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Investigating the Effect of Additives and Nanomaterials on the Physical Properties of Self-Compacting Concrