 38.9, still considered ‘good’), and the liquid limit and plasticity index of the cohesive soil decreased,

facilitating its use in roads. It was concluded that the best dose to improve cohesion and reduce permeability is 2% eucalyptus resin. Similarly, researchers from the Señor de Sipán University and the Technical University of Loja used eucalyptus resin as a binder in the manufacture of ecological briquettes. A fixed ratio of 20% resin to 80% rice husks was used. With this formulation, the briquettes obtained had low moisture content (5.35%), ash content (13.71%) and a calorific value of 18,464.6 kJ/kg. In addition, the briquettes showed high cohesion and physical strength, without crumbling, and CO emissions within acceptable limits (44.75 ppm), supporting the effectiveness of natural resin as a sustainable binder [21].

2.3. Ojé Resin (*Ficus insipida*) and Croton Lechleri (*sangre de grado*)

In Peru, experimental research was conducted in the city of Pucallpa to evaluate the impact of ojé resin (*Ficus insipida*) on the physical and mechanical properties of hydraulic concrete used in storm drainage systems. To this end, they extracted and characterised the ojé resin, finding that it had a density of 1.025 g/mL, an acid pH of 3.8 and a volatile moisture content of 21.19%. The resin was incorporated in different proportions (1%, 3%, 5%, and 7% relative to the weight of the water in the mixture) together with lime, partially replacing the cement. Different experimental mixtures were prepared, and concrete test tubes were manufactured and cured, on which permeability, absorption, compressive strength, and flexural strength tests were performed at ages of 7, 14, and 28 days. The results showed that the addition of ojé resin, especially at a dose of 3% together with 7% lime, increased compressive strength to 278.38 kg/cm² and flexural strength to 50.63 kg/cm² at 28 days, as well as improving the impermeability of the concrete (0.40 mm compared to 0.46 mm for the control sample), thus demonstrating the potential of ojé resin as a natural additive to optimise the performance of hydraulic concrete in drainage applications [22].

In Rondonia, they conducted research in the Brazilian Amazon, where they collected Croton lechleri (*sangre de grado*) bark to study the extraction and profile of its bioactive compounds. In the laboratory, they applied a factorial design that combined different solvents (water and ethanol), times (30 and 90 minutes) and temperatures (35°C and 70°C), and prepared the extracts using 3 g of dry bark per 30 mL of solvent. They analysed the extracts using High-Performance Liquid Chromatography (HPLC), identifying gallic acid, catechin, epicatechin and syringic acid as the main phenolic compounds. They found that the aqueous extract at 35°C for 90 minutes yielded the highest total phenolic compounds (46.57 mg GAE/g) and the highest antioxidant capacity (283 mmol Trolox/g). The authors highlighted the remarkable potential of Croton lechleri resin as a source of natural antioxidants and additives with applications in the food, pharmaceutical and other technological industries.

Furthermore, considering the high content of hydroxyl groups present in its phenolic compounds, as well as the recognised ability of these functional groups to generate barriers against various external agents, it is reasonable to suggest that the resin could confer waterproofing properties [23].

At the University of Padova, Italy, research was conducted to evaluate the biological activity of freeze-dried sap from *Croton lechleri* (sangre de grado). To this end, in vitro tests were carried out using different concentrations of sap (from 0.01 to 100 mg/mL) to analyse its effect on the glycation of bovine albumin, the oxidation of low-density lipoproteins (LDL) and the production of Reactive Oxygen Species (ROS) in human endothelial cells (HUVEC). The results showed that the sap inhibited protein glycation in a range of 5 to 50 mg/mL, significantly reduced LDL oxidation—prolonging the lag phase by 60% at a concentration of 0.8 mg/mL—and decreased both basal and induced ROS production in endothelial cells, in addition to having a high content of phenolic compounds (713.8 mg GAE/g) and remarkable antioxidant capacity. Although the main focus of the study was biomedical, the ability of *Croton lechleri* sap to form protective barrier A s, block the penetration of oxidising agents, and its high polyphenol content suggest that these results can be used to justify its use as a natural waterproofing additive in materials susceptible to moisture and oxidation [24].

In Iquitos, Peru, a systematic review was conducted that analysed 33 recent articles on the phytochemistry and pharmacology of *Croton lechleri* resin ('sangre de grado'). To this end, a search was conducted in specialised databases such as Scopus and Google Scholar, compiling research that used resin formulations in 10% and 15% creams, pure extracts and solutions of different concentrations, applied in clinical trials, animal models and cellular systems. Among the representative results, it was found that *Croton lechleri* resin contains up to 90% proanthocyanidins by dry weight, in addition to polyphenols, flavonoids, saponins, and alkaloids; its applications demonstrated healing, anti-inflammatory, antioxidant, and barrier properties. For example, a 10% cream accelerated the healing of diabetic ulcers in three months, and a 15% cream achieved 95.73% wound healing in 20 days. In addition, the resin showed a potent ability to form protective films, inhibit lipid oxidation and reduce water loss in tissues. Based on these results, it is scientifically justified that the compounds present in *Croton lechleri* resin can be used as natural waterproofing additives, taking advantage of their high content of tannins and polyphenols that promote the formation of barriers against moisture and oxidation [25].

In the city of Lima, an experimental study was conducted to evaluate the bioactive properties of *Ficus insipida* (ojé) resin, specifically its latex, which was collected in the Padre Abad region of Ucayali. The latex underwent methanolic extraction and subsequent phytochemical analysis, identifying

a high concentration of alkaloids, saponins, free amino acids, and the presence of phenolic compounds and anthraquinones. These molecules, known for their ability to form protective films and macromolecular structures, give the latex properties of stabilisation and protection of biological membranes.

Experimentally, the dry extract was tested at concentrations of 10, 50, 100, and 200 µg/mL on human erythrocytes, observing that the higher the concentration, the greater the percentage of protection against haemolysis: at 200 µg/mL, protection reached 62.36%, even exceeding the reference drug (indomethacin, 59.06%). This remarkable ability to protect and strengthen membranes is directly associated with the phytochemical composition of the latex, in particular saponins and alkaloids, which promote the formation of physical and chemical barriers [26].

2.4. Resina de copaiba (*Copaifera* spp.)

Likewise, research was conducted to characterise and compare the functional properties of *Copaifera paupera* (copaiba) oil and the methanolic extract of *Ficus insipida* Willd (ojé) latex, both obtained through controlled extraction in the Ucayali region. Phytochemical analysis revealed that copaiba oil is mainly composed of sesquiterpenes, diterpenes, phenolic compounds and alkaloids, while ojé latex is notable for its high content of tannins, phenolic compounds, saponins and free amino acids. These secondary metabolites are known for their ability to form films, seal surfaces and create barriers against moisture and the entry of external agents.

The combination of both resins, in optimised proportions (specifically 30:70 copaiba:ojé), demonstrated greater efficacy in the formation of resistant and stable structures, as a result of the synergy between their bioactive components [27]. Therefore, the results obtained not only validate their traditional use as anti-inflammatories, but also scientifically substantiate the potential of ojé resin as a natural waterproofing additive in materials subjected to moisture and degradation, taking advantage of its ability to generate protective films and reduce the penetration of external agents.

A study was conducted in Brazil in which 26 samples of copaiba resin (oleoresin) extracted from different species and regions, specifically including *Copaifera langsdorffii*, were analysed. To this end, nuclear magnetic resonance spectroscopy techniques were applied, together with chemometric analysis, in order to differentiate and characterise the chemical composition of each sample.

The results made it possible to identify and distinguish the profiles of the main terpenes present in the resin, in particular hardwickic acid, caryophyllene oxide and kaurenoic acid, which were structurally characterised as marker compounds of *C. langsdorffii*. It was observed that the composition of the oleoresin varies significantly depending on the species and place of extraction, but that it is always composed mainly of

sesquiterpenes and diterpenes such as α -humulene, β -caryophyllene and caurenoic acid, compounds known for their anti-inflammatory and bactericidal properties and their ability to form protective films.

In addition to its recognised medicinal and cosmetic uses, the research documents that copaiba resin is used in the varnish and paint industry, precisely because of its ability to form waterproof and durable layers on different surfaces. Therefore, the results obtained support the idea that copaiba resin, due to its terpene-rich composition and traditional application in sealing and protecting materials, can be used as a natural waterproofing additive in materials susceptible to moisture and degradation [28].

In recent decades, the search for sustainable alternatives for construction has driven research into natural additives capable of improving concrete performance, especially in terms of waterproofing, durability and resistance to aggressive agents. Although the literature reports some advances using resins such as pine, willow, and eucalyptus, recognised for their ability to reduce capillary absorption and reinforce the internal cohesion of concrete, the use of Amazonian resins, particularly sangre de grado (*Croton lechleri*), ojé (*Ficus insipida*) and copaiba (*Copaifera* spp.), remains virtually unexplored in the scientific and technical fields.

To date, only one study has been identified that analyses the application of ojé resin in cementitious mixtures, while there are no documented studies on the incorporation of sangre de grado or copaiba as additives in concrete. These Amazonian resins, due to their rich composition of phenolic compounds, terpenes, saponins and alkaloids, have remarkable potential to act as natural barriers against moisture, chemical penetration and degradation, as well as offering environmental advantages as they are renewable, biodegradable resources available in various regions of the country.

The specialised literature emphasises that resinous additives can have a favourable effect on key properties of concrete, such as workability, mechanical strength, durability and impermeability, depending on the dosage and form of incorporation. However, there is a marked knowledge gap regarding the real and comparative effect of sangre de grado, ojé and copaiba resins in the same cementitious matrix.

In this context, this research addresses, for the first time, the collection, characterisation, and incorporation of blood-grade resin, ojé resin, and copaiba resin as additives in fresh concrete mixtures $f_c=210$ kg/cm². The study evaluates the impact of each of these resins on the workability and temperature control of the fresh mixture, compressive strength and indirect tensile strength tests to determine structural behaviour, and finally water absorption and water penetration

under pressure tests to assess the impermeability of the concrete. This experimental approach seeks to generate scientific information on the potential of these Amazonian resins as natural and innovative solutions for the development of more impermeable, sustainable concretes adapted to the climatic and environmental conditions of the region.

3. Materials and Methods

This section describes the materials and methods, as well as the natural additives used in concrete modification, highlighting the incorporation of Amazonian resins such as sangre de grado, ojé and copaiba, whose application in concrete is virtually unexplored. The processes of collection, preparation, characterisation and integration of these resins into the cement matrix are detailed, with an emphasis on their potential to improve the impermeability and durability of concrete exposed to humid and aggressive environments. To ensure the quality and performance of the modified concrete, slump tests were carried out to evaluate the workability of the fresh mix, temperature control during mixing, compressive strength and indirect tensile strength tests to determine structural behaviour, as well as water absorption and water penetration under pressure tests to assess the impermeability of the concrete. These experimental procedures provided a comprehensive overview of the behaviour and durability of concrete under demanding conditions, evaluating the viability and contribution of these natural additives to the sustainable and functional improvement of construction materials.

3.1. Resins

Resin is a natural substance secreted mainly by conifers and composed of terpenes and phenolic compounds. It is obtained by making incisions in the trunk and is notable for its sticky nature and insolubility in water [29, 30]. These properties make resin useful in the construction industry, especially as an additive in concrete, as it helps to improve the impermeability and durability of materials, as well as providing resistance to moisture and external agents.

3.1.1. Ojé Resin

Ojé resin, also known as ojé latex, is a milky exudate extracted by making incisions in the trunk of the Amazonian tree *Ficus insipida*. This latex is a complex aqueous suspension, produced and stored in specialised cells called laticifers, and is characterised by its high protein content, especially proteolytic enzymes known as ficins, as well as a wide variety of amino acids, terpenoids, tannins, alkaloids and sterols [22, 31]. In the plant itself, this latex performs defence and self-healing functions against external aggressions, while, at the ethnobotanical level, it has been traditionally used by the indigenous populations of the Amazon to treat parasitic infections and various diseases. The diversity of bioactive compounds present in ojé resin gives it biological properties of interest for both medicinal and technological applications [32, 33]. Its properties are shown in Table 1.

Table 1. Properties of ojé resin

Property	Description
Colour	Milky white (fresh), may turn yellowish over time [22].
Appearance	Viscous, dense [31, 32].
Chemical composition	70% tannins, 20% water, 3% polysaccharides and sugars, 2% alkaloids, 2% flavonoids, 1% diterpenes and terpenoids, 1% saponins, 1% lignans and others [31, 32].
Solubility	Partially soluble in water; soluble in ethanol and hydroalcoholic mixtures [33].
Non toxic	Natural and biodegradable[33].
pH	3.8 (Acidic) [33].

According to the properties described in Table 1 and the literature review, ojé resin stands out for its high content of condensed tannins, together with polysaccharides, as well as its viscous texture, low solubility in water, naturalness, biodegradability and slightly acidic pH. The abundance of tannins and phenolic compounds in its composition favours the formation of protective layers that act as a barrier against water absorption and penetration into the cement matrix. Likewise, its low solubility in water and chemical stability contribute to the greater durability of the treated concrete. According to a study, ojé resin applied at 3% of the weight of the cement showed the best results in terms of impermeability and concrete performance in humid environments [22]. Therefore, to validate and expand on these data, this research will evaluate the incorporation of ojé resin in a range of dosages (1%, 2%, 3%, 4%, 5% and 6%) with the aim of identifying the most efficient percentage as a waterproofing additive. The copaiba resin was obtained through a traditional process and subsequently stored for incorporation into concrete mixtures, as shown in Figure 2.



Fig. 2 Ojé resin

3.1.2. Grado Blood Resin

Grado blood is a dark red plant resin obtained from the Amazonian tree *Croton lechleri* [34]. Traditionally used for its healing, anti-inflammatory and antimicrobial properties, this

resin is notable for its ability to form a protective film on the surfaces where it is applied, facilitating tissue repair and preventing the entry of external agents [35-37]. Its properties are shown in Table 2.

Table 2. Properties of sangre de grado [36, 37]

Property	Description
Colour	Intense brick red [36].
Appearance	Viscous liquid [36].
Chemical composition	85% condensed tannins, 8% water, 2% alkaloids and 5% flavonoids, diterpenes, lignans and others [36, 37].
Solubility	Slightly soluble in water, soluble in methanol and chloroform [36, 37].
Non toxic	Natural and biodegradable [36, 37].
pH	6.37 (Weak Acid) [36, 37].

According to the properties described in Table 2 and the literature review, bloodwood resin (*Croton lechleri*) stands out for its high content of condensed tannins, phenolic compounds, diterpenes and alkaloids, as well as being a viscous liquid, slightly soluble in water, natural, biodegradable and slightly acidic in pH. The presence of tannins and phenolic compounds promotes the formation of resistant layers that limit water absorption and penetration, while its low solubility in water and stable chemical nature contribute to its durability within concrete. To optimise the properties of concrete by adding blood resin, it is recommended to use proportions of (1%, 2%, 3%, 4%, 5% and 6%) relative to the weight of cement used in the mixture, taking as a reference the case of ojé resin, for which previous research has determined that a dosage of 3% is optimal for improving impermeability [22]. The blood resin was obtained through a traditional process and subsequently stored under controlled conditions for incorporation into concrete mixtures, as shown in Figure 3.



Fig. 3 Blood grade resin



Fig. 4 Copaiba resin

3.1.3. Copaiba Resin

Copaiba is a clear to yellow liquid resin extracted from Amazonian trees of the *Copaifera* genus. Recognised for its traditional use in natural medicine, copaiba has healing, anti-inflammatory and antimicrobial properties, attributed to its rich composition of terpenes and resin acids. These characteristics give it the ability to form protective barriers and promote wound closure [34, 38, 39]. Its properties are shown in Table 3.

Table 3. Properties of copaiba resin [40]

Property	Description
Density	0.912 gr/cm ³ .
Chemical composition	Sesquiterpenes (70%), Diterpenes (30%)
Hydrophobicity	Water repellent, insoluble in water.
Adhesion	Natural resins have adhesive properties that could improve the bonding between particles in the mixture.
Antimicrobial properties	Contains compounds with a biocidal effect (terpenes, tannins).
Texture	Initially liquid and fluid, but thickens and darkens on contact with air due to oxidation.
pH	5.2 (slightly acidic).

According to Table 3, thanks to its high content of compounds such as sesquiterpenes and diterpenes, copaiba resin can form a protective layer on concrete that prevents water and moisture from penetrating the material. In addition, it is insoluble in water and stable, which helps to ensure long-lasting protection even in humid or aggressive environments. For all these reasons, copaiba resin is a natural and sustainable option for improving the impermeability and extending the useful life of concrete. To optimise the properties of concrete by adding bloodwood resin, it is recommended to use proportions of (1%, 2%, 3%, 4%, 5% and 6%) relative to the weight of cement used in the mixture, taking as a reference the case of oje resin, for which previous research has determined that a dosage of 3% is optimal for improving impermeability [22]. As in the previous cases, copaiba resin was extracted using a traditional process and then stored for incorporation into concrete mixtures, as shown in Figure 4.

3.2. Concrete with strength $f'c = 210 \text{ kg/cm}^2$

Concrete is a heterogeneous composite material consisting mainly of a combination of Portland cement, coarse and fine aggregates, water, and, in many cases, chemical additives and supplementary cementitious materials, which allow its microstructure and mechanical properties to be modified [41, 42]. In this study, a mixture designed to achieve 210 kg/cm² (21 MPa) compressive strength at 28 days was used, complying with structural standards [43].

3.2.1. Waterproof Concrete

Waterproof concrete is a composite material designed to offer superior resistance to water passing through its internal structure, thanks to the incorporation of waterproofing additives during the mixing stage [44, 45]. These additives, generally formulated from water-repellent or pore-blocking chemical compounds, act by modifying the microstructure of the concrete, reducing the connectivity and size of the capillaries and, therefore, the permeability of the material, as shown in Figure 5. Among the most widely used waterproofing additives in the industry is Sika 1, considered the most commercial due to its effectiveness, availability, and wide acceptance in construction projects [46, 47].



Fig. 5 Waterproof Concrete [48]

3.2.2. Quantity of Materials for Concrete

The precise dosing of materials, including Andino Type I cement, coarse aggregates from the 3 de Diciembre quarry, fine aggregate from the Orcotuna quarry, water and the Sika-1 additive, is essential to meet the strength, workability and durability requirements of concrete [49, 50]. The dosing procedure was carried out based on the mix design prepared by the C3 Laboratory, which considered the physical-

mechanical properties previously determined in the aggregates, such as natural moisture content, absorption, specific gravity and fineness modulus, fundamental parameters for adjusting the volumes and unit masses of each component. Table 4 shows the amount of materials used per cubic metre of concrete, specifying the proportions of each component and the chemical additive, which allows for a direct comparison between conventional concrete and concrete modified with natural additives.

Table 4. Amount of materials for concrete per m³

Description	Unit	Amount
Cement	Kg	413
Sand	Kg	935
Crushed stone	Kg	779
Theoretical water	L	186
Corrected water	L	198
Sika-1 (2%)	L	8.2705

The initial theoretical amount of water calculated was 186 litres. However, due to the moisture content and absorption capacity of the aggregates, it was necessary to make a water correction to reach 198 litres of effective water. For this calculation, the difference between the absorption (A%) and the actual moisture content (H%) of each aggregate was used, multiplied by the corresponding dry mass, according to the following expression:

$$Water_{Corrected} = \frac{A\% - H\%}{100} \times dry\ mass$$

This dosage allows for a balanced mixture, suitable for conventional structural elements, ensuring the strength and workability required on site [51].

3.2.3. Amount of Natural Additives

Table 5 shows the amount of natural additives incorporated into the concrete, calculated based on the total weight of cement used in the mixture (413 kg/m³). For oje, sangre de grado and copaiba resins, increasing doses between 1% and 6% of the weight of the cement were established in order to systematically evaluate the effect of each addition

level on the impermeability and durability properties of the material. The specific quantities of each additive are expressed in litres per cubic metre of concrete, which ensures accurate and reproducible dosing in experimental tests.

Table 5. Dosage quantity relative to cement weight

Dosage (% cement weight)	Oje resin (L)	Blood Grade Resin (L)	Copaiba resin (L)
1.0 %	4.135	4.135	4.135
2.0 %	8.271	8.271	8.271
3.0 %	12.406	12.406	12.406
4.0 %	16.541	16.541	16.541
5.0 %	20.676	20.676	20.676
6.0 %	24.812	24.812	24.812

It is important to note that, since these additives are incorporated in liquid form, the volume corresponding to each dose must be deducted from the corrected water volume (198 L/m³). This practice is necessary in order not to alter the effective water-cement ratio, thus ensuring the reproducibility of the mixtures and compliance with the design criteria. This procedure is in line with the technical specifications of the Sika-1 additive, which explicitly recommend subtracting the volume of liquid additive from the mixing water to avoid variations in the workability and w/c ratio of the concrete.

3.2.4. Preparation of the Concrete Mix

The concrete mix was prepared in a drum mixer, using Andino Type I cement, sand from the Orcotuna quarry ¾” crushed stone from the 3 de Diciembre quarry, and water corrected according to the mix design. In addition, liquid additives (Sika-1 and natural resins from oje, copaiba and sangre de grado) were incorporated by partially replacing the water in order to maintain a constant water-cement ratio. The materials were dosed and mixed until a homogeneous mass was obtained, from which cylindrical specimens measuring 100 × 200 mm were moulded in three layers by manual compaction. These were then cured under controlled conditions, following experimental practices and protocols recognised in the literature [51-53], as shown in Figure 6.



Fig. 6 Preparation of the concrete mixture

3.3. Concreto Impermeabilizado Superficialmente Con Sika - Bitumen

Asphalt primer is a material formulated from refined asphalts and organic solvents, designed to penetrate the pores and capillaries of concrete, improving adhesion, surface sealing and impermeability before the application of asphalt coatings or systems [54, 55]. On the market, products such as Sika Bitumen 4L stand out for their regulatory compliance, compatibility with different waterproofing systems and controlled drying times, making them widely used in civil engineering and infrastructure works [56, 57].

In this research, the product was applied to cylindrical concrete test specimens cured for 28 days, following a dosage of 0.4 L/m² in a single uniform layer. To do this, the surfaces were previously cleaned and dried, the material was homogenised in its container for three minutes, and then applied with a brush. The test specimens were then left to dry for six hours at room temperature until the surface stickiness had completely disappeared. Nine test specimens were used, divided into three experimental groups: the first was completely coated, the second was partially coated on the upper surface for the water penetration test, and the third was the standard concrete without coating. Figures 7 show the product used and the final result of the treated test specimens, respectively.



Fig. 7 Sika Bitumen 0.4 L/m²

3.4. Tests Performed

This section presents the tests performed to evaluate the performance of the concrete, which include the slump test, temperature measurement during mixing, indirect compressive and tensile strength tests, as well as water absorption and penetration tests under pressure.

3.4.1. Slump Test

The slump test was used to evaluate the workability and consistency of fresh concrete, following standard MTC E705 [58, 59]. The procedure consisted of filling a truncated cone-shaped metal mould in three layers, each compacted with 25 rod strokes, levelling the top surface and removing the mould vertically to allow the concrete to settle freely [60]. The difference between the height of the mould and the final height of the specimen was used to determine the slump value of each mixture. Figure 8 shows the slump test, where the mould, rod and slump measured in the concrete can be seen.

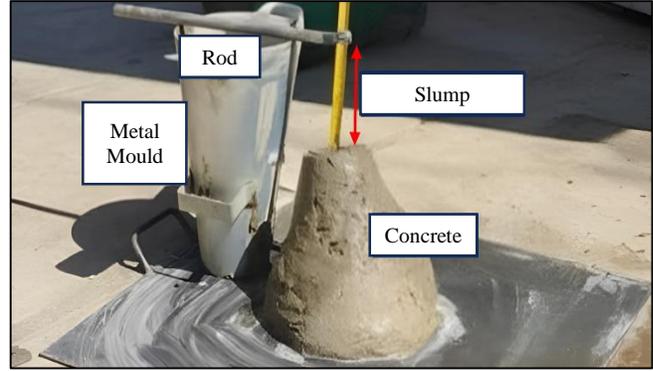


Fig. 8 Slump test

3.4.2. Fresh Concrete Temperature

The fresh concrete temperature test was performed to verify that the mixture met the requirements established at the time of its preparation and placement, as this parameter directly influences the setting, strength gain, and durability of the material [61-63]. The procedure was carried out in accordance with standard MTC E 724, using a calibrated Thermo Lab digital thermometer, inserted into the centre of a representative sample contained in a non-absorbent container, ensuring adequate coverage of the sensor and recording the reading once it had stabilised. Figure 9 shows the measurement of the fresh concrete temperature during the test.



Fig. 9 Temperature test

3.4.3. Compressive Strength

The purpose of this test was to determine the compressive strength of 100 × 200 mm cylindrical specimens, both moulded and extracted cores, by applying a continuous axial load until failure and calculating the strength as the ratio between the maximum load supported and the cross-sectional area [64, 65]. The procedure was carried out in accordance with standard MTC E 724, using a TÉCNICAS CP S.A.C. compression machine equipped with a digital control system and hardened steel plates as shown in Figure 10, previously verified and calibrated to ensure the accuracy and reliability of the results.



Fig. 10 Compression testing machine

Concrete Cylinder Compression Test Procedure

The concrete compressive strength test was performed in accordance with standard MTC E 724 in order to evaluate the development of mechanical strength at 7, 14 and 28 days. A total of 18 cylindrical test specimens measuring 100×200 mm were prepared, distributed across six formulations (one standard concrete and five mixtures modified with natural additives), with three specimens for each mixture. The test specimens were previously cured and conditioned, and then tested in a hydraulic press under continuous and controlled axial load until failure. The procedure included the preparation and organisation of the test specimens (Figures 11(a) and 11(b)), the centred placement of each specimen in the compression machine (Figure 11(c)) and the progressive application of the load until failure. Finally, the maximum load supported was recorded and the mode of fracture of the concrete was observed (Figure 11(d)), ensuring the reliability of the results obtained.

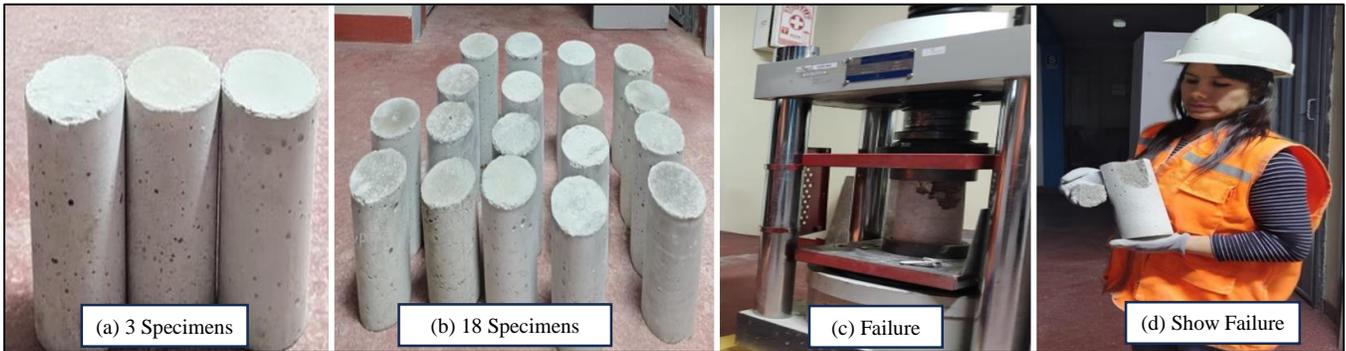


Fig. 11 Concrete compressive strength test

3.4.4. Indirect Tension

The indirect tension test on concrete cylinders was carried out in accordance with standard MTC E 708 and the guidelines established in the specialised literature [66, 67], with the aim of determining the tensile strength of the material indirectly, given that direct tension in concrete is difficult to perform in the laboratory. To this end, 18 cylindrical specimens measuring 100×200 mm were tested, corresponding to a standard concrete and five mixtures modified with natural

additives, with three specimens for each formulation and evaluated at ages 7, 14 and 28 days. Each cylinder was placed horizontally in the hydraulic compression machine and a progressive load was applied along its diameter until the characteristic failure by diametrical division occurred, recording the maximum load reached and documenting the fracture modes observed. Figure 12 shows the experimental procedure, from the preparation of the test specimens to the breakage and recording of results.



