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Article

Using Biopolymers as Anti-Washout Admixtures under Water Concreting

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Abstract: In this study, we investigate the use of natural additives (biopolymers) resistant to scouring. To this end, three natural substances, Kathira, sodium alginate, and guar gum, have been utilized as additives resistant to scouring, and we examine their mechanical performance, resistance to scouring, and the properties of fresh concrete including slump test, setting time, and ultimately shrinkage test. For this purpose, a total of 12 cylindrical specimens with dimensions of 15 by 30 cm were prepared for 28-day compressive strength test, and 12 cylindrical specimens with dimensions of 15 by 30 cm were prepared for 28-day indirect tensile strength test. Additionally, 12 concrete beams with dimensions of 10 by 10 by 35 cm were fabricated for a 28-day flexural strength test. All laboratory specimens were submerged in lime-saturated water for hydration for a period of 28 days for maintenance and preservation. The results indicate that all three biopolymers improve resistance to scouring, and, two substances enhance compressive, tensile, and flexural strength. Furthermore, all of them lead to a reduction in concrete shrinkage.

Keywords: underwater concrete; biopolymer additives; washout resistance; environmentally friendly

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1. Introduction

Concrete is a versatile material extensively utilized across a wide array of structures. With the advancements in science and technology in the present era, there has been a notable growth in comprehending the diverse types of concrete, additives, and their respective properties.

Piles serve as structural elements employed for transferring surface loads to soil depths, particularly when superficial soil layers lack adequate resistance and underground assessments indicate the presence of resilient layers at depth. Piles mitigate foundation uplift and lateral movement during seismic events.

Nevertheless, challenges arise when groundwater levels are elevated or when constructing piles in water bodies such as rivers or lakes, where casting concrete for these piles becomes problematic. One such challenge pertains to the casting of underwater concrete, leading to concrete washout and subsequent reduction in compressive, tensile, and flexural strengths. Cement dissolution in groundwater, rivers, and seas during concrete casting contributes to pollution and environmental concerns.

In contemporary times, a variety of concrete types, including underwater concrete, are manufactured utilizing different materials and additives, each tailored to specific properties and applications. Among these, washout-resistant concrete stands out.

To optimize concrete performance under varying conditions, a range of additives is employed. However, given the global environmental scenario and concerns about climate change, the use of natural biopolymers emerges as one of the most promising additives, owing to their environmental compatibility and minimal ecological footprint [1,2].

Underwater concrete (UWC) is manufactured using anti-washout admixtures (AWAs), which are water-soluble polymers that, upon absorbing water, create viscous concrete mixes. However, in practical applications, underwater concrete often faces issues such as segregation, cement washout, cold joints, and low workability during construction. To address these challenges and uphold the concrete's strength, workability, durability, and flowability, viscosity modifiers are incorporated. These modifiers increase the concrete's viscosity, thereby reducing its fluidity and enhancing its resistance to dispersion. Additionally, non-dispersible underwater concretes exhibit self-leveling and self-compacting characteristics.

Anti-washout underwater concrete boasts notable features such as excellent viscosity and flexibility, low dispersibility, minimal water pollution potential, and low heat of hydration. As a result, it proves to be more dependable for large-scale applications in underwater and underground engineering projects. To ensure adequate flowability and heightened washout resistance, UWC must possess appropriate rheological properties [3].

This article utilizes three natural biopolymers as additives for concrete, and various experiments have been conducted on different samples to determine the performance of each of them.

2. State-of-the-Art Review

Khayat et al. (1995) investigated the effect of scour-resistant additives on fresh concrete. According to their findings, these additives can be categorized into five groups based on their physical performance:

The first category comprises natural, water-soluble organic polymers that enhance concrete viscosity. The second category includes natural coagulants soluble in water, which bond cement particles together, increasing concrete viscosity. Some examples include various types of resins. The third category involves emulsions of organic materials that boost particle attraction, such as acrylics. The fourth category consists of minerals with a high specific surface area that swells upon contact with water, enhancing concrete adhesive holding capacity. Bentonites are an example of this category. The fifth category encompasses minerals with a high specific surface area that increases the amount of fine particles in concrete binders, such as fly ash. Test results on these materials indicated that incorporating any of them into concrete enhances water resistance and reduces the risk of concrete particle separation. The use of these materials mitigates cement separation by melting and increases concrete viscosity, facilitating easier workability [2].

In 2001, Sonebi et al. conducted research on the effects of anti-washing additive concentration, water-to-cement (w/c) ratio, and binder compounds on washing resistance. Two types of anti-washing additives and two w/c ratios (0.41 and 0.47) were utilized. The conclusion drawn from the tests highlighted that the concentration of anti-washing additives directly influences concrete resistance against washing [4].

In 2015, Heniegal et al. explored underwater concrete containing anti-wash additives, specifically a concrete mixture incorporating Silica Fume. Various tests were performed, ultimately concluding that the use of anti-wash additives has numerous advantages in underwater concrete, including increased concrete strength and prevention of concrete washout [5].

In 2018, Tabaoda et al. researched recycled self-compacting concrete (SCRC) and evaluated its thixotropy. Two bending tests and a water permeability test were conducted, revealing that thixotropy and interlayer strength are influenced by variations in the water-to-cement (w/c) ratio. Consequently, higher uncompensated water absorption levels were observed in the fine particles of recycled and produced aggregates [6].

In 2018, Joshaghani and colleagues investigated the effects of environmental conditions on the mechanical properties, structure, and durability of concrete. They concluded that temperature, environmental conditions, and humidity impact the properties and durability of concrete. Their research aimed to examine the effects of environmental conditions on the dielectric constant, microscopic analysis, and electrical resistance. Samples with two water-to-cement ratios were subjected to three temperatures (25, 46, and 65 degrees Celsius) and two humidity levels (30% and 90%). The test results indicated that higher temperatures could reduce compressive strength, while higher relative humidity positively contributed to concrete properties and durability [7].

In 2019, Grzeszczyk et al. investigated the effects of nanoparticles (SiO_2) on the washing of underwater and hardened concrete, utilizing infrared spectroscopy (FTIR) and thermal analysis (TGA), along with the application of an anti-washing additive (AWA). The chemical structure of the additive was determined, concluding that nanoparticles (SiO_2) have a beneficial effect on underwater concrete, reducing concrete washing underwater [8].

Zhang et al. (2020) studied the effect of adding super-lubricant additives to combat scouring and concluded that using polycarboxylate-based super lubricants improves resistance properties against scouring. However, exceeding the saturation level reduces viscosity and anti-washing properties [9].

Eskander et al. (2020) investigated the effect of different types of washing water-resistant additives on the non-dispersive properties of underwater concrete. Additives were categorized into three natural groups, including gum arabic and xanthan gum; semi-industrial, including modified starch; and industrial, including magnesium aluminum silicate. Experimentation concluded that all mentioned cases led to improved concrete properties underwater, with gum arabic and xanthan gum having the greatest effect. The use of natural materials also reduced concrete shrinkage more than other materials [3].

Feng et al. (2020) studied the effect of flocculants in concrete to improve dispersion properties. Poly carboxylic was used as a scour-resistant additive, and the composition of different materials was optimized through various experiments. The materials used in super concrete were polyacrylate 0.9%, bentonite 0.8%, water retention agent 0.4%, and water-reducing agent 0.25%. The research found that using these materials resulted in underwater concrete with good flowability and anti-dispersion, meeting the desired requirements. Additionally, the cost of coagulant materials was lower than the average of other scour-resistant materials [10].

In Kyu Jun et al. (2021), the resistance against scouring and dispersion of underwater concrete was measured due to the addition of nano silica SiO_2 and magnesium oxide MgO. The tests included slump test, viscosity, setting time, turbidity, and pH. The results indicated that SiO_2 and MgO decreased slump, primary and secondary setting time, increased viscosity and improved resistance against scouring. Compressive strength increased with SiO_2, while MgO showed a slight decrease in strength [11].

3. Materials and Methods

Concrete resistant to scouring is not fundamentally different from ordinary concrete in terms of design. Alongside Portland cement, sand, and water, this concrete includes additional materials such as scour-resistant additives, super lubricants, and controlling agents. The purpose of incorporating these materials is to enhance the properties of the concrete. A critical factor distinguishing this type of concrete underwater is the percentage and ratio of scour-resistant additives in the mix.

Aggregates, a crucial component of concrete, must meet specific quality criteria. They should have a clean appearance, free from mud and silt, exhibit appropriate granulation, and possess the necessary resistance without physical or chemical impurities. Material grading is determined through a grading test and the construction of a grading curve

(Figure 1). Following ASTM C33 [12] standards, a designated amount of aggregates is weighed and passed through a series of standard sieves. For a 19 mm aggregate, a minimum of 5 kg of test material is chosen. The aggregates are then stacked from large to small and poured onto the top sieve. Within 1 min, more than 1% of the remaining material on the sieve should not pass through it. The weight of aggregates on each sieve is meticulously determined, and the percentage is calculated relative to the total weight. Subtracting the total percentages remaining on each sieve above 100 yields the percentage passing through each sieve. Drawing the size of sieves against the percentage passing through each sieve creates the granulation diagram. If the difference between the weight of sieved materials and the initial sample weight exceeds 2%, the results are considered unacceptable and should be repeated.

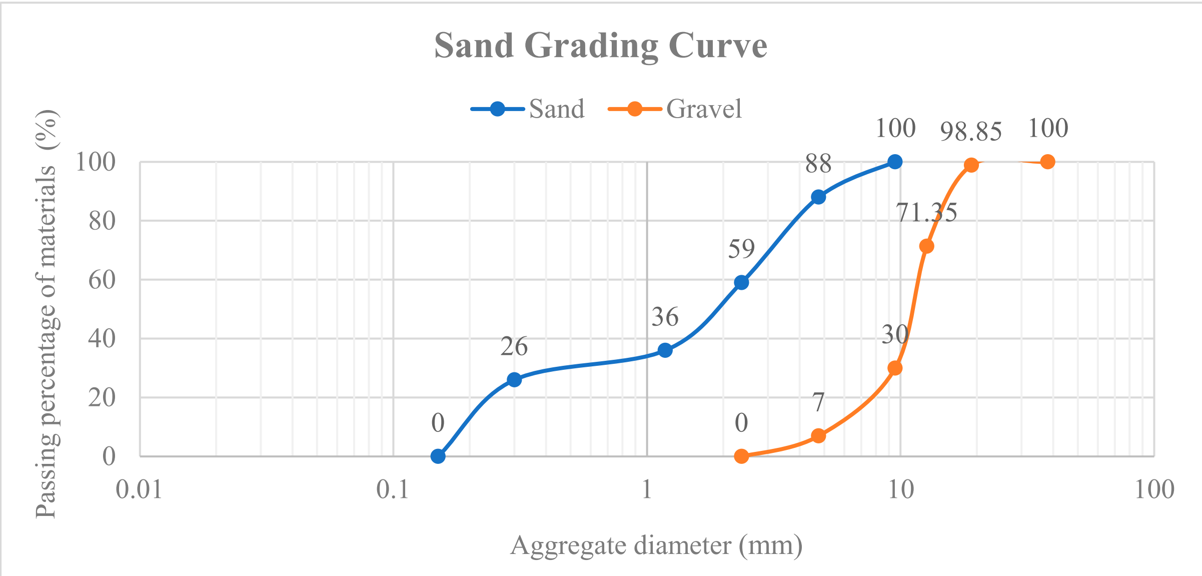

Figure 1. Sand grading curve.

Granulation and aggregate size impact the proportion of aggregates, influencing the required cement and water, pumpability, porosity, and durability of concrete. Continuous granulation affects the plastic properties, fluidity, and ease of working with concrete, contributing to increased freshness.

In this research, basalt aggregate with a maximum nominal size of 19 mm and basalt crushed sand from Shahriar Mine was used to create the desired concrete. The sand underwent a granulation test based on ASTM C136 [13] standards, utilizing standard wire mesh sieves (numbers 4, 8, 16, 30, 50, and 100). The modulus of elasticity, calculated from the granulation test following ASTM C31 [14], is 2.89, within the standard range of 2.3 to 3.1, indicating that the fine grain used is suitable for this project.

Through the hydration reaction with the main components of cement, water assumes a fundamental and crucial role in determining the necessary strength of concrete. In the concrete mix, water contributes to fluidity and efficiency while aiding in the formation and compaction of the concrete. It is imperative that water used in concrete should be clear, transparent, free from dirt and mud, and odorless. Additionally, it should not be acidic or alkaline, with the percentage of sulfates, suspended materials, and carbonates below 0.1. The chlorine percentage should also be kept below 0.05.

The water-to-cement ratio stands out as one of the most significant factors influencing the compressive and bending strength of concrete. A lower water-to-cement ratio leads to higher bending and compressive strength. This ratio affects all concrete properties, both during the fresh state and after hardening [15].

3.1. Materials

3.1.1. Cement

The cement used in this research to make concrete resistant to scouring is type II cement, which is manufactured by the Tehran cement factory; its physical properties are shown in Table 1 and its chemical decomposition properties are shown in Table 2 [15].

The specifications of the cement used in this study are summarized in the following table:

Table 1. Physical characteristics of type II Portland cement of Tehran.

Physical Characteristic Value	Physical Characteristics of Cement
150 min	Initial capture time
185 min	Final take time
185 kg/cm^2	3 days resistance
304 kg/cm^2	7 days resistance
420 kg/cm^2	28 days resistance

Table 2. Chemical analysis of type II Portland cement in Tehran.

Percentage of Chemical Composition	The Name of the Chemical Compound	Percentage of Chemical Composition	The Name of the Chemical Compound
0.3–0.5	Na_2O	6.3–6.5	CaO
0.5–0.7	K_2O	3.5–4	Fe_2O_3
1.5–2.5	SO_3	4.6–5.3	Al_2O_3
1.5–2.5	MgO	20.5–22	SiO_2

3.1.2. Admixtures

One of the most important components of durable and high-performance concrete is the use of concrete admixtures. Admixtures, whether natural or synthetic chemicals, are incorporated into concrete during mixing, along with aggregate, cement, and water. These additives can have very positive effects, such as the following:

- Increasing the resistance against the scouring of fresh concrete.
- Reducing the solubility of cement in fresh concrete during underwater concreting.
- Controlling the setting time of concrete.
- Serving as a water reducer to decrease the amount of water in the mixing plan for better quality and durability.
- Enhancing the fluidity and efficiency of concrete.
- Minimizing the use of cement as an air-polluting material.
- Reducing water leakage in fresh concrete.
- Increasing the integrity of concrete and reducing the separation of aggregates.
- Diminishing porosity and permeability.
- Enhancing the specific weight of concrete.
- Generating bubbles in concrete to increase durability.
- Economizing the design through the correct selection of additives.

The method of adding additives involves initially mixing sand and cement with water, followed by the gradual addition of admixtures. The admixtures must be mixed with concrete in a way that ensures the fastest and most uniform distribution throughout the mixture [15].

3.1.3. Natural Admixtures Resistant to Scouring

Biopolymers are polymers produced by living organisms that fill the voids in concrete and enhance their properties. In recent years, the utilization of various types of gums, such as xanthan gum, guar gum, agar gum, and gellant gum, as biopolymers in concrete, has gained popularity. These gums are available and used in powder form. Modifying concrete with a specific type of biopolymer, depending on the type and composition of the soil, the amount of admixtures used, the duration of the reaction, and the mixing conditions, can yield different results.

The necessity to stabilize concrete, on the one hand, and the numerous environmental disadvantages associated with industrial and traditional additives in concrete stabilization, on the other hand, have underscored the importance of environmentally friendly stabilizing sources. Biopolymers represent one of these biological sources that contribute to concrete stability due to their robust hydrophilic properties, high adhesion, and the capability to create particles with a larger diameter. Moreover, they are highly favored among unconventional stabilizers due to their abundance in nature, cost-effectiveness, and ease of use.

The notable characteristics of biopolymers, including high concentration and viscosity, improvement in textures, and stabilization of solutions, along with the global demand for environmentally friendly materials, have motivated researchers to explore new sources of biopolymers. The term "gum," denoting glue in chemistry, is employed to define this group of biopolymers due to their tendency to form gels or viscous solutions [16].

3.1.4. Kathira

Dried gummy secretions are obtained from several different plant species. The productive species of Kathira gum are small plants, one meter high, and native to Asia Minor, Iran, Syria, and Greece.

Kathira gum, as shown in Figure 2, is a viscous, odorless, tasteless, and water-soluble mixture of biopolymers. This gum is obtained by tapping the milky branches and roots of Kathira, a low-growing and thorny shrub native to the mountainous regions of the Middle East. Kathira is predominantly found in the Middle East, Iraq, and Iran, and even in West Asia.

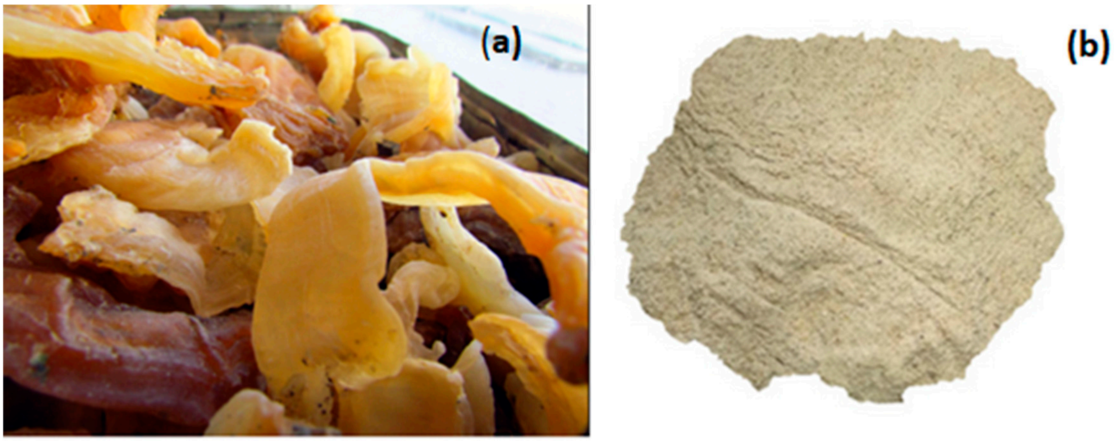

Figure 2. Kathira gum (**a**); Powder of Sodium Alginate (**b**).

Kathira gum (Figure 2a) is a biopolymer with many heterogeneous branches, including galacturonic acid, xylose, arabinose, galactose, and fucose. This gum is highly suitable for water retention purposes in concrete.

In this research, threshing clay, which is the most cost-effective and readily available type of clay, was utilized in concrete. This biopolymer was sourced from the pastures of Isfahan province and incorporated into the concrete in powdered form. The powder of this biopolymer (Figure 2b) is depicted in the figure below and exhibits a yellowish-white color. The quantity used in the concrete is 0.5% of the cement weight. Upon adding this biopolymer to the concrete, a mixing time of 3 min is allocated. Post mixing, the viscosity of the concrete increases, and its fluidity decreases, necessitating the use of a super lubricant.

3.1.5. Sodium Alginate

Sodium Alginate (Figure 3a) is a biopolymer composed of β-D-mannuronic acid units 1 and 4 connected, along with residues of L-guluronic acid. It is widely distributed in organisms such as seaweed and bacteria. Sodium alginate is a gum obtained from seaweed. This gum is soluble in both hot and cold water, forming solutions with varying viscosity. Upon reaction with water or acids, it undergoes irreversible gelation. The gum possesses hardening, bonding, and gel formation properties. The presence of polygonal cations in aqueous coatings induces the development of sodium alginate solution gel formation. The exchange of sodium ions with polygonal cations is the primary mechanism behind the binding and production of sodium alginate gel [16].

Figure 3. (**a**) Sodium Alginate; (**b**) Powder of Sodium Alginate.

In this research, sodium alginate sourced from Temad Kala Company, produced in China, was employed in concrete. This biopolymer was utilized in powdered form (Figure 3b) within the concrete mixture. The powder of this biopolymer has a yellowish-white color. The quantity used in the concrete constitutes 0.5% of the cement weight. Upon incorporating this biopolymer into the concrete, a 3 min duration is allocated for mixing. Post mixing, the viscosity of the concrete increases, leading to a decrease in its fluidity, thereby necessitating the use of a super lubricant.

3.1.6. Guar Gum

The guar plant is extensively cultivated in India, America, Australia, and Africa for the extraction of gum from its seeds, primarily for industrial use, and it exhibits resistance to drought. This plant bears a resemblance to the soybean plant. Initially, the guar flower buds are white, undergoing a color change as the flowers open. Guar seeds (Figure 4) contain 35 to 42% galactomannans. The production of guar seeds in America surged from 0 to 15 thousand tons between 1950 and 1963. Additionally, the consumption of these seeds witnessed substantial growth from 2.5 to 65 million pounds over the years spanning from 1954 to 1978. Guar biopolymer is extracted from the seeds and constitutes a polysaccharide comprising the main component of mannose with branches of galactose on each mannose unit. Recent studies indicate that guar gum is utilized for purifying drinking water, treating industrial waste liquids, and addressing persistent organic pollutants [16] (Figure 5).

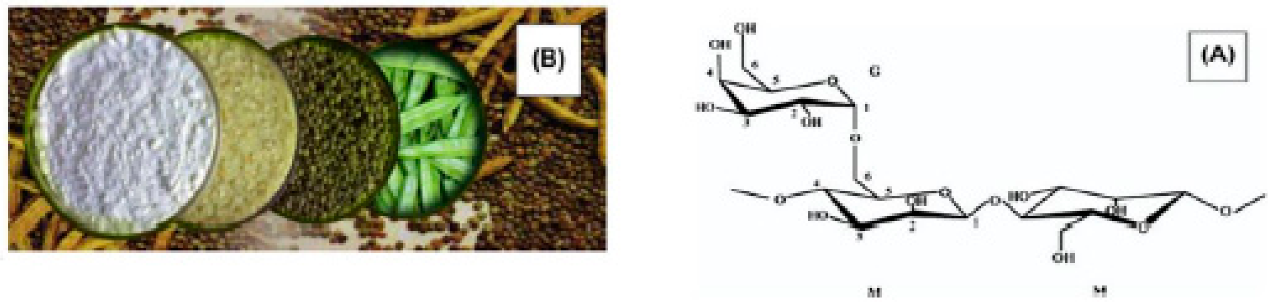

Figure 4. (**A**) The chemical structure of guar gum, which shows the polymer chain of guar gum. (**B**) Guar gum seeds and powder [16].