Fig. 12 Indirect tensile test

3.4.5. ASTM C642 Test

The procedure for testing the absorption, density and void percentage of hardened concrete, carried out in accordance

with ASTM C642 [68-70], is shown in Figure 13. In a), the test specimens are shown drying in an oven at 105°C for 24 hours in order to remove all internal moisture; subsequently,

in b), they were weighed on an electronic balance, thus obtaining the oven-dried mass as an initial reference. Next, in c), the specimens were immersed in water at 22 °C for 48 hours to allow the pores to become saturated, which led to d), where they were weighed again to determine the saturated mass on a dry surface. Next, in e), the specimens were boiled

in water for 5 hours to displace the air trapped in the internal pores; after cooling, in f), they were weighed again to obtain the saturated mass after boiling. Finally, in g), the submerged mass was determined by suspending each test piece in water in a controlled manner, taking care to remove any adhering bubbles and ensuring complete immersion.

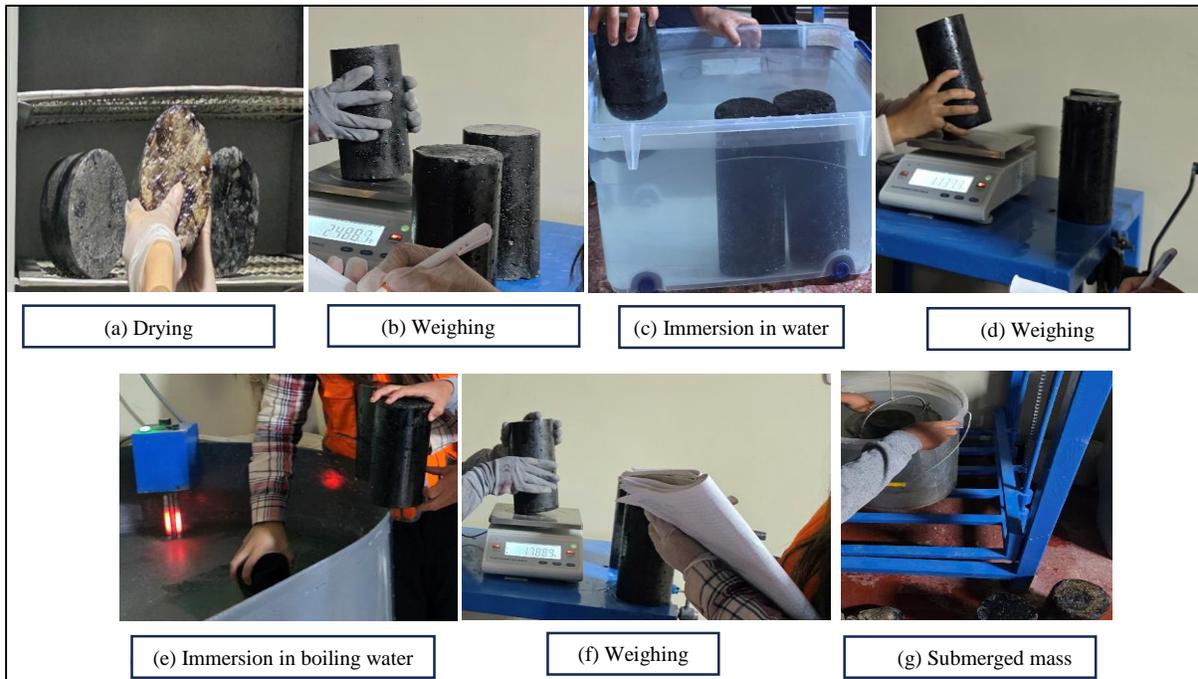


Fig. 13 Water absorption test

3.4.6. UNE-EN 12390-8 Standard

The water penetration depth test under pressure was performed in accordance with standard UNE-EN 12390-8 [71, 72], using cylindrical test specimens measuring 100 × 200 mm after 28 days of curing. This procedure allows the intrinsic permeability of concrete to be quantified against an imposed hydraulic gradient, providing a criterion for comparing different mixtures in terms of their waterproofing capacity and durability. Figure 14 illustrates the main stages. In a), water is applied at a constant pressure of 20 psi for 72 hours, confined exclusively to one of the circular bases of the test piece, while the periphery was hermetically sealed, ensuring that the

hydraulic flow was transmitted only through the exposed section. This controlled pressure regime made it possible to simulate severe hydrostatic conditions equivalent to those experienced by concrete structures in continuous contact with water. Subsequently, in b), the test specimens were cut longitudinally along their axis, exposing the internal microstructure and revealing the wet zone resulting from the penetration of pressurised water. Finally, in c), the maximum penetration depth was measured directly using a digital vernier, recording the distance from the exposed base to the upper limit of the area darkened by saturation.



Fig. 14 Water penetration test under pressure

4. Results

This section presents the results obtained from modifying conventional concrete by incorporating natural resins from ojé, sangre de grado and copaiba. The mixtures were prepared according to the dosage established for concrete with a compressive strength of 210 kg/cm², and each additive was evaluated in different proportions relative to the weight of the cement. The specimens produced were subjected to tests of workability (slump), fresh concrete temperature, compressive and indirect tensile strength, water absorption, and water penetration under pressure.

4.1. Slump

Table 6 shows that conventional concrete had a base slump of 3.5 inches, while the mixture with Sika 1 achieved a slightly higher value of 3.7 inches, demonstrating that this additive improves initial workability. When oxy resin was added, a maximum slump of 4.0 inches was recorded with a 1% dosage, representing an increase of 0.5 inches over the conventional mix and 0.3 inches over Sika 1. However, as the dose of oje resin increased, the slump decreased progressively

to 2.4 inches at a dose of 6%, which is 1.1 inches below the conventional mixture and 1.3 inches less than Sika 1, indicating that at low concentrations the resin promotes fluidity, but at high doses it increases the viscosity and cohesion of the mixture. For grade A blood resin, the highest slump value was 4.1 inches at 1%, i.e. 0.6 inches above the conventional value and 0.4 inches more than Sika 1. As the dose increased, the slump decreased to 2.5 inches at 6%, which is 1.0 inch less than the conventional resin and 1.2 inches less than Sika 1, reflecting a similar effect of loss of workability at high doses. In the case of copaiba resin, the maximum slump was 4.2 inches with a 1% addition, exceeding conventional concrete by 0.7 inches and Sika 1 by 0.5 inches. However, as the dosage increased, the slump decreased to 2.6 inches at 6%, which is 0.9 inches below conventional concrete and 1.1 inches less than Sika 1. These results indicate that, for the three resins evaluated, low dosages improve the workability of the concrete, acting as plasticising agents, while at higher dosages there is a significant decrease in slump, associated with increased internal cohesion and reduced fluidity of the mixture.

Table 6. Slump test results

Description	Dosage	Slump (inches)
Conventional concrete	0.00%	3.5
Concrete + Sika 1	2.00%	3.7
Blood Grade Resin M- 1	1.00%	4.1
Blood Grade Resin M- 2	2.00%	3.8
Blood Grade Resin M- 3	3.00%	3.5
Blood Grade Resin M- 4	4.00%	3.1
Blood Grade Resin M- 5	5.00%	2.8
Blood Grade Resin M- 6	6.00%	2.5
Ojé Resin M- 1	1.00%	4
Ojé Resin M- 2	2.00%	3.7
Ojé Resin M- 3	3.00%	3.3
Ojé Resin M- 4	4.00%	3
Ojé Resin M- 5	5.00%	2.7
Ojé Resin M- 6	6.00%	2.4
Copaiba Resin M- 1	1.00%	4.2
Copaiba Resin M- 2	2.00%	3.9
Copaiba Resin M- 3	3.00%	3.5
Copaiba Resin M- 4	4.00%	3.2
Copaiba Resin M- 5	5.00%	2.9
Copaiba Resin M- 6	6.00%	2.6

Figure 15 shows that, when using a 1% dose, ojé resin increased the slump of the concrete by 14.3% compared to conventional concrete and by 8.1% compared to Sika 1; grade blood resin showed increases of 17.1% and 10.8%, respectively, while copaiba resin achieved increases of 20% and 13.5% over the reference concretes. However, when the dosage of these resins was increased, the percentage values were reversed. For example, at a dose of 6%, ojé resin showed a 31.4% reduction in slump compared to conventional

concrete and a 35.1% reduction compared to Sika 1; blood grade resin showed a decrease of 28.6% and 32.4%; and copaiba resin showed a reduction of 25.7% and 29.7%, respectively. The decrease in slump at higher resin dosages is explained by the high viscosity and hydrophobic nature of their compounds, which modify the water-cement interaction. In the case of ojé resin and grado blood, the high content of tannins and polysaccharides generates water retention and the formation of protective films on the particles, reducing the free water available to lubricate the mixture. Similarly, copaiba

resin, rich in water-insoluble terpenes and diterpenes, tends to coat the aggregates with a hydrophobic layer that limits wetting and internal mobility. These mechanisms increase the

cohesion and flow resistance of the mixture, which explains the progressive loss of workability and reduction in slump as the resin concentration increases.

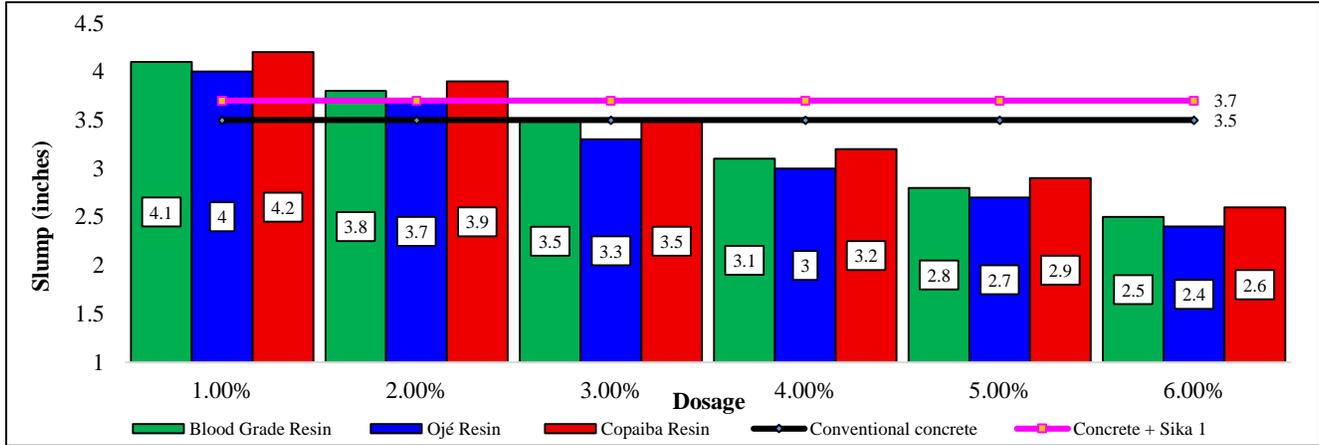


Fig. 15 Slump test

Table 7. Temperature test results

Description	Dosage	Temp (°)
Conventional concrete	0.00%	22
Concrete + Sika 1	2.00%	21.62
Blood Grade Resin M- 1	1.00%	20.92
Blood Grade Resin M- 2	2.00%	20.78
Blood Grade Resin M- 3	3.00%	20.69
Blood Grade Resin M- 4	4.00%	20.62
Blood Grade Resin M- 5	5.00%	20.47
Blood Grade Resin M- 6	6.00%	20.51
Ojé Resin M- 1	1.00%	21
Ojé Resin M- 2	2.00%	20.88
Ojé Resin M- 3	3.00%	20.71
Ojé Resin M- 4	4.00%	20.66
Ojé Resin M- 5	5.00%	20.61
Ojé Resin M- 6	6.00%	20.54
Copaiba Resin M- 1	1.00%	20.85
Copaiba Resin M- 2	2.00%	20.63
Copaiba Resin M- 3	3.00%	20.58
Copaiba Resin M- 4	4.00%	20.51
Copaiba Resin M- 5	5.00%	20.14
Copaiba Resin M- 6	6.00%	20.19

4.2. Temperature Test

Table 7 shows that conventional concrete had an initial temperature of 22.00 °C, while the mixture with Sika 1 recorded a slightly lower temperature of 21.62 °C, suggesting that this additive contributes to a slight thermal reduction in the mixture. When oxy resin was added, the temperature of the mixture gradually decreased from 21.00 °C with a 1% dose to 20.54 °C at 6%, remaining below the values for conventional concrete and Sika 1 at all times. For blood-grade resin, a similar behaviour was observed, starting at 20.92 °C at 1% and decreasing to 20.51 °C at 6%, showing a consistent thermal decrease as the dosage increased. In the case of copaiba resin,

the temperature started at 20.85 °C at 1% and decreased progressively to 20.19 °C at 6%, also remaining below both reference concretes in all the proportions evaluated. These results indicate that the addition of natural resins not only contributes to a slight decrease in the mixing temperature, but also promotes moisture retention and the dissipation of heat generated during the process, potentially improving the conditions for curing and performance of the concrete compared to traditional mixtures.

Figure 16 shows that all doses of ojé resin, grado blood, and copaiba caused a percentage reduction in the temperature

of the concrete compared to conventional concrete and Sika 1. For oje resin, at a dose of 1%, the temperature was 4.5% lower than that of conventional concrete and 2.9% lower than Sika 1; at the maximum dose evaluated (6%), the reduction reached 6.6% and 5.0%, respectively. Blood-grade resin showed similar decreases, with a reduction of 4.9% compared to conventional concrete and 3.2% compared to Sika 1 at 1%, and up to 6.8% and 5.1% at 6% dosage. In the case of copaiba resin, the initial decrease was 5.2% compared to conventional concrete and 3.6% compared to Sika 1, reaching 8.2% and 6.6% less at the highest dose. The progressive reduction in temperature in concrete with natural resins is mainly due to the chemical composition and physicochemical properties of

these additives. Oje resin and sangre de grado, with high tannin, polysaccharide and phenolic compound content, act as colloidal agents that increase water retention and limit the immediate release of hydration heat, generating a thermal moderation effect. Copaiba resin, rich in terpenes and insoluble in water, forms hydrophobic films around the particles, promoting gradual heat dissipation and reducing heat transfer within the mixture. Thus, the observed decrease in temperature responds both to the ability of the resins to maintain higher moisture in the cementitious matrix and to their influence on the kinetics of hydration, contributing to more stable mixing and more controlled curing conditions compared to conventional concrete.

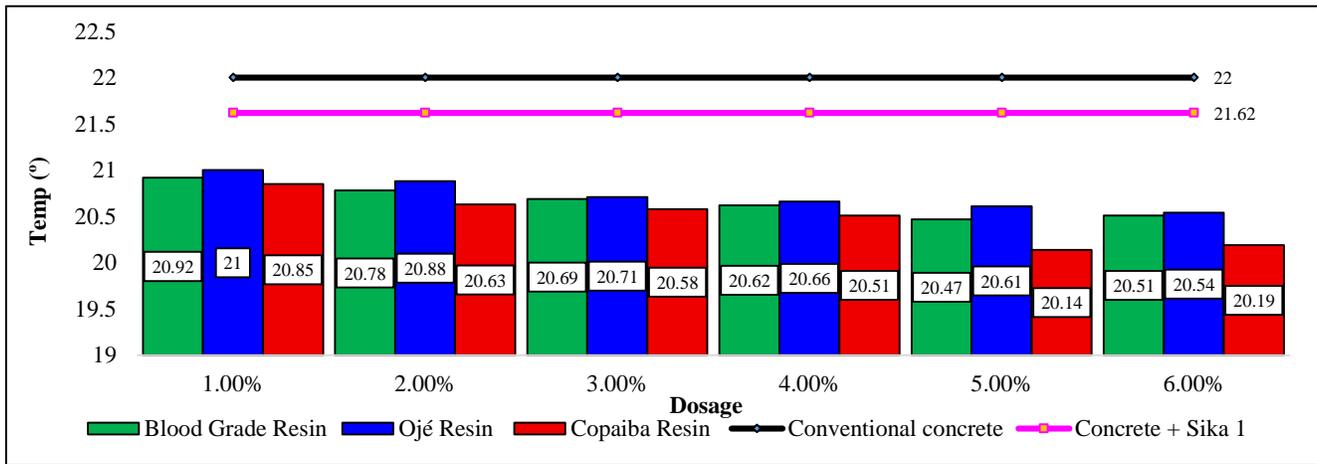


Fig. 16 Temperature test

Table 8. Compressive strength test results

Description	7 days F'c (kg/cm2)	14 days F'c (kg/cm2)	28 days F'c (kg/cm2)
Conventional concrete	146.83	184.37	219.6
Concrete + Sika 1 - 2%	144.65	181.29	217.11
Blood Grade Resin 1%	151.96	193.26	216.78
Blood Grade Resin 2%	158.22	199.11	224.31
Blood Grade Resin 3%	162.43	204.27	229.96
Blood Grade Resin 4%	159.61	200.15	226.14
Blood Grade Resin 5%	154.28	193.94	219.84
Blood Grade Resin 6%	150.74	187.63	214.37
Oje Resin 1%	151.21	190.98	215.42
Oje Resin 2%	156.88	197.14	222.63
Oje Resin 3%	161.34	201.73	228.19
Oje Resin 4%	157.82	198.35	223.68
Oje Resin 5%	153.79	192.46	217.87
Oje Resin 6%	149.33	189.51	212.56
Copaiba Resin 1%	150.13	189.75	215.26
Copaiba Resin 2%	155.94	196.52	222.07
Copaiba Resin 3%	160.25	200.88	227.63
Copaiba Resin 4%	157.47	197.43	223.29
Copaiba Resin 5%	153.61	191.74	217.15
Copaiba Resin 6%	148.29	185.32	211.68

4.3. Compressive strength F'c (kg/cm²)

Table 8 shows that, after 7 days, conventional concrete had an initial strength of 146.83 kg/cm², slightly higher than concrete with Sika 1 (144.65 kg/cm²), demonstrating that this additive does not generate a significant early gain in strength. When oje resin was added, the strength increased progressively up to a 3% dose, reaching a maximum of 161.34 kg/cm², indicating a positive effect on hydration and initial matrix formation. At higher doses, the strength decreased, probably due to excess organic matter interfering with the cohesion of the mixture. A similar behaviour was observed for blood resin, with a maximum value of 162.43 kg/cm² at 3%, suggesting that low and moderate doses optimise the microstructure, while high doses generate saturation and reduced efficiency. Copaiba resin reached its highest strength at a 3% dose (160.25 kg/cm²), also showing improvement at intermediate doses and a downward trend thereafter. After 14 days, conventional concrete and concrete with Sika 1 recorded strengths of 184.37 kg/cm² and 181.29 kg/cm², respectively.

The three resins evaluated showed sustained improvements in the range of 2% to 3% of dosage, with maximum values of 201.73 kg/cm² for oje resin, 204.27 kg/cm² for grado blood, and 200.88 kg/cm² for copaiba.

This behaviour shows that the addition favours the continuity of the hydration process and internal densification, but higher doses can generate voids or interfere with the cementitious matrix. Finally, at 28 days, conventional concrete achieved 219.60 kg/cm² and concrete with Sika 1 achieved 217.11 kg/cm², matching performance at older ages. Natural resins showed their greatest positive effect at a 3% dosage, reaching values of 228.19 kg/cm² (oje), 229.96 kg/cm² (sangre de grado) and 227.63 kg/cm² (copaiba), confirming that a moderate addition enhances final strength. However, higher doses do not provide additional advantages and may even be counterproductive. Thus, the results indicate that the optimal dosage of natural resins is between 2% and 3%, allowing for improved mechanical strength of the concrete compared to traditional systems.

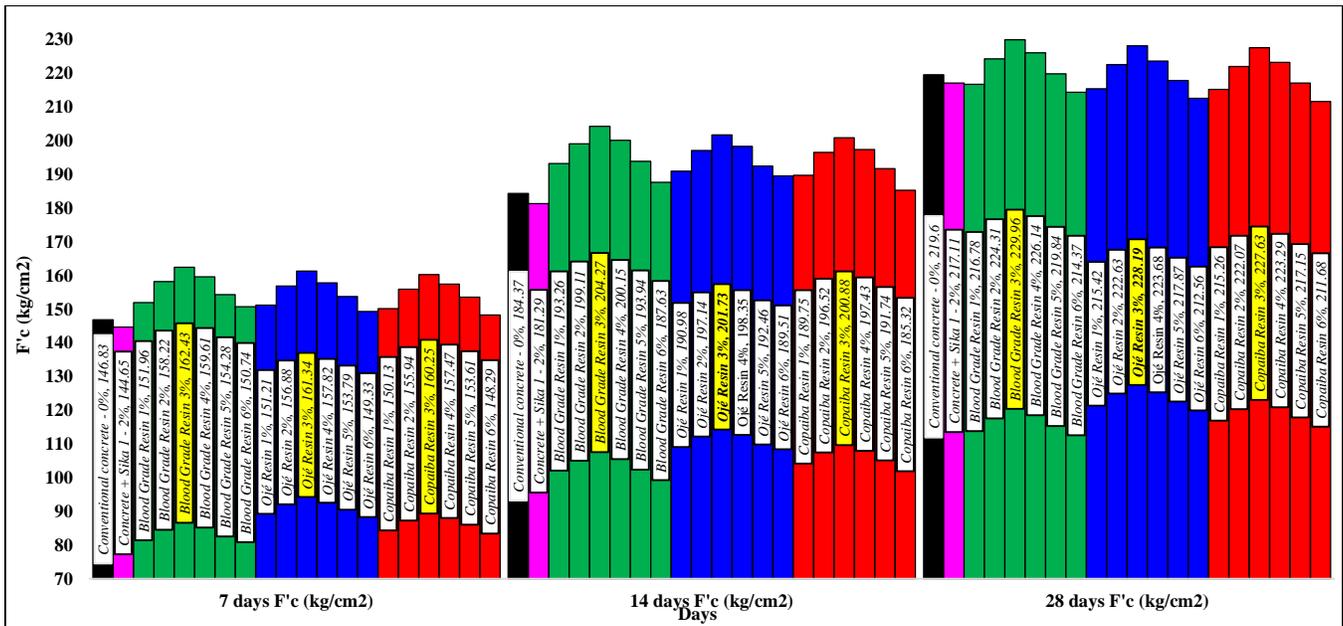


Fig. 17 Compressive strength test

Figure 17 shows that, at 7 days, oje, sangre de grado and copaiba resins show a progressive increase in compressive strength as the dose increases to 3%, with maximum improvements of between 9% and 12% compared to both conventional concrete and concrete with Sika 1. In particular, 3% sangre de grado resin achieves a 12.3% increase over Sika 1 and 10.6% over conventional concrete, oje resin achieves up to 11.5% and 9.9% respectively, and copaiba resin shows increases of 10.7% and 9.1%. However, when the dose exceeds 3%, the benefit of all resins decreases, with improvements falling below 2% and tending to equal or barely exceed the base values, and even at high doses, a slight reduction is observed compared to the reference concretes.

After 14 days, the percentage improvement compared to conventional concrete and Sika 1 increases with the resins, with the maximum trend remaining in the 3% range. Bloodwood resin shows the greatest increase, with 12.7% over Sika 1 and 10.8% over conventional concrete at a 3% dose, followed by oje resin (11.3% and 9.4%) and copaiba resin (10.8% and 8.9%). Beyond this range, the percentage improvement begins to decrease. Finally, at 28 days, the greatest positive effect is consolidated in the intermediate doses. Blood resin achieves a 6.0% improvement over Sika 1 and 4.7% over conventional concrete at a 3% dosage, oje resin achieves 5.1% and 3.9% respectively, and copaiba resin achieves 5.0% and 3.7%. The increase observed in the

compressive strength of concrete with a 3% dosage of natural resins is mainly due to the fact that, in this range, the organic compounds present (tannins, terpenes, flavonoids, and polysaccharides) favour the controlled hydration of Portland cement, generating a greater amount of C-S-H (hydrated calcium silicate), which is the main product of the hydration of cement silicates and is responsible for internal cohesion and up to 70% of the mechanical strength of hardened concrete. The initial plasticising action of the resins allows for better particle distribution and reduces capillary porosity, facilitating the formation of a dense and continuous microstructure. However, when the dosage exceeds 3%, the excess organic matter acts as a physical and chemical barrier, interfering with the hydration reactions and limiting the precipitation of C-S-H. This causes additional voids and a less compact matrix, which explains the progressive reduction in strength at higher percentages. Therefore, the behaviour identified confirms that an intermediate dosage (2 to 3%) is optimal, as it balances the modifying action of the resins with the normal development of cement hydration products, while at higher doses the effect of saturation and obstruction of the cementitious reaction predominates.

4.4. Indirect Tensile Strength Fct (kg/cm2)

Table 9 shows that, after 7 days, conventional concrete had a tensile strength of 16.21 kg/cm² and concrete with Sika 1 reached 15.77 kg/cm². Ojé, sangre de grado and copaiba

resins showed progressive increases in strength as the dose was increased to 3%, reaching maximum values of 19.04, 19.36 and 18.67 kg/cm² respectively, which is attributed to greater matrix cohesion and a reduction in early microcracks. However, at doses above 3%, strength began to decrease, probably due to the presence of excess organic matter that affected the internal adhesion of the concrete. At 14 days, conventional concrete and concrete with Sika 1 achieved strengths of 20.07 kg/cm² and 19.84 kg/cm², respectively. The three natural resins achieved maximum strengths at around 3% dosage: 23.88 kg/cm² for ojé resin, 24.10 kg/cm² for sangre de grado, and 23.59 kg/cm² for copaiba, showing that moderate dosing promotes the formation of bonding bridges and reinforces the internal microstructure. For higher doses, the strength tended to decrease gradually. Finally, after 28 days, the tensile strength of conventional concrete was 23.13 kg/cm² and that of Sika 1 was 22.48 kg/cm². Ojé, sangre de grado and copaiba resins achieved their highest values at around 3% dosage (26.49, 28.03 and 26.87 kg/cm², respectively), demonstrating that dosages in this range optimise the internal cohesion and final strength of the concrete. Higher doses decreased the beneficial effect, possibly due to saturation or physical interference in the hardened matrix. Thus, the results confirm that the incorporation of natural resins significantly improves tensile strength when used in intermediate doses, while higher doses may limit this effect.

Table 9. Tensile strength test results

Description	7 days Fct (kg/cm2)	14 days Fct (kg/cm2)	28 days Fct (kg/cm2)
Conventional concrete	16.21	20.07	23.13
Concrete + Sika 1 - 2%	15.77	19.84	22.48
Blood Grade Resin 1%	17.25	21.45	24.59
Blood Grade Resin 2%	18.41	22.66	26.18
Blood Grade Resin 3%	19.36	24.1	28.03
Blood Grade Resin 4%	18.98	23.03	26.54
Blood Grade Resin 5%	18.62	21.94	25.13
Blood Grade Resin 6%	17.88	20.89	23.73
Ojé Resin 1%	17.12	21.32	24.36
Ojé Resin 2%	17.96	22.07	25.93
Ojé Resin 3%	19.04	23.88	27.49
Ojé Resin 4%	18.57	22.61	26.12
Ojé Resin 5%	17.68	21.82	24.92
Ojé Resin 6%	16.51	20.57	23.38
Copaiba Resin 1%	16.87	21.17	24.24
Copaiba Resin 2%	17.73	22.15	25.49
Copaiba Resin 3%	18.67	23.59	26.87
Copaiba Resin 4%	18.08	22.79	25.75
Copaiba Resin 5%	17.35	21.68	24.88
Copaiba Resin 6%	16.23	20.53	23.19

Figure 18 shows that, after 7 days, all doses of natural resins (ojé, sangre de grado and copaiba) caused a notable improvement in tensile strength compared to conventional concrete and concrete with Sika 1, reaching their maximum values at intermediate doses (around 3%). Blood of degree, ojé, and copaiba resins showed increases of between 14% and 19% over conventional concrete, and between 21% and 24% over Sika 1, highlighting the positive effect on the cohesion and toughness of the mixture in the early stages. At doses above 3%, the percentage of improvement began to decrease, and even at the highest doses (6%), some resins equalled or barely exceeded the values of the reference concretes. To 14 days, the percentages of improvement remained the same or even increased, reaching maximum values around 3% dose. For example, the 3% blood-grade resin showed an increase of up to 21% over conventional concrete and 24% over Sika 1. The other resins maintained the same pattern of optimal improvement at intermediate doses, although in all cases, higher doses caused a progressive reduction in the percentage increase. Finally, in 28 days, the beneficial effect of the resins was consolidated, maintaining the optimal range at intermediate doses. The three resins evaluated achieved increases of 19% to 21% over conventional concrete and 22% to 24% over Sika 1 at around 3% dosage. At doses above this

range, the percentage improvement decreased, although up to 6% they still remained above the reference values, falling below only when exceeding 6%. The increase in indirect tensile strength at around 3% resin addition is due to the fact that, at this proportion, the phenolic compounds, terpenoids and natural oils present in the resins act as colloidal agents that modify the paste-aggregate interface. This effect produces greater adhesion in the Interfacial Transition Zone (ITZ), reducing the formation of microcracks and increasing the effective transfer of tensile stresses through the matrix. Additionally, the presence of these organic molecules promotes moisture retention, which prolongs the hydration of the clinker and allows for the continuous formation of hydrated calcium silicate (C-S-H) gel around the cement grains, densifying the microstructure. However, when the dosage exceeds 3%, excess organic compounds can cause weak inclusions or physical interference in the matrix, generating surface films that reduce internal friction and facilitate the propagation of cracks under tensile stress. This saturation explains the progressive decrease in strength observed at high dosages, where the beneficial effect of resins on the ITZ and paste cohesion is counteracted by the loss of structural integrity of the cementitious network.