Figure 5. Guar gum powder used in concrete.

3.1.7. Lubricants

Lubricants, also known as water-reducing agents, are materials that, when added to concrete, enhance its fluidity and efficiency without the need for additional water. The primary and active components of lubricants are materials with an active surface that accumulates at the interface of two immiscible phases, altering the physical–chemical forces at this internal contact surface. These materials can reduce the water-to-cement ratio by up to 15%. The role of lubricants in the concrete mixture is to separate the cement grains from each other, allowing them to disperse widely in the mixed concrete. If the maximum recommended amount is exceeded, it may lead to a loss of adhesion in the concrete.

Lubricants serve various purposes in concrete, including the following:

1. Achieving higher concrete strength by reducing the water-to-cement ratio.
2. Reducing cement consumption while maintaining strength and minimizing water usage.
3. Enhancing the fluidity and efficiency of concrete by preserving the balance of water and cement.

Lubricants can be used with all types of cement, and their consumption typically ranges from 0.5% to 3% of the weight of the cement used. These agents are absorbed by the cement grains, giving them a negative charge, causing repulsion between particles, and dispersing them throughout the concrete mixture. The negative charge also results in the formation of a smooth shell of water molecules around each particle, contributing to increased concrete efficiency [15].

3.1.8. Super Lubricants

High water-reducing admixtures, also known as super lubricants, significantly enhance the fluidity and efficiency of concrete when added to the mix. These substances can reduce water consumption by up to 30% without compromising the effectiveness of concrete. Additionally, due to lower water usage, the concrete produced with super lubricants experiences less loss compared to normal concrete.

Reducing the amount of water in concrete offers the following advantages:

1. Increased compressive and bending strength of concrete.
2. Enhanced resistance to climate and weather factors.
3. Decreased permeability and water absorption capacity of concrete.
4. Minimized aggregate segregation in concrete.
5. Reduced shrinkage cracking.
6. Less volume changes due to consecutive drying and wetting.
7. Improved connection between concrete layers as well as reinforcement and concrete [15].

3.1.9. Consumable Super Lubricant

In this research, the super lubricant fluid HP2-AO, manufactured by Alborz Chemical Company, was utilized for producing concrete. The specified super lubricant has a brown color. The recommended and suggested amount for usage ranges from 0.1 to 0.5 relative to the cement weight. As the quantity of super lubricant increases, the fluidity is enhanced, but beyond a certain limit, increased amounts can lead to grain separation. In this study, the consumption of super lubricant is 0.28 percent of the cement weight, and it is added to the mixer during the final stage of mixing.

3.2. Specimen Geometry and Type Specimen Preparation

The purpose of the concrete mixing plan is to determine the most economical and best combination of materials that are easily available to produce concrete, providing optimal performance criteria and efficiency under specific working conditions. In this research, as we aim to compare the mechanical, physical, and rheological properties of normal concrete against scouring with concrete containing additives resistant to scouring, we used the initial mixing plan of the previous materials to commence the work. Subsequently, by creating the first mixture and measuring various parameters of fresh concrete through tests such as slump, it was determined that minor adjustments in the quantity of different materials are necessary. Finally, the mixing plan in the following Table 3 was chosen as the most acceptable [15].

Table 3. Mixing design of concrete resistant to scouring.

	Cement (kg/m^3)	Coarse Aggregate (kg/m^3)	Fine Aggregate (kg/m^3)	Water (kg/m^3)	Additive Resistant to Scouring (kg/m^3)	Super Lubricant (kg/m^3)	*w/c*
Ordinary concrete	488	977	675	205	-----------	6	0.42
Concrete containing Kathira	488	977	675	205	2.24	6	0.42
Concrete containing sodium alginate	488	977	675	205	2.24	6	0.42
Concrete containing guar gum	488	977	675	205	2.24	6	0.42

In the selected mixing plan, the density of sand is 2.68 (g/cm^3), the density of cement is 2.64 (g/cm^3), the softness modulus of sand is 2.89, and the largest dimension of the aggregate is 19 mm. Additionally, the target slump is set at 70 mm, and the target compressive strength is 40 MPa.

3.3. Description of the Test

The Concrete Technology Laboratory at Tehran University was utilized for the production and testing of samples. To create scour-resistant concrete, the process involved sieving and accurately weighing the sand and cement. The specified amounts of each material were then prepared for a mixing plan intended for 150 L of concrete. These prepared materials were poured into a pre-washed mixing machine and blended together. Based on laboratory experience, the recommended sequence for pouring materials into the mixer is to first add water, followed by aggregates, ensuring the aggregates are wet and their voids are filled with water. Subsequently, cement powder is gradually added to the rotating water and aggregate. This rotational mixing process continues until the cement dissolves in the water, and the cement paste is formed as the cement grains are crushed by the aggregates. Once a uniform cement paste is achieved, sand is slowly added to the mixture, with a mixing duration of 4–5 min allocated for the sand.

After the uniform concrete mixture is prepared, the powder of water-resistant additives is introduced, with a designated 3 min mixing duration for the additives. Due to the water absorption caused by the addition of scour-resistant additives, leading to a significant drop in efficiency and slump, the super lubricant is finally added to restore the desired fluidity level. Subsequent to conducting fresh concrete tests, the concrete is placed into pre-prepared molds, cleaned, and lubricated with mold oil. The pouring is carried out in three stages, compacting with 25 rod blows in each stage. The surface is smoothed, and the concrete is kept at a constant temperature and humidity for 24 h to facilitate the hardening process.

After this initial hardening period, the samples are removed from the molds and placed in lime-saturated water ponds with a temperature ranging between 18 and 24 degrees Celsius for proper curing.

For the mechanical property testing of concrete, including compressive strength (ASTM C39) [17], indirect tensile strength (ASTM C78) [18], and bending strength (ASTM C293) [19], a total of 12 cylindrical molds measuring 15 × 30 cm, 12 cylindrical samples measuring 15 × 30 cm, and 12 concrete beam molds with dimensions of 10 × 10 × 35 cm were lubricated and prepared. Table 4 lists the number of concrete samples tested for each property.

Table 4. Tests performed for fresh concrete.

Measured Feature	Test Name
Performance	Slump test according to ASTM C143 [20]
Scouring	Free fall of concrete inside the mesh basket according to CRD-C 65.1
Dissolution of concrete cement in water	PH test according to Japanese concrete regulations
Time consuming	Vicat needle according to ASTM C191 [21]

Quality control tests are conducted on the water-resistant concrete mixing plan to assess the following:

1. Slump Test Approval:
    - Fluency and efficiency must meet the required standards in the slump test.
2. Scouring Resistance:
    - The concrete's ability to resist scouring is evaluated.
3. Dissolution Resistance:
    - The resistance of fresh concrete cement to dissolution in water is examined.
4. Setting Time Determination:
    - The time taken for fresh concrete to set is determined to assess its usability.

3.4. Test Setup

3.4.1. Slump Test

Freshly mixed concrete, which is about to be poured, must meet specific standards before being used in a construction project. A concrete slump test is conducted to measure the consistency of a concrete batch and determine how easily the concrete will flow. This test not only ensures consistency across batches but also helps identify any defects in the mix, allowing operators to make necessary adjustments before pouring it on-site.

By measuring the overall 'slump' of the concrete, one can assess whether the water-cement ratio is too high and predict the workability of the mix.

The main objective of conducting this test is to guarantee consistent quality and strength across batches of the same concrete. Increased water content in the mix leads to a reduction in concrete strength. In cases where customers request higher workability or increased flowability in the concrete, indicated by a higher slump result, we adjust the cement content accordingly to ensure that the concrete still meets its targeted strength. This test serves as one of the measures employed to ensure the quality of our concrete, recognizing that water is detrimental to concrete strength (Figure 6).

Figure 6. Measurement of concrete slump.

1. Place the cone on a flat, smooth, horizontal surface and stand on the footholds on either side to ensure the cone is firmly planted on the ground.
2. Fill the cone in three layers, compacting the concrete after each layer using the steel tamping rod in a consistent and uniform manner (this should be performed 25 times per layer).
3. Once the cone is filled, remove any excess concrete from the top, ensuring that the concrete precisely reaches the top level of the cone. Also, clean any spilled concrete from the base of the cone.
4. Lift the cone vertically with a slow and steady motion until it is clear of the concrete. Invert the cone and place it on the surface adjacent to the concrete.
5. The concrete will either settle or slump. To measure the slump, position the steel rod across the top of the inverted cone so that it extends over the concrete.
6. Measure the distance from the rod to the top of the slump. The slump level is measured to the nearest 5 mm [22,23].

3.4.2. Immersion Test or Free Fall of Concrete from Mesh Basket (Plung Test)

Based on CRD-C61, this test (Figure 7) is used to determine the amount of water leached from concrete under submerged or water-exposed conditions. The percentage of leached water is calculated using the following formula:

$$D = \frac{\left(M_i - M_f\right)}{M_i} \times 100 \quad (1)$$

where D is equal to the percentage of scouring, M_i is equal to the initial mass of fresh concrete, and M_f is equal to the mass of concrete after scouring [15,24].

Figure 7. Fresh concrete scouring test device.

3.4.3. PH Test of Fresh Concrete

The purpose of this test (Figure 8) is to compare the amount of cement dissolution in water. In this test, 500 g of fresh concrete is introduced into a receptacle containing 1500 cc of fresh water in three steps. After three minutes, 500 cc of water is extracted from the receptacle containing fresh concrete and collected using a pipette. Subsequently, its pH value is measured with a pH meter. The higher the value, the greater the cement dissolution rate.

Figure 8. Measuring the dissolution rate of concrete cement with a PH meter.

3.4.4. Fresh Concrete Setting Time Test

The term "setting" is used to determine the hardening time of concrete. Fresh concrete is essentially a mixture of water, cement, and aggregate, which gradually solidifies over time. However, the concrete setting does not signify the complete hardening of concrete; instead, it is defined based on different stages, such as the initial and final setting, to measure the concrete setting with Vicat [21].

Among the mechanical characteristics of water-resistant concrete, we can mention compressive strength, indirect tensile strength, bending strength of reinforced concrete beams, and the shrinkage test.

Clearly, The Vicat test (Figure 9) is a standardized procedure used to measure the setting times of cement paste and mortar. It operates on the principle of the paste's resistance to dynamic penetration by a rod of known weight [25].

Figure 9. Vicat device for measuring concrete setting time.

3.4.5. Compressive Strength Test

Fot this test (Figures 10 and 11) Cylindrical samples with dimensions of 15 × 30 cm were employed to measure compressive strength. After ensuring the dimensional accuracy of the molds and the smoothness of their internal surfaces, the molds were lubricated with mold oil to prevent concrete from adhering to them and prepared for concreting. In the concreting process within the molds, efforts were made to obtain samples in a uniform and homogeneous manner. The molds were filled in three stages, each stage being compacted with a standard rod 25 times. Subsequently, the molds' surfaces were smoothed, and they were kept at a constant temperature and humidity for 24 h. After this duration, the molds were opened, and the hardened samples were immersed in lime-saturated water ponds at a temperature of 20 degrees Celsius.

After 28 days, the concrete samples were taken out of the water ponds (see Figure 10). After allowing a 2 h period for the surface of the samples to dry, the surfaces were polished (ensuring the surfaces were smoothed to prevent asymmetry in tension from surface aggregates). Following the polishing process, the samples were placed under the compressive strength measuring device according to ASTM C93 [26]. Vertical force was then applied to the cylindrical samples by the pressure jack at a consistent speed until the samples fractured under the pressure load, as shown in Figure 11. Subsequently, the compressive strength of the samples was determined by recording the value displayed on the compressive strength device and using the following relationship:

$$\acute{f}_c = \frac{P}{A} \tag{2}$$

where $\acute{f_c}$ is equal to the compressive strength of concrete, P is equal to the breaking force applied by the machine to concrete samples, and A is equal to the cross-sectional area of cylindrical samples.

Figure 10. Samples removed from water ponds saturated with lime.

Figure 11. Compressive strength measuring device.

3.4.6. Indirect Tensile Strength Test

The weakest behavior of concrete manifests in tension. This test (Figures 12 and 13), known as the Brazilian test, illustrated in Figure 12, was conducted in accordance with the ASTM C78 [18] standard to determine the tensile strength of concrete. The tested concrete cylinder was positioned inside the shaped steel sheath and, together with it, placed inside the pressure machine. The load on the sample was sustained until rupture occurred. The maximum applied force at the moment of rupture was then used in the following relationship, and the indirect tensile strength was calculated:

$$f_{ct} = \frac{2P}{\pi DL} \tag{3}$$

where f_{ct} is the maximum applied force at the moment of rupture, D is the diameter of the sample, and L is the length of the sample.

Figure 12. Cylindrical concrete specimen inside a steel sheath for indirect tensile test.

Figure 13. A number of broken concrete samples in indirect tensile test.

3.4.7. 3-Point Bending Strength Test of Concrete Beam

The tensile strength of concrete is induced by bending, evaluated using a 3-point test on a small concrete beam, illustrated in (Figure 14). This test adheres to the ASTM C293 [19] standard, involving the application of a concentrated load at the center of the opening of a concrete beam with a width of 10 cm, a height of 10 cm, and a length of 35 cm. The concentrated load at the moment of rupture and failure is then utilized in the following relationship to determine the bending strength of the beam:

$$R = \frac{3PL}{3bd^2} \tag{4}$$

where P is the applied concentrated force, L is the length of the concrete beam, b is the width of the concrete beam, and d is the height of the concrete beam [15].

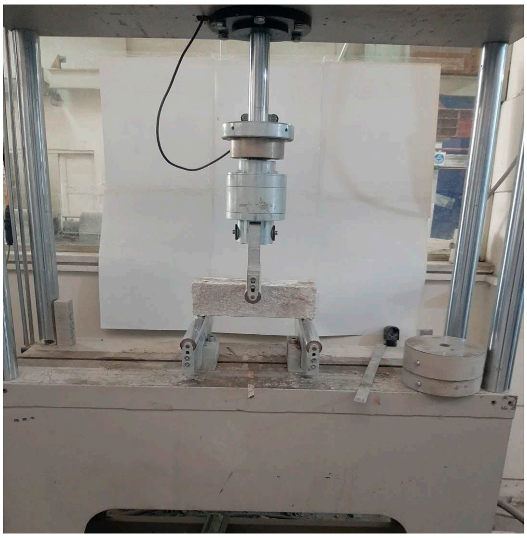

Figure 14. The 3-point bending strength test of the concrete beam.

3.4.8. Shrinkage Test

For this purpose, in accordance with the ASTM C157 [27] standard, three rectangular cube concrete samples were prepared for each concrete containing additives, illustrated in (Figure 15). These samples had dimensions of 7.5 × 7.5 cm and a length of 28 cm, with two metal pins at the head of each sample. Initially, they were kept at a specific temperature and humidity for 24 h, after which they were transferred to a humidity room with a temperature of 25 ± 1 degrees Celsius and a humidity level of 50%. Subsequently, the samples were removed from the humidity room every 10 days. The shrinkage rate was measured using a designated device, and the corresponding shrinkage strain was then calculated.