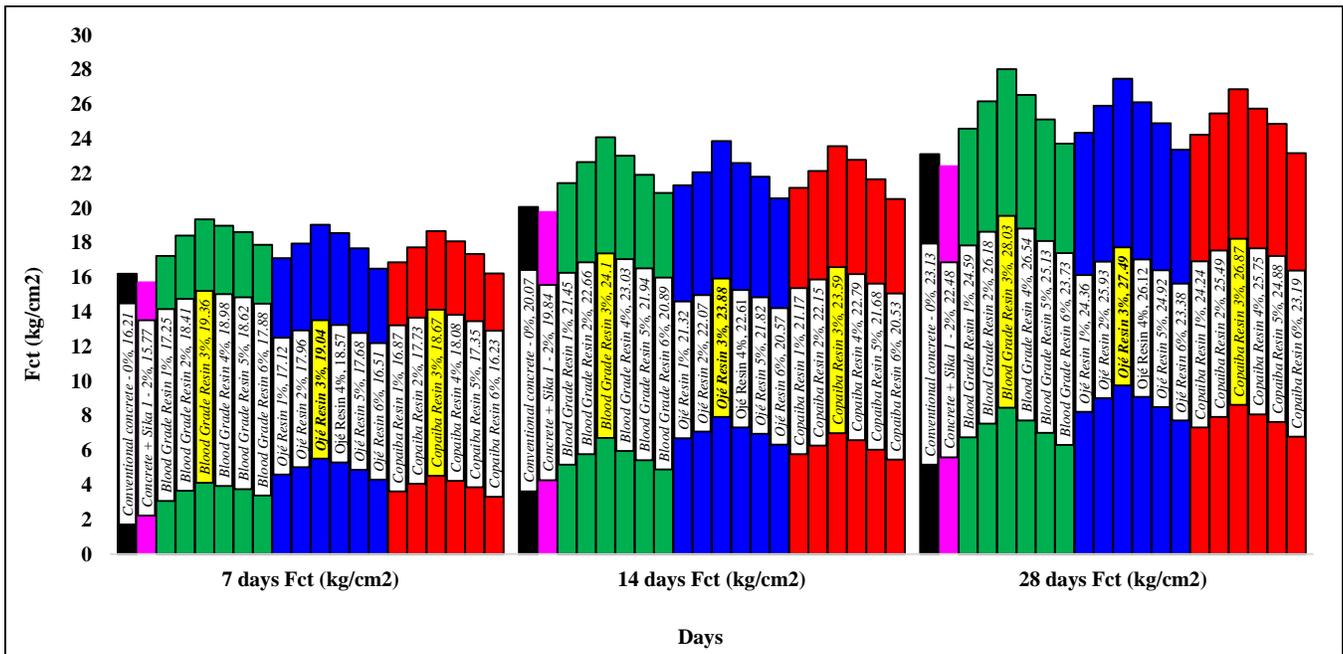


Fig. 18 Tensile strength test

4.5. ASTM C642 Test

Table 10 shows that conventional concrete had the highest absorption percentage (2.87%), indicating high porosity and ease of water ingress. Concrete with Sika 1 recorded the lowest value (1.36%), confirming its effectiveness in densifying the matrix and reducing absorption, while Sika-Bitumen achieved an intermediate

value (1.95%), reflecting its waterproofing action, although less effective than Sika 1. When analysing natural resins, a progressive decrease in absorption is observed until optimal doses are reached: ojé resin reduced absorption from 1.62% to 3%, sangre de grado from 1.55% to 3%, and copaiba from 1.66% to 3%. These values represent a significant decrease compared to conventional concrete and are close to the

efficiency shown by Sika-Bitumen. However, when the doses are increased above 3%, absorption increases slightly again, possibly due to insufficient dispersion of the additive or the formation of internal voids in the mixture. In conclusion, ojé, sangre de grado and copaiba resins proved to be effective additives for reducing the water absorption of concrete when used at optimal doses (around 3%), thus improving the impermeability of the matrix, although without reaching the maximum performance of Sika 1.

Table 10. Resultados del ensayo ASTM C642 – Absorción

Description	Absorción (%)
Conventional concrete - 0%	2.87%
Concrete + Sika 1 - 2%	1.36%
Sika – Bitumen 0.4 L/m ²	1.95%
Blood Grade Resin 1%	2.09%
Blood Grade Resin 2%	1.76%
Blood Grade Resin 3%	1.55%
Blood Grade Resin 4%	1.60%
Blood Grade Resin 5%	1.83%
Blood Grade Resin 6%	2.04%
Ojé Resin 1%	2.15%
Ojé Resin 2%	1.82%
Ojé Resin 3%	1.62%
Ojé Resin 4%	1.67%
Ojé Resin 5%	1.90%
Ojé Resin 6%	2.10%
Copaiba Resin 1%	2.18%
Copaiba Resin 2%	1.85%
Copaiba Resin 3%	1.66%
Copaiba Resin 4%	1.71%
Copaiba Resin 5%	1.93%
Copaiba Resin 6%	2.13%

Figure 19 shows a notable percentage reduction in absorption compared to conventional concrete (2.87%) for all natural additives at their optimal doses. Concrete with Sika 1 (1.36%) and Sika-Bitumen (1.95%) were used as references to compare waterproofing performance. For oje resin, the minimum absorption value was obtained at a 3% dosage (1.62%), representing a reduction of 43.5% compared to conventional concrete and 16.9% compared to Sika-Bitumen, although it remained 19.1% above Sika 1. In the case of blood grade resin, the lowest value was also recorded at 3% (1.55%), with a reduction of 46.0% compared to conventional concrete and 20.5% compared to Sika-Bitumen, but still 13.9% higher than Sika 1. Copaiba resin showed its best performance at a 3% dose (1.66%), with a decrease of 42.2% compared to conventional concrete and 14.9% compared to Sika-Bitumen. The behaviour observed in the ASTM C642 absorption test shows that natural resins have a densifying effect on the cement matrix when used in intermediate doses, particularly around 3%. In this range, organic compounds present in resins such as tannins, flavonoids, and resinous oils act as sealing agents in capillary pores, decreasing void connectivity and reducing internal permeability. This effect promotes the impermeability of concrete, as it limits water penetration into the porous network and improves the integrity of the Interfacial Transition Zone (ITZ) between paste and aggregate. However, when this threshold is exceeded, excess resin can cause microdefects due to agglomeration or poor dispersion in the mixture, which increases absorption again. Consequently, it is confirmed that the optimal dosage of natural resins to reduce water absorption is around 3%, where they achieve efficiencies comparable to commercial waterproofing additives such as Sika-Bitumen, although without reaching the maximum performance level recorded with Sika 1, whose mechanism of action is based on the formation of insoluble compounds that more effectively clog the capillary pores of concrete.

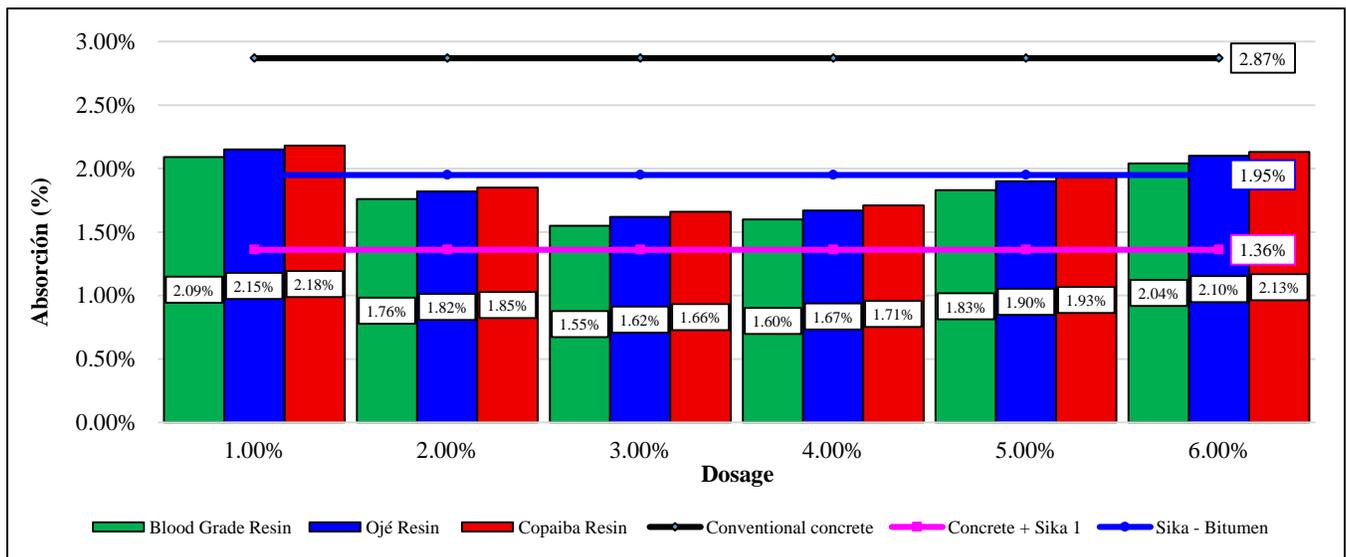


Fig. 19 ASTM C642 test

Table 11 shows that conventional concrete had the highest porosity (6.21%), confirming its greater vulnerability to permeability and deterioration due to external agents. Concrete with Sika 1 drastically reduced porosity to 3.02%, demonstrating its high effectiveness as a waterproofing additive, while Sika-Bitumen achieved an intermediate porosity of 4.01%. When analysing natural resins, it was observed that oje, sangre de grado and copaiba resins achieved their lowest porosity values at around 3% dosage (4.22%, 4.19% and 4.30%, respectively), indicating that at low to intermediate dosages they promote matrix compaction and effective pore closure. However, when the dosage was increased above 4%–5%, porosity increased again, exceeding 5% in some cases, which could be related to segregation or poor dispersion of the additive within the concrete. These results confirm that oje, sangre de grado, and copaiba resins significantly reduce the porosity of concrete within their optimal dosage range, contributing to improved impermeability and durability compared to conventional concretes.

Oje Resin 5%	4.75%
Oje Resin 6%	5.06%
Copaiba Resin 1%	5.20%
Copaiba Resin 2%	4.69%
Copaiba Resin 3%	4.30%
Copaiba Resin 4%	4.36%
Copaiba Resin 5%	4.76%
Copaiba Resin 6%	5.11%

Table 11. ASTM C642 test results – Porosity

Description	Porosity (%)
Conventional concrete - 0%	6.21%
Concrete + Sika 1 - 2%	3.02%
Sika – Bitumen 0.4 L/m ²	4.01%
Blood Grade Resin 1%	5.17%
Blood Grade Resin 2%	4.48%
Blood Grade Resin 3%	4.19%
Blood Grade Resin 4%	4.25%
Blood Grade Resin 5%	4.64%
Blood Grade Resin 6%	5.02%
Oje Resin 1%	5.13%
Oje Resin 2%	4.61%
Oje Resin 3%	4.22%
Oje Resin 4%	4.31%

Figure 20 shows a significant reduction in porosity percentage compared to conventional concrete (6.21%) with all additives and references evaluated. Concrete with Sika 1 obtained the minimum porosity value (3.02%), representing a 51.4% decrease compared to conventional concrete, while Sika-Bitumen recorded 4.01% (35.4% less than conventional concrete). Among the natural resins, the optimum porosity value for oje resin was achieved at a 3% dose (4.22%), achieving a reduction of 32.0% compared to conventional concrete and 5.0% compared to Sika-Bitumen, although it remained 39.7% above Sika 1. Blood-grade resin and copaiba resin also presented their lowest values at a 3% dose (4.19% and 4.30%, respectively), achieving reductions of 32.5% and 30.7% compared to conventional concrete and 4–5% compared to Sika-Bitumen. The decrease in porosity at a dosage of 3% is due to the fact that the polymeric compounds in natural resins (tannins, flavonoids and resinous oils) interact with the calcium ions released during cement hydration, generating precipitates and secondary bonds that contribute to the sealing of capillary pores. At the same time, the colloidal action of these molecules increases the viscosity of the liquid phase and promotes a more homogeneous distribution of the hydrated calcium silicate gel (C-S-H), densifying the microstructure. This chemical-physical equilibrium is optimally achieved at around 3%, resulting in a more compact matrix with lower pore connectivity, while higher doses cause saturation and internal defects that partially reverse the benefit.

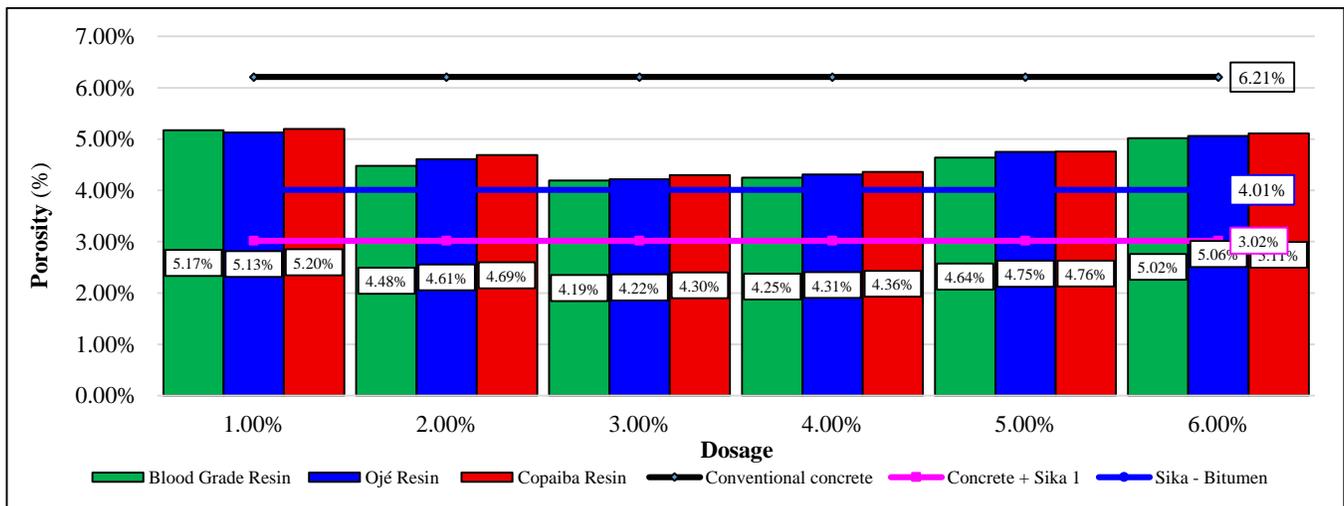


Fig. 20 ASTM C642 test results – Porosity

4.6. UNE-EN 12390-8 Test

Table 12 shows that conventional concrete had the highest water penetration depth (25.80 mm), which indicates high permeability and lower durability against aggressive agents. Concrete with Sika 1 achieved the lowest penetration value (13.10 mm), demonstrating its high waterproofing capacity, while Sika-Bitumen (18.90 mm) showed an intermediate effect.

Analysing the natural resins, it can be seen that the best reductions in water penetration were achieved at a dose of 3%, with values of 14.30 mm for oje resin, 13.80 mm for grado blood and 14.80 mm for copaiba. These results suggest that a controlled resin dosage optimises the closure of capillary pores and reinforces the internal barrier against water ingress, approaching the efficiency observed with synthetic additives.

However, when the optimal doses were exceeded, water penetration increased again, showing that an excess of organic matter can negatively affect the compaction and waterproofing performance of concrete. In summary, oje, sangre de grado, and copaiba resins were effective in reducing water penetration when used in optimal doses, providing a favourable balance between impermeability and sustainability.

Table 12. Results of the UNE-EN 12390-8 test

Description	Penetration (mm)
Conventional concrete - 0%	25.8
Concrete + Sika 1 - 2%	13.1
Sika - Bitumen	18.9
Blood Grade Resin 1%	20.1
Blood Grade Resin 2%	16.7
Blood Grade Resin 3%	13.8
Blood Grade Resin 4%	14.7
Blood Grade Resin 5%	16.4
Blood Grade Resin 6%	19
Oje Resin 1%	20.7
Oje Resin 2%	17.2
Oje Resin 3%	14.3
Oje Resin 4%	15.1
Oje Resin 5%	16.9
Oje Resin 6%	19.6
Copaiba Resin 1%	21
Copaiba Resin 2%	17.5
Copaiba Resin 3%	14.8
Copaiba Resin 4%	15.4
Copaiba Resin 5%	17.2
Copaiba Resin 6%	20

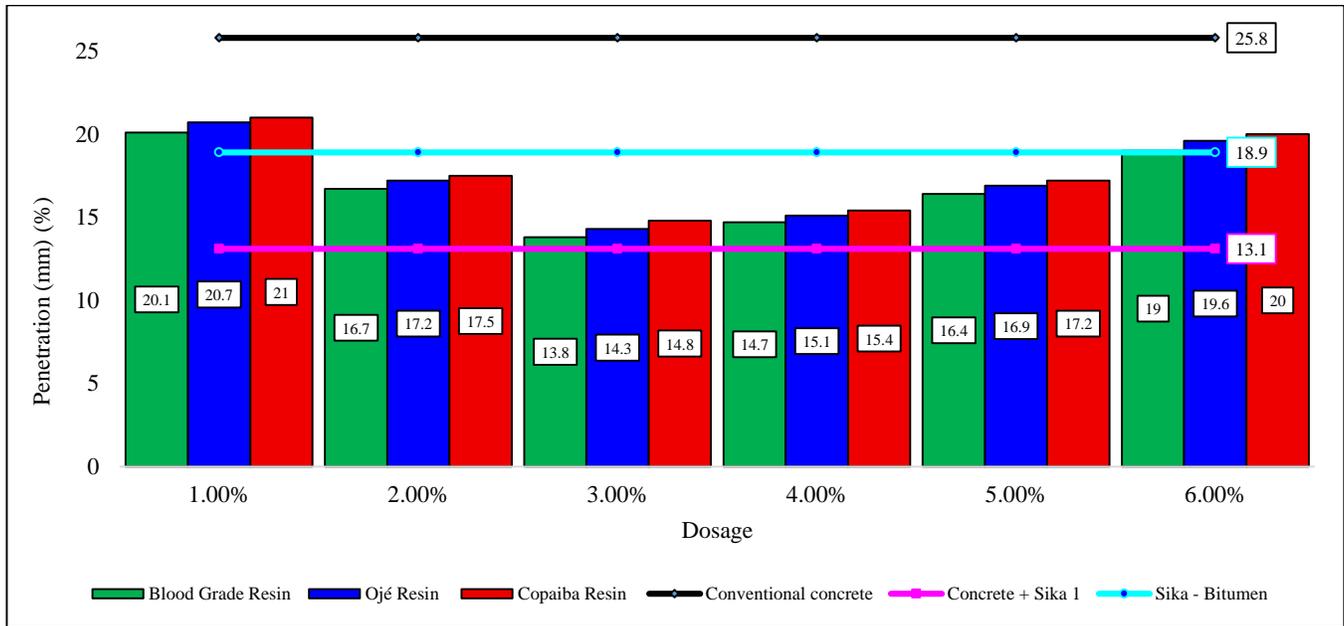


Fig. 21 UNE-EN 12390-8 test — Water penetration depth (mm)

Figure 21 shows a significant reduction in water penetration depth compared to conventional concrete (25.80 mm) for all additions and references evaluated. Concrete with Sika 1 obtained the lowest value (13.10 mm), representing a 49.2% decrease compared to conventional concrete, followed

by Sika-Bitumen with 18.90 mm (26.7% less than conventional concrete). Among the natural resins, the optimal values were achieved at a 3% dosage: oje resin reduced penetration to 14.30 mm (44.6% less than the conventional product and 24.3% less than Sika-Bitumen), while

sanguinolenta resin reached 13.80 mm (46.5% less than the conventional product and 27.0% less than Sika-Bitumen), just 5.3% above Sika 1. Copaiba resin showed 14.80 mm (42.6% less than conventional resin and 21.7% less than Sika-Bitumen). The UNE-EN 12390-8 test showed that the decrease in water penetration at a 3% dosage of natural resins is due to a physical sealing mechanism combined with a microstructural modification of the cementitious matrix. In this range, the phenolic compounds, terpenes, and acids present in the resins interact with the cement hydration products, mainly with the hydrated calcium silicate gel (C-S-H), promoting colloidal adsorption that reduces the connectivity of the capillary network and limits water transport. This process increases the densification of the matrix and improves impermeability, reaching penetration depths close to those obtained with synthetic additives, such as Sika-Bitumen, and close to the performance of Sika 1. However, when the addition exceeds 3%, the excess organic matter generates segregation and microvoids that interrupt the continuity of the C-S-H, re-establishing capillary routes and increasing penetration again. Therefore, 3% is the optimal technical dosage at which natural resins achieve an adequate balance between capillary sealing, internal densification, and resistance to water ingress.

4.7. Optimal doses of Natural Additives

The comparative evaluation of the tests carried out identified that the optimal doses for maximising the performance of concrete with natural additives were 3% of the weight of the cement for ojé, sangre de grado, and copaiba resins. These proportions achieved the highest compressive and tensile strength values, as well as the lowest absorption, porosity, and water penetration values. Within this optimal range, Amazonian resins reduced absorption by up to 46% and porosity by more than 32% compared to conventional concrete, in addition to reducing water penetration by between 42% and 47%, approaching or even exceeding the results obtained with Sika-Bitumen and showing values very close to Sika 1 in several parameters. Specifically, ojé, sangre de grado, and copaiba resins at a 3% dosage achieved water penetration depths and impermeability levels comparable to industrial additives, while doses above this optimal range did not generate additional benefits and even caused increases in the porosity and absorption of the concrete. Thus, the results justify that the use of these natural resins, in the correct doses, is an efficient and sustainable alternative to commercial waterproofing agents, contributing to improving the durability and performance of concrete in humid environments or those exposed to aggressive agents.

4.8. Cost of Obtaining Natural Additives

The collection of Ojé, Sangre de Grado, and Copaiba resins was carried out using traditional methods, drawing on traditional knowledge of field collection. This approach involved a greater requirement for direct labour, so 0.5 additional labourer days and 0.2 operator days were

incorporated into the unit cost analysis in order to accurately reflect the time and effort invested in the extraction, filtering, and initial preparation of the resins, as shown in Table 13. These labour costs are in addition to those considered in the unit analyses of conventional concrete, as well as those that include commercial additives such as bitumen or Sika-1, since these inputs do not require manual collection or prior treatment.

In terms of logistics, given that the amount required for each cubic metre of concrete was 12,406 litres of resin, only the cost of shipping was considered, as the resins were collected directly at source. This transport was valued according to the rate charged by a local company, which charges S/ 10.00 for every 20 litres transported, equivalent to S/ 0.50 per litre. Therefore, the total shipping cost per m³ was estimated at S/ 6.20, an amount that was included in the materials category for each type of resin. This valuation allowed for a more realistic reflection of the costs associated with an artisanal approach to production, highlighting both the human contribution and the specific logistical conditions of the rural context of origin.

Table 13. Total labour cost by type of concrete

Labour	Normal Concrete / Sika-1 / Bitumen	Concrete with Resins
Labourer (HH)	4	4.5
Operator (HH)	1	1.2
Equipment Operator (HH)	1	1
Total Cost (S/.)	S/ 136.69	S/ 152.25

4.9. Total Application Cost

Table 14 shows the total cost per cubic metre of conventional concrete and concrete modified with different waterproofing additives, both industrial and natural, at their optimal doses. Traditional concrete has the lowest cost, S/ 468.67, followed by concrete with Sika Bitumen (S/ 475.45). The addition of Sika-1 increases the cost to S/ 532.71, making it the most expensive option among the industrial additives evaluated.

In the case of natural Amazonian additives, concrete modified with 3% Amazonian resins (Ojé, Sangre de Grado, and Copaiba) has a uniform total cost of S/ 490.88 per cubic metre. These values show that natural resins, although slightly more expensive than classic concrete or concrete modified with Sika Bitumen, are more economical than the use of Sika-1, while offering a sustainable and renewable alternative. Thus, the use of these resins represents a technically and environmentally viable option for improving the durability and impermeability of concrete in areas exposed to high humidity, allowing for a balance between technical, economic, and ecological criteria in construction.

Table 14. Total cost of additives at optimal dosage

Description	Total Cost (m ³)
Classic Concrete	S/ 468.67
Concrete with Sika - 1	S/ 532.71
Concrete with Sika Bitumen	S/ 475.45
Concrete + Oje Resin (3%)	S/ 490.88
Sangre de Grado Resin (3%)	S/ 490.88
Copaiba Resin (3.0%)	S/ 490.88

Figure 22 shows the behaviour of the total cost per cubic metre of concrete when incorporating different types of waterproofing additives, both industrial and natural, in their optimal doses. Although the addition of these additives increases the cost compared to classic concrete, this increase is fully justified by the technical benefits and improved

durability they offer. Industrial additives such as Sika Bitumen (S/ 475.45) and Sika-1 (S/ 532.71) provide effective protection with a variable economic impact, facilitating the choice in projects where waterproofing is a priority. On the other hand, 3% Amazonian resins (Ojé, Sangre de Grado, and Copaiba) have a unified cost of S/ 490.88 per m³, and stand out for their natural origin and the use of local renewable resources. These alternatives not only improve the service life of concrete in humid environments but also promote sustainability, responsible use of biodiversity, and innovation in construction materials. Therefore, the choice of the most suitable additive should consider not only the initial cost, but also the long-term added value, the reduction of future maintenance and repair costs, structural durability, and the environmental benefit it represents for the community.

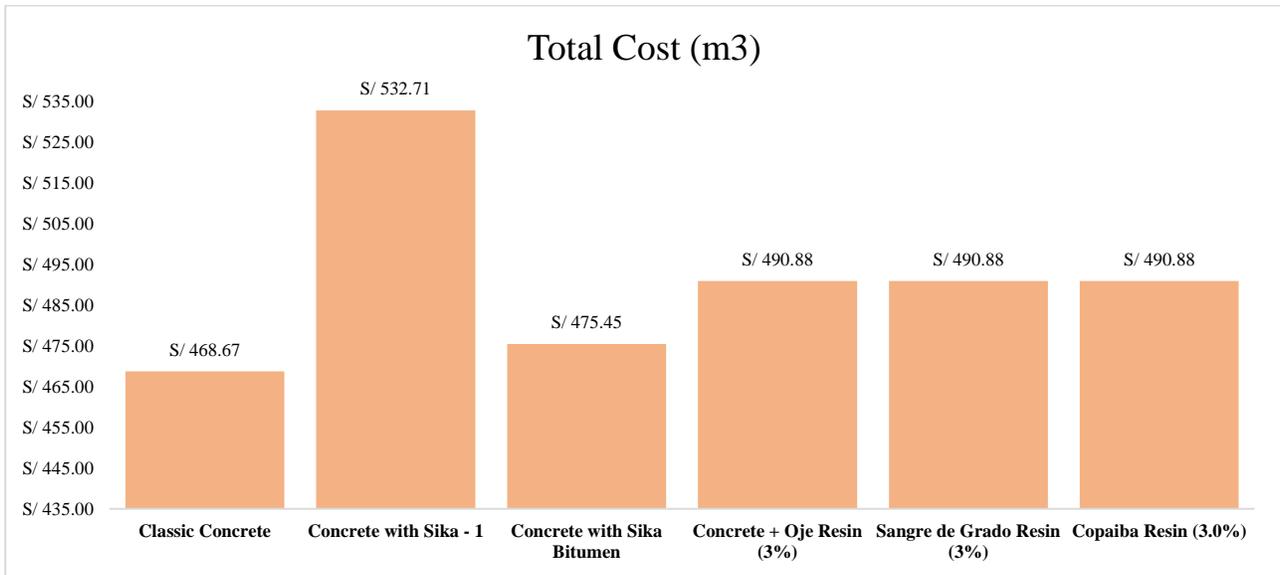


Fig. 22 Total cost per m³

4.10. Environmental Impact of Natural Additives

From an environmental engineering standpoint, the incorporation of Amazonian resins such as ojé, sangre de grado, and copaiba represents a measurable advance toward reducing the ecological footprint of cementitious materials. These bio-based additives are obtained through low-impact extraction processes, carried out under traditional forest management systems that avoid deforestation and maintain the regenerative capacity of the species. The tapping method employed involves shallow incisions in the bark of mature trees, ensuring sustainable yield cycles without compromising the physiological integrity or population density of the resource.