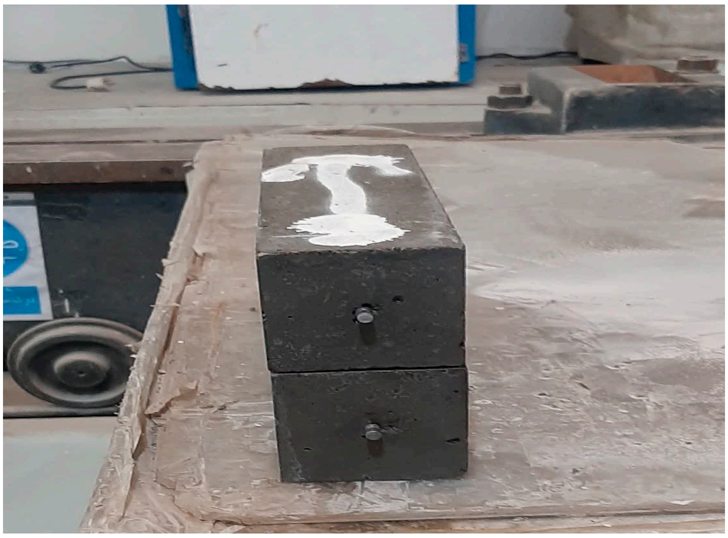

Figure 15. Specimens made for shrinkage testing.

4. Results and Discussion

4.1. Slump Test Result

The slump test was employed to compare the fluidity and workability of various types of concrete containing additives resistant to scouring. In this research, the experiment aimed to assess the smoothness and efficiency of four designs: concrete without additives concrete containing Kathira, concrete containing guar gum, and concrete containing sodium alginate. The tests were conducted both without super lubricants (Figure 16), and with super lubricants (Figure 17).

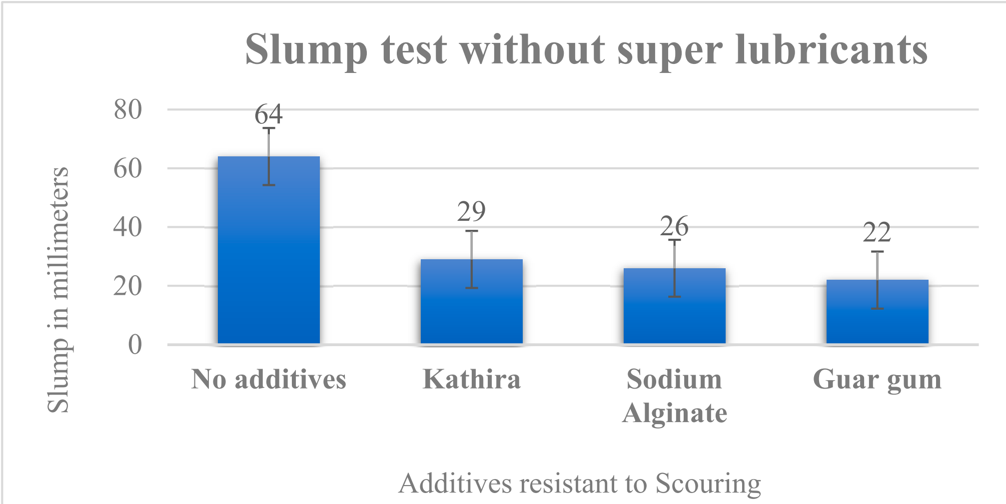

Figure 16. Slump test results without using super lubricants.

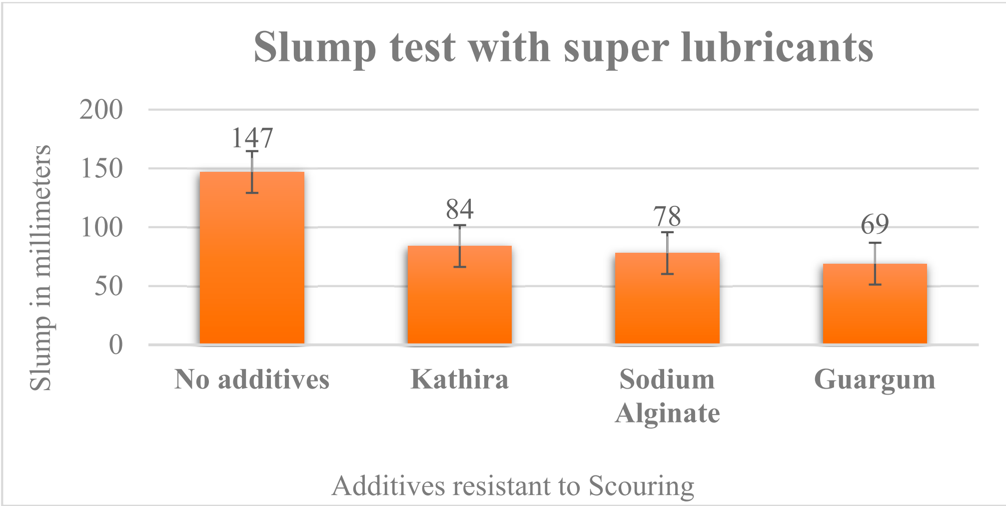

Figure 17. Slump test results using super lubricants.

As observed, the utilization of water-resistant additives leads to an increase in the viscosity and cohesion of concrete, while reducing its fluidity, workability, and segregation. This is attributed to the water absorption by biopolymer additives.

4.2. The Results of Concrete Immersion or Free Fall Test from Mesh Basket

This test is employed to determine the washing rate of concrete under water or in contact with water. In this research, the test was conducted to compare the washing rates of concrete without additives, concrete containing Kathira, concrete containing guar gum, and concrete containing sodium alginate.

As can be observed, all scouring-resistant additives employed in this research enhance the resistance to scouring and the integrity of concrete while diminishing the separation of concrete components. This phenomenon is attributed to the water absorption by biopolymer additives, resulting in the creation of a high-viscosity gel (Figure 18).

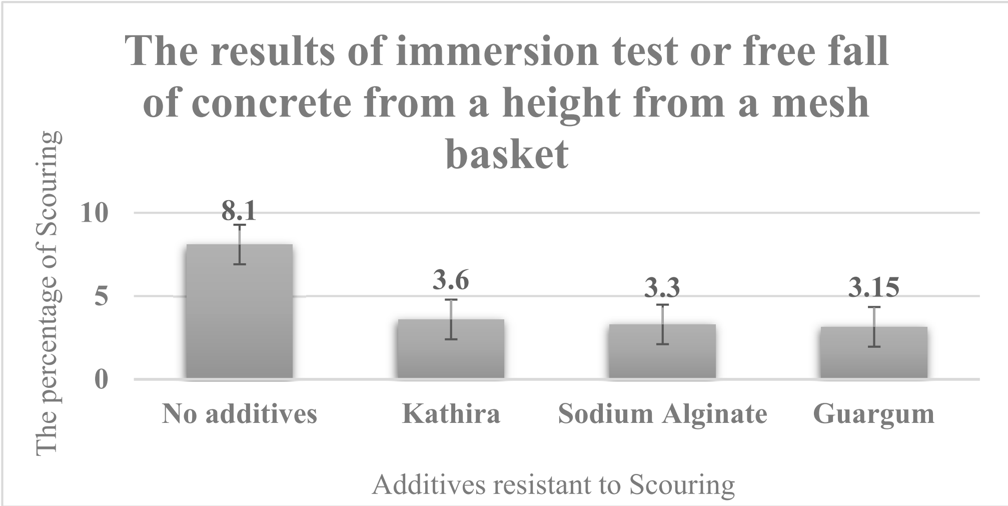

Figure 18. The results of concrete immersion or free fall test from mesh basket.