The production chain of these resins is characterised by minimal energy consumption and the absence of synthetic catalysts or volatile organic solvents, resulting in a negligible generation of greenhouse gases and non-hazardous residues. All by-products from filtering and concentration are

biodegradable and reintegrated into the environment through natural decomposition. This contrasts sharply with industrial waterproofing agents derived from petrochemical synthesis, whose manufacture involves high embodied energy and the emission of persistent pollutants.

At the material level, the use of natural resins as partial substitutes for synthetic additives directly contributes to the decarbonisation of the concrete manufacturing process. The substitution of petroleum-based compounds by renewable biopolymers allows for a reduction in life-cycle CO₂ emissions, improvement in the circularity index of construction materials, and alignment with sustainability frameworks such as ISO 14040 (Life Cycle Assessment) and the United Nations Sustainable Development Goals (9, 12, and 13).

Furthermore, the local sourcing of these resins generates short supply chains, reducing transportation-related emissions

and promoting territorial resilience. Their extraction provides economic incentives for rural and indigenous communities, fostering responsible forest management and the preservation of Amazonian biodiversity. This integration of traditional knowledge with applied engineering contributes to the social and environmental sustainability of construction materials, aligning technological development with ecosystem conservation principles.

5. Discussion

According to research conducted by Vargas Mamani (2022), the incorporation of molle and pine resins into rigid concrete increased compressive strength by 32.7% and improved flexural strength, provided that optimal doses were used to avoid negative effects on the workability of the mixture [73]. These results coincide in part with the findings of the present research, where the use of Amazonian resins such as ojé, sangre de grado and copaiba, dosed at 3%, increased compressive strength to 229.96 kg/cm² (4.7% more than conventional concrete and 6.0% more than Sika 1), in addition to improving indirect tensile strength and significantly reducing absorption, porosity, and water penetration in the concrete. Thus, it is validated that the use of natural resins as additives can provide structural reinforcement and impermeability comparable to or superior to that reported in the national literature, confirming their viability as an efficient and sustainable solution for civil works exposed to severe environmental conditions.

According to international research conducted in Canada by McIsaac and Fam (2018), the incorporation of FRP with bio-based resins in concrete beams exposed to 300 freeze-thaw cycles not only did not reduce mechanical strength, but even showed increases of up to 17% in maximum load capacity, attributed to additional curing in wet conditions. [74]. These results are consistent with those obtained in the present study, where the incorporation of Amazonian resins from ojé, sangre de grado and copaiba, at optimal doses of 3%, increased compressive strength (up to 229.96 kg/cm²), improved tensile strength and significantly reduced water absorption, porosity and penetration, equalling or even exceeding the performance of industrial additives such as Sika-1. In both studies, the use of bio-based additives improved both the structural performance and durability of concrete in aggressive environmental conditions. This reinforces the value of natural solutions, not only from a technical point of view, but also from an environmental and socio-economic perspective, promoting the responsible use of renewable resources in the construction industry.

According to research conducted by Kaya and Kar in Turkey, the incorporation of natural tragacanth resin into lightweight concrete with EPS aggregates increased porosity and decreased density, which significantly improved thermal insulation capacity, although it also reduced compressive and tensile strength compared to conventional concrete [75].

These findings are related to the results of the present investigation, where the use of Amazonian resins such as ojé, sangre de grado, and copaiba, dosed at 3%, improved impermeability and significantly reduced water absorption and penetration in concrete, while maintaining optimal mechanical strength values. Unlike the Turkish study, where the main focus was on lightness and insulation, this study achieved a balance between improved durability and structural reinforcement, validating that the use of plant resins not only contributes to sustainability but can also produce more efficient and durable concrete in demanding environmental conditions.

According to research conducted by Puntillo and Valverde (2023), partially replacing the mixing water with prickly pear mucilage in percentages of 2%, 5%, and 8% in concrete with a strength of 210 kg/cm², increased compressive strength by up to 14.5% and reduced water absorption by up to 17.41% with 8% mucilage, thus achieving greater durability and impermeability of the material [76]. These results coincide with those observed in the present study, where the incorporation of Amazonian resins such as ojé, sangre de grado, and copaiba in optimal doses (3%) also produced significant improvements in both mechanical strength and reduced water absorption, porosity, and penetration, even surpassing conventional industrial additives in several cases. This validates that the use of natural plant-based additives, such as Amazonian resins and prickly pear mucilage, provides both structural and environmental advantages, promoting more durable and sustainable concrete.

6. Conclusion

Firstly, the results obtained in this research confirmed that the incorporation of natural additives, specifically ojé resin, sangre de grado resin, and copaiba resin, represents a highly effective strategy for improving the impermeability, durability, and mechanical strength of concrete, especially for applications in walls exposed to high humidity. The controlled addition of these materials made it possible to optimise fundamental parameters such as compressive and tensile strength, as well as significantly reduce water absorption and penetration, in several cases exceeding the performance of conventional concrete and concrete treated with industrial additives.

Secondly, the addition of 3% oxy resin by weight of cement had a positive impact on the workability, mechanical strength, and impermeability of the concrete. This dosage achieved a compressive strength of 228.19 kg/cm² at 28 days (3.9% higher than conventional concrete and 5.1% higher than Sika - 1), and a tensile strength of 27.49 kg/cm² (18.85% higher than conventional concrete and 22.28% higher than Sika - 1). In terms of durability, absorption was reduced to 1.62% (43.5% less than conventional concrete), porosity to 4.22% (32% less), and water penetration to 14.30 mm (44.6% less than conventional concrete). These results confirm that

oje resin, at its optimal dosage, is an efficient natural alternative for improving the performance of concrete against moisture and external agents. Thirdly, blood resin, at an optimal dose of 3%, showed the greatest increase in compressive strength (229.96 kg/cm² at 28 days, equivalent to 4.7% more than the conventional product and 6.0% more than Sika 1) and the highest tensile strength among the additives evaluated (28.03 kg/cm², i.e., 21.2% higher than the conventional additive and 24.7% higher than Sika 1).

It also achieved the lowest water absorption (1.55%), the lowest porosity (4.19%), and the lowest water penetration depth (13.80 mm, only 5.3% above Sika 1). This positions blood-grade resin as the natural additive with the best overall performance, surpassing even the results obtained with some industrial additives and promoting more sustainable solutions for construction.

Fourthly, 3% copaiba resin yielded a compressive strength of 227.63 kg/cm² at 28 days (3.7% higher than conventional concrete and 5.0% higher than Sika 1), and a tensile strength of 26.87 kg/cm² (16.2% higher than conventional concrete and 19.6% higher than Sika 1). In terms of durability, the minimum absorption was 1.66% (42.2% less

than conventional concrete), porosity was 4.30% (30.7% less), and water penetration depth was 14.80 mm (42.6% less than conventional concrete). Fifthly, all the Amazonian resins evaluated (Ojé, Sangre de Grado, and Copaiba) were applied at a dosage of 3% of the weight of the cement, reaching a total cost per m³ of concrete of S/ 490.88. This value is lower than that of concrete modified with Sika-1 (S/ 532.71) and just above that of concrete with Sika Bitumen (S/ 475.45), demonstrating that these natural alternatives not only offer substantial technical improvements but also economic competitiveness compared to industrial additives.

This balanced relationship between performance and cost reinforces the viability of vegetable resins as sustainable solutions in works exposed to humid and aggressive environmental conditions. Finally, the results obtained establish a solid basis for the development and implementation of more sustainable and efficient construction solutions through the use of natural additives. The replicability of this methodology and its technical, economic, and environmental benefits position plant-based resins as high-value-added alternatives, promoting innovation and sustainability in the construction industry in regions with available resources and structural durability challenges.

References

- [1] Nicol Selene Baldeón Trigozo et al., "Urban Renaturalization Strategies for Social Integration and Prevention of Informal Expansion in Laderas de Villa María del Triunfo, Lima, Peru," *U. Llaqta*, vol. 2, no. 1, pp. 35-53, 2024. [[Google Scholar](#)] [[Publisher Link](#)]
- [2] Giofianni Peirano, Luis Enrique de la Flor Sáenz, and Jordy Vilchez Astucuri, "Analysis of Urban Growth and Expansion at the National Level and its Impact at the Regional Level," National Center for Strategic Planning, pp. 1-44, 2023. [[Google Scholar](#)] [[Publisher Link](#)]
- [3] Collantes Yanqui, and Frederic Jair, "Green Spaces and Sustainable Urban Development in the District of San Ramón," Thesis, 2021. [[Google Scholar](#)]
- [4] Jhon Maycoll Rene, and Ramos Caso, "Floodable Areas in Different Return Periods Applying the Hydraulic Simulation Model, Urban Section of the San Ramón River, Pangoa-Satipo," Thesis, National University of Central Peru, pp. 1-173, 2019. [[Google Scholar](#)] [[Publisher Link](#)]
- [5] Xinyu Huo et al., "Experimental Study on the Mechanical Properties and Impermeability of Basalt-PVA Hybrid Fibre Reinforced Concrete," *Case Studies in Construction Materials*, vol. 21, pp. 1-13, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [6] Shun Kang et al., "Enhancing Concrete's Resistance to Sulfate Corrosion: Comparative Study of Silane Surface Protection and Polyvinyl Alcohol Aggregate Encapsulation," *Case Studies in Construction Materials*, vol. 22, pp. 1-14, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [7] Maldonado Huayaney, Ronald Fred, and Miguel Augusto Alan Nolasco, "Evaluation of Concrete with HS Cement and Pozzolan against Sulfate Attack in the Presence of Moisture - Chilca District," Bachelor Thesis, Peruvian University of Applied Sciences (UPC), pp. 1-63, 2024. [[Google Scholar](#)] [[Publisher Link](#)]
- [8] Maribel Trujillo, and Y. Alexandra OSSA, "Resistance to Moisture-Induced Damage in Air-Purifying Flooring," *Geotechnical Engineering in the XXI Century: Lessons Learned and Future Challenges*, pp. 1657-1666, 2019. [[Google Scholar](#)]
- [9] New Infrastructure at Iquitos Hospital "is Leaking Everywhere", Diariolaregion, 2022. [Online]. Available: <https://diariolaregion.com/nueva-infraestructura-del-hospital-iquitos-hace-agua-por-todos-lados/>
- [10] Pucallpa Regional Hospital Flooded by Torrential Rains, Infobae, 2022. [Online]. Available: <https://www.infobae.com/america/peru/2022/11/02/hospital-regional-de-pucallpa-se-inunda-por-torrencales-lluvias/>
- [11] Heavy Rains Flood Streets and Homes in Iquitos, Exitosa Noticias, 2023. [Online]. Available: <https://www.exitosanoticias.pe/edic-impres/lluvias-inundan-calles-viviendas-iquitos-n14254>
- [12] Residents Report a Leak of Drinking Water in their Street, Diariolaregion, 2022. [Online]. Available: <https://diariolaregion.com/vecinos-denuncian-filtracion-de-agua-potable-en-su-calle/>
- [13] Méndez Aguilar, and Junior José, "Natural Waterproofing for Roofs in Historic Buildings Based on Lignin for its Hydrophobic Properties," Master Thesis, Autonomous University of Aguascalientes, pp. 1-178, 2023. [[Google Scholar](#)] [[Publisher Link](#)]

- [14] Edith Hernández-Piedrazul, Ivan E. Castañeda-Robles, and Liliana Lizárraga-Mendiola, “Bioconcrete as a Repair Agent in Concrete Structures,” *Pädi Scientific Bulletin of Basic Sciences and Engineering of the ICBI*, vol. 10, no. S2, pp. 176-183, 2022. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [15] Shyamkumar Mani, Pachaiyannan Partheeban, and C. Chella Gifta, “A Comprehensive Review on Multilayered Natural-Fibre Composite Reinforcement in Geopolymer Concrete,” *Cleaner Materials*, vol. 16, pp. 1-15, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [16] Şermin Koçyiğit, “Thermal and Mechanical Properties of Eco-Friendly Lightweight Concrete Based on Pine Resin and Recycled Expanded Glass Aggregate,” *Journal of Materials in Civil Engineering*, vol. 36, no. 12, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [17] Ayse Bicer, and Nevin Celik, “Influence of Pine Resin on Thermo-Mechanical Properties of Pumice-Cement Composites,” *Cement and Concrete Composites*, vol. 112, 2020. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [18] Ayse Bicer, “The Effect of Fly Ash and Pine Tree Resin on Thermo-Mechanical Properties of Concretes with Expanded Clay Aggregates,” *Case Studies in Construction Materials*, vol. 15, pp. 1-10, 2021. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [19] Se-Eon Park et al., “Surface Properties of Concrete and Bonding Strength of Pine Resin-Based Adhesives to Concrete Surfaces,” *Advances in Civil Engineering*, vol. 2023, no. 1, pp. 1-10, 2023. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [20] Arianna Zanoni et al., “Redispersible Polymer Powders with High Bio-Based Content from Core-Shell Nanoparticles,” *Macromolecular Materials and Engineering*, vol. 308, no. 1, pp. 1-10, 2023. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [21] Cieza Orrillo, Liliana Dalila, and Diana Carolina Rivadeneyra Larrain, “Formulation of Briquettes Based on Rice Husk (*Oryza Sativa*) to be Used as Fuel for Ecoregional Stoves, in the Lambayeque Region, 2012,” Thesis, Lord of Sipán University, 2013. [[Google Scholar](#)] [[Publisher Link](#)]
- [22] Torres Romero Dana Cibignia, and Vasquez Bonifaz Jhonatan Kelvin, “Physical and Mechanical Properties of Hydraulic Concrete Modified with Ojé Resin and Lime Applied in Stormwater Drainage, Ucayali 2022,” Degree Thesis, Cesar Vallejo University, 2022. [[Google Scholar](#)] [[Publisher Link](#)]
- [23] Camila Diedrich et al., “Bioactive Compounds Extraction of Croton Lechleri Barks from Amazon Forest Using Chemometrics Tools,” *Journal of King Saud University - Science*, vol. 33, no. 4, pp. 1-6, 2021. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [24] Zheng Chen et al., “Effects of Croton Lechleri Sap (Sangre de Drago) on AGEs Formation, LDL Oxidation and Oxidative Stress Related to Vascular Diseases,” *Natural Product Research*, vol. 36, no. 16, pp. 4165-4169, 2022. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [25] Ricardo D.D.G. de Albuquerque et al., “A Review on Phytochemistry and Recent Pharmacology of Dragon’s Blood (Croton lechleri), a Multifunctional Ethnomedicinal Resource from the Amazon Forest,” *Planta Medica*, vol. 91, no. 8, pp. 409-418, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [26] Apaza Ipanaqué, Manuel Ángel, and Nataly Milagros Verástegui Legua, “In Vitro Anti-Inflammatory Effect of the Methanolic Extract of the Latex of *Ficus Insipida* (ojé) on the Stabilization of the Erythrocyte Membrane,” Degree Thesis, pp. 1-41, 2021. [[Google Scholar](#)] [[Publisher Link](#)]
- [27] Mendoza Elías Natalia Andrea, and Chávez Lozada José Luis, “Healing Effect of the Gel Made from the Combination of *Copaifera Paupera* (Copaiba) Oil and the Methanolic Extract of *Ficus Insipida* Willd (ojé) Latex on Wounds Induced in Albino Mice,” Thesis, Inca Garcilaso de la Vega University, 2019. [[Google Scholar](#)] [[Publisher Link](#)]
- [28] Fernanda Lopes de Mesquita Vieira et al., “Applicability of NMR in Combination with Chemometrics for the Characterization and Differentiation of Oil-Resin Extracted from *Copaifera Langsdorffii* and *Copaifera* spp.,” *Microchemical Journal*, vol. 197, pp. 1-23, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [29] Joaquín Antonio Quiroz Carranza, and Miguel Alberto Magaña Alejandro, “Natural Resins from Mexican Plant Species: Current and Potential Uses,” *Wood and Forests*, vol. 21, no. 3, pp. 171-183, 2015. [[Google Scholar](#)] [[Publisher Link](#)]
- [30] Félix Pinillos, Álvaro Picardo, and Miguel Allué-Andrade, *Resin: A Tool for Preserving our Pine Forests*, pp. 1-78, 2009. [[Google Scholar](#)] [[Publisher Link](#)]
- [31] Anai Paola Prissila Flores Gonzales, Gracienhe Gomes Santos, and Marcos Tavares-Dias, “Anthelmintic Potential of the *Ficus Insipida* Latex on Monogeneans of *Colossoma Macropomum* (Serrasalmidae), A Medicinal Plant from the Amazon,” *Acta Parasitologica*, vol. 64, pp. 927-931, 2019. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [32] Curinuqui López Luz Margarita, and Pérez Reátegui Viviana, “Efficacy of *Ficus Insipida* Latex in the Control of Monogenean Ectoparasites of *Brochis Splendens* and *Colossoma Macropomum* in Loreto,” Thesis, National University of the Peruvian Amazon, pp. 1-54, 2021. [[Google Scholar](#)] [[Publisher Link](#)]
- [33] Anders Hansson, Julio C. Zelada, and Hugo P. Noriega, “Reevaluation of Risks with the Use of *Ficus Insipida* Latex as a Traditional Anthelmintic Remedy in the Amazon,” *Journal of Ethnopharmacology*, vol. 98, no. 3, pp. 251-257, 2005. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [34] Fernando M. Mendive, “Sangre de Grado and Copaiba: Amazonian Resins that Protect your Skin,” *Mantrasurbanos*, 2015. [[Google Scholar](#)] [[Publisher Link](#)]

- [35] Arana Solis, and Antony Alejandro, “Preliminary Studies of the Therapeutic Potential of (*Croton Lechleri*) Sangre de Grado,” Bachelor Thesis, Catholic University of Saint Mary, pp. 1-60, 2024. [[Google Scholar](#)] [[Publisher Link](#)]
- [36] Dieter Manstein, and Vanessa Silebi, “Enhanced Antibacterial Effect of Blue Light in Combination with an Amazonian Tree Sap (*Croton Lechleri*),” *Photochemistry and Photobiology*, vol. 101, no. 5, pp. 1350-1360, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [37] Deepika Gupta, Bruce Bleakley, and Rajinder K. Gupta, “Dragon's Blood: Botany, Chemistry and Therapeutic Uses,” *Journal of Ethnopharmacology*, vol. 115, no. 3, pp. 361-380, 2008. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [38] Giovana Solheid Gil et al., “Effect of Copaiba Oil-Resin on Dental Sensitivity Control and Color Change after Bleaching: A Randomized Clinical Trial,” *Clinical Oral Investigations*, vol. 29, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [39] Leonardo C. Queiroz et al., “Determination of Adulterants in Copaiba Oil-Resin Using ¹H NMR,” *Microchemical Journal*, vol. 213, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [40] Thaís Magalhães Acacia, “Phytochemical Study, Quality Control and Development of a Phytotherapeutic Formulation of *Copaifera Officinalis* (Copaiba) Resin Oil for Adjuvant Therapy in Cancer Patients,” Master's Thesis, Federal University of Minas Gerais, pp. 1-153, 2023. [[Google Scholar](#)] [[Publisher Link](#)]
- [41] Dan Huang, Guangshuai Han, and Ziyang Tang, “Optimizing Concrete Strength: How Nanomaterials and AI Redefine Mix Design,” *Case Studies in Construction Materials*, vol. 22, pp. 1-20, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [42] Rishikesh Duarah et al., “Inclusive approach for Mix Proportioning of Dry Lean Concrete Based on the Experimental Study on the Effect of Cement and Coarse Aggregate Content on Strength and Abrasion Characteristics,” *Construction and Building Materials*, vol. 486, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [43] Muzeyyen Balcikanli Bankir, “Statistical Investigation of the Effects of w/c, Cement Dosage and Fibers on Bond Strength and Carbonation Coefficient of Hybrid Fiber Concretes,” *KSCCE Journal of Civil Engineering*, vol. 27, pp. 4812-4822, 2023. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [44] Pacori Herb Nilton Elvis, “Evaluation of the Permeability and Mechanical Properties of Concrete in the Construction of a Cistern, with Sika -1 Additive, in the City of Juliaca, Province of San Román - Puno,” Thesis, Continental University, pp. 1-150, 2024. [[Google Scholar](#)] [[Publisher Link](#)]
- [45] Cruz León, Arturo Marcos Guillermo, and Bryan Alexis Medina Romero, “Influence of the Water-Cement Ratio, Type of Waterproofing Additive and Cement on Compressive Strength and Permeability in Concrete in Hydraulic Structures, Trujillo, 2018,” Thesis, Private University of the North, 2019. [[Google Scholar](#)]
- [46] 2024 ASI Top 20: Sika, Adhesivesmag. [Online]. Available: <https://www.adhesivesmag.com/articles/101085-2024-asi-top-20-sika>
- [47] Baiheng Liao et al., “A Review of Exterior Waterproofing Technologies in Prefabricated Buildings,” *E3S Web of Conferences*, vol. 606, pp. 1-11, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [48] Concrete Waterproofing. [Online]. Available: <https://impermeabilizaciondelconcreto.wordpress.com/2019/06/30/como-actua-el-concreto-impermeable-para-evitar-filtraciones-de-agua/>
- [49] Md. Habibur Rahman Sobuz et al., “Microstructural Behavior and Explainable Machine Learning Aided Mechanical Strength Prediction and Optimization of Recycled Glass-Based Solid Waste Concrete,” *Case Studies in Construction Materials*, vol. 22, pp. 1-24, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [50] Muhammad Waqas Ashraf et al., “Experimental Investigation of Coal Bottom Ash Concrete Mechanical Properties and Development of Novel Swarm Optimized Tree-Based Explainable Models,” *Case Studies in Construction Materials*, vol. 22, pp. 1-20, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [51] M. Guadalupe, “Costs and Budgets in Building-CAPECO,” pp. 1-375, 2015. [[Google Scholar](#)] [[Publisher Link](#)]
- [52] Concrete Mix Design 210: How to Ensure Quality and Strength, Construyendoseguro. [Online]. Available: <https://www.construyendoseguro.com/dosificacion-de-concreto-210-como-asegurar-calidad-y-resistencia/>
- [53] Sathya Sai Regalla, and N. Senthil Kumar, “Optimizing Ultra High-Performance Concrete (UHPC) Mix Proportions Using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for Enhanced Performance: Precision towards Optimal Concrete Engineering,” *Case Studies in Construction Materials*, vol. 22, pp. 1-20, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [54] Vania. Vilcahuaman Irigoyen, “Analysis of Plain Concrete with Bituminous Additives for Foundation Walls Against the Effects of Saltpeter in the City of San José,” Bachelor's Thesis, Catholic University Santo Toribio de Mogrovejo, 2024. [[Google Scholar](#)] [[Publisher Link](#)]
- [55] Kevin Pool Steal Vicente, “Analysis of the Concrete Strength $f'c = 280 \text{ kg/cm}^2$ Under five Types of Curing According to the ACI 308 Technical Standard in Huánuco in 2020,” Thesis, University of Huanuco, pp. 1-127, 2022. [[Google Scholar](#)] [[Publisher Link](#)]
- [56] Sika® Bitumen, 2022. [Online]. Available: https://per.sika.com/dam/dms/pe01/x/sika_bitumen.pdf
- [57] Concrete Primer: Bituminous Roofing Primer. [Online]. Available: <https://bitumat.com/pdf/bituminous/Concrete%20Primer.pdf>
- [58] Callum White, and Janet M. Lees, “The Concrete Slump Test—A Rheometer by Definition?,” *Construction and Building Materials*, vol. 462, pp. 1-16, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [59] Tobias Schack, Max Coenen, and Michael Haist, “Digital Slump Flow: Image-Based Assessment of Fresh Concrete Homogeneity as Part of the Slump Flow Test,” *Case Studies in Construction Materials*, vol. 21, pp. 1-19, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]

- [60] Michael Autischer et al., “Improved Rheological Characterisation of Self-Compacting Cementitious Pastes and Concrete by Advanced Slump Flow Test Analysis,” *Construction and Building Materials*, vol. 452, pp. 1-19, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [61] Bo Wu, and DaoZhong Wu, “Test Study on Hydration Temperature of Compound Concrete Made of Demolished Concrete Lumps and Fresh Concrete,” *Procedia Engineering*, vol. 210, pp. 120-125, 2017. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [62] Abdeliazim Mustafa Mohamed et al., “Fresh, Hardened, Durability and Microstructure Properties of Seawater Concrete: A Systematic Review,” *Journal of CO2 Utilization*, vol. 83, pp. 1-25, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [63] Yu Xiang et al., “A New Approach for Characterizing Internal Stress of Fresh Concrete During Thermal Treatment Period,” *Case Studies in Construction Materials*, vol. 20, pp. 1-15, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [64] Ghasem Pachideh et al., “Compressive Strength Ratios of Concretes Containing Pozzolans under Elevated Temperatures,” *Heliyon*, vol. 10, no. 5, pp. 1-16, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [65] Chi-Cong Vu, and Ngoc-Khoa Ho, “A Comparative Study on the Probability Distribution Model for the Compressive Strength of Concrete with Consideration of the Size Effect,” *Journal of Engineering Research*, vol. 13, no. 2, pp. 1403-1413, 2023. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [66] Mounir El Marzak et al., “Rheological and Mechanical Analysis of Self-Compacting Concrete Incorporating Rubber Aggregates,” *Case Studies in Construction Materials*, vol. 22, pp. 1-15, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [67] Zhengyang Song, Thomas Frühwirt, and Heinz Konietzky, “Fatigue Characteristics of Concrete Subjected to Indirect Cyclic Tensile Loading: Insights from Deformation Behavior, Acoustic Emissions and Ultrasonic Wave Propagation,” *Construction and Building Materials*, vol. 302, 2021. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [68] Stefany Smithand Álvarez Hilorio, and Christian Gerard Coriat Zavaleta, “Study of the Density, Absorption Percentage, and Voids of Cement-Sand Concrete Using the ASTM C 642 Standard, Iquitos - 2021,” Thesis, Scientific University of Peru, pp. 1-131, 2021. [[Google Scholar](#)] [[Publisher Link](#)]
- [69] Hanz Abraham Pérez Calderón, “Permeability of Concrete, Made with Hydraulic Cement for General Use, Comparative Analysis According to ASTM C-642-92 and ASTM C1202 Standards; Using Different Water-Cement Ratios,” Thesis, University of San Carlos of Guatemala, pp. 1-124, 2021. [[Google Scholar](#)] [[Publisher Link](#)]
- [70] Jorge Luis Espino Guevara, “Study of the Reduction of Permeability of Concrete Intended for Water Storage Structures, Using Permeability-Reducing Additives,” Thesis, Pontifical Catholic University of Peru, 2019. [[Google Scholar](#)] [[Publisher Link](#)]
- [71] Paulina Viera, Dayra Morillo, and Jofre Parion, “Influence of Natural and Synthetic Fibers on the Permeability of Cement Mortars - Sand, and, Cement, Lime and Sand,” *FIGEMPA: Research and Development*, vol. 13, no. 1, pp. 59-69, 2022. [[Google Scholar](#)] [[Publisher Link](#)]
- [72] Ismar José Pérez Monroy, “Permeability of Concrete, Made with Hydraulic Cement for General Use, According to Standard UNE-EN 12390-8 and ASTM C1202, Using Different Water-Cement Ratios,” Thesis, University of San Carlos of Guatemala, pp. 1-126, 2019. [[Google Scholar](#)] [[Publisher Link](#)]
- [73] Armando Vargas Mamani, “Influence of Molle and Pine Resins on Rigid Pavement f.c. 210kg/cm² Triunfadores Street, San Jerónimo-Cusco 2022,” Thesis, César Vallejo University, 2022. [[Google Scholar](#)]
- [74] Anne McIsaac, and Amir Fam, “Durability under Freeze–Thaw Cycles of Concrete Beams Retrofitted with Externally Bonded FRPs Using Bio-Based Resins,” *Construction and Building Materials*, vol. 168, pp. 244-256, 2018. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [75] Ayse Kaya, and Filiz KAR, “Properties of Concrete Containing Waste Expanded Polystyrene and Natural Resin,” *Construction and Building Materials*, vol. 105, pp. 572-578, 2016. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [76] Puntillo Suarez Anthony Jeremy, and Valverde Agama Noe, “Influence of Prickly Pear Mucilage on the Properties of 210kg/cm² Concrete, Carhuaz 2023,” Thesis, Cesar Vallejo University, 2023. [[Google Scholar](#)] [[Publisher Link](#)]