4.3. The Results of the PH Test of Fresh Concrete under Water

The purpose of this test is to compare the dissolution rate of cement in water. A lower dissolution rate indicates a lower pH reading on the pH meter and a higher level of resistance against scouring. In this research, the experiment aimed to compare the amount of cement dissolution in water and the extent of scouring in concrete without additives, concrete containing Kathira, concrete containing guar gum, and concrete containing sodium alginate (Figure 19).

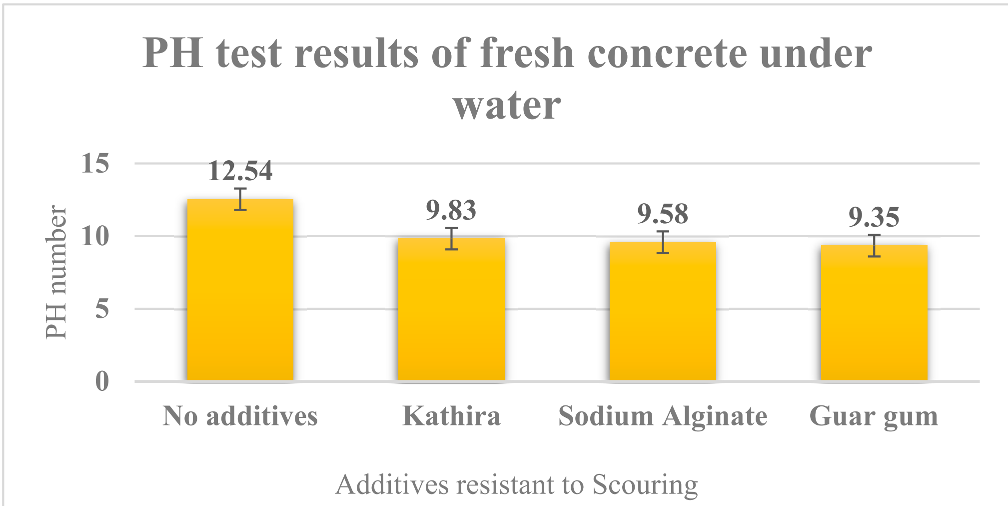

Figure 19. PH test results of fresh concrete under water.

4.4. The Results of the Setting Time Test of Fresh Concrete

This test is utilized to determine the hardening time of fresh concrete. In this research, the experiment aimed to compare the initial and final setting times of concrete without additives, concrete containing Kathira, concrete containing guar gum, and concrete containing sodium alginate. The results are presented in Figure 20.

As observed in the diagram, the incorporation of all three scouring-resistant additives reduces the duration of both the initial and final setting of fresh concrete. This is attributed to the accelerated rate of cement hydration facilitated by the particles of scouring-resistant additives (Figure 20).

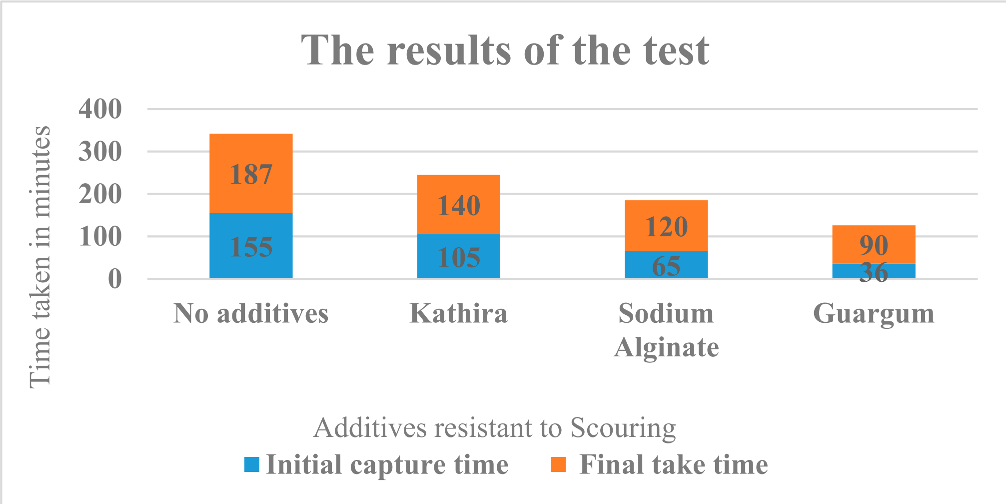

Figure 20. Results of setting time test of fresh concrete.

4.5. Compressive Strength Test Results

The average compressive strength obtained for samples made of all four types of concrete containing scouring-resistant additives at the age of 28 days is illustrated in the figure below (Figure 21):

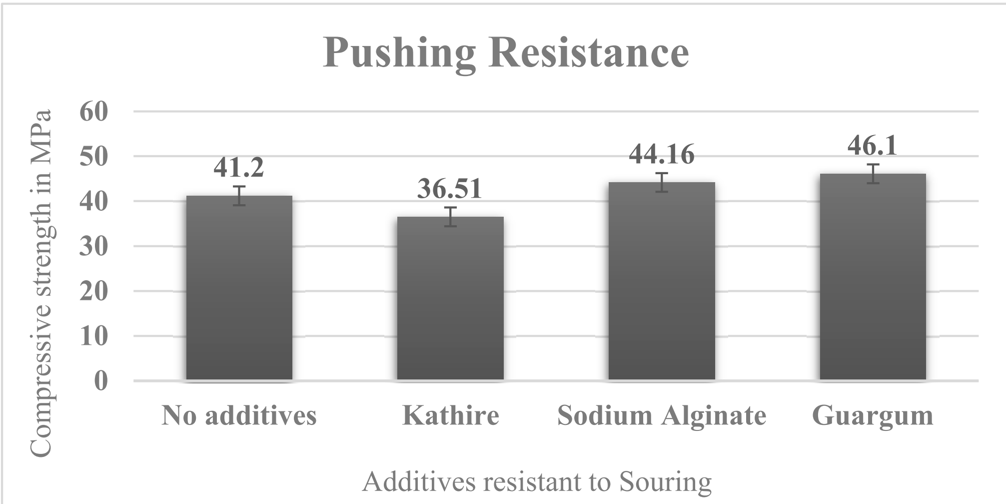

Figure 21. Graph of compressive strength test results.

As evident from the graph, the compressive strength of concrete at the age of 28 days increased with the addition of Guar gum and sodium alginate, while the Kathira additive decreased the compressive strength.

The reason for the enhanced compressive strength with guar gum and sodium alginate lies in the accelerated rate of cement hydration. Regarding the mechanism and means of improving the compressive strength of concrete containing guar gum and sodium alginate, it can be explained that these materials fill the pores in the cement paste due to their high specific surface area, creating a dense material with molecular stability. Consequently, this results in very low permeability and higher compressive strength.

4.6. The Results of the Indirect Tensile Strength Test

The average indirect tensile strength obtained for samples made of all four types of concrete containing scouring-resistant additives at the age of 28 days is illustrated in the figure below (Figure 22):

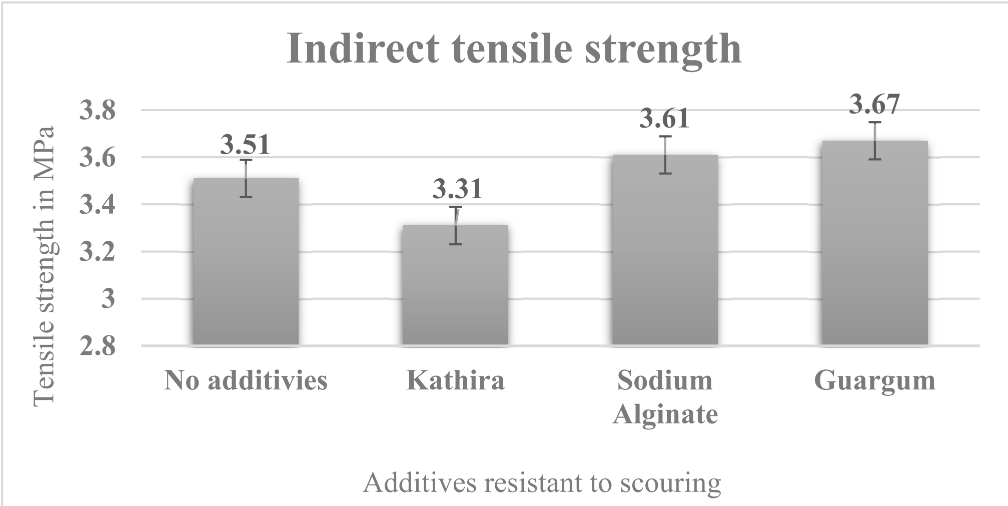

Figure 22. Indirect tensile strength test results.

As evident from the graph above, the additives guar gum and sodium alginate increased the indirect tensile strength, while the Kathira additive decreased it. The reason for the increase in indirect tensile strength with the addition of guar gum and sodium alginate lies in the enhanced adhesion between concrete components, resulting in greater integrity.

4.7. The Results of the 3-Point Bending Strength Test of the Concrete Beam

The average bending strength obtained for samples made of all four types of concrete containing scouring-resistant additives at the age of 28 days (Figure 23).

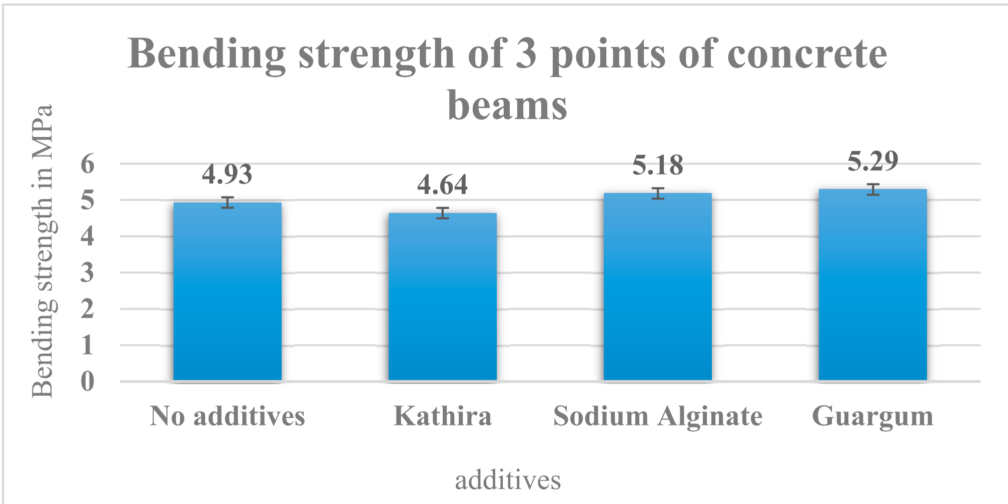

Figure 23. 3-point bending strength test results of concrete beam.

As evident from the graph above, the additives guar gum and sodium alginate led to an increase in the bending strength, while the Kathira additive resulted in a decrease in the bending strength. The reason for the enhanced flexural strength with the addition of guar gum and sodium alginate is that, due to their larger specific surface area, they fill the pores in the cement paste, creating denser concrete. As a result, its flexural strength increases.

4.8. The Results of the Shrinkage Test

The purpose of this test is to measure the amount of shrinkage in concrete samples. The average shrinkage strain was obtained for samples made of all four types of concrete containing water-resistant additives at the age of 28 days (Figure 24).

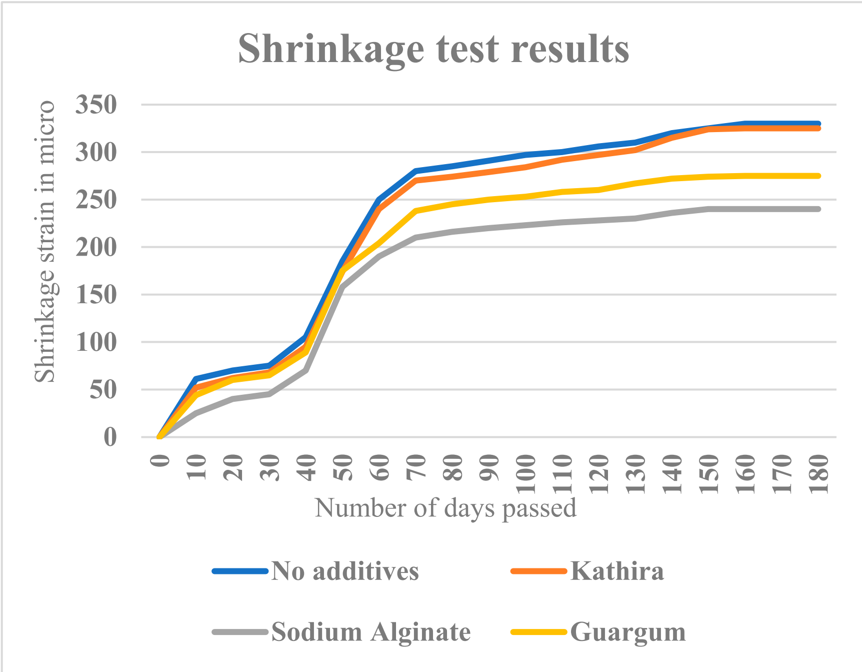

Figure 24. A graph of the results of the shrinkage test.

As evident from the diagram above, the use of biopolymers reduces shrinkage. This reduction can be attributed to the exceptional water absorption and retention capabilities of biopolymers.

5. Conclusions

The aim of this research is to compare normal concrete with concrete containing biopolymer additives resistant to scouring. The study investigates the effects of utilizing different biopolymers as water-resistant additives. Based on the physical and mechanical tests conducted in the laboratory on the mentioned concretes, the following results were obtained:

1. The incorporation of biopolymer additives resistant to scouring, due to the increased water absorption of concrete by biopolymers, resulted in heightened viscosity and reduced slump and efficiency in all three concrete samples containing such additives.
2. Water absorption by long-chain molecules of scouring-resistant additives contributed to the stability, integrity, and non-separation of concrete components, leading to a decrease in scouring for all three concrete samples containing such additives, especially in the case of concrete containing guar gum.
3. The pH value of fresh concrete decreased with a reduction in scouring and dissolution of cement in water.
4. The use of water-resistant additives reduced the initial and final setting time for all three concrete samples containing water-resistant additives.
5. In mechanical performance tests, including compressive strength, indirect tensile strength, and bending strength, concretes containing guar gum and sodium alginate outperformed concretes without additives due to their denser and more integrated structure, while concretes containing Kathira exhibited weaker performance compared to the concrete without additives.
6. According to the shrinkage test results, all the biopolymers used in this experiment were effective in controlling the shrinkage of concrete, with the lowest amount of shrinkage observed in the concrete containing guar gum biopolymer.

In general, considering that additives are of natural origin, they are environmentally friendly and pose no environmental hazards to nature. Furthermore, based on the conducted experiments and their results, the best additive can be added to the concrete to increase its strength and to make the concrete structure more cohesive.

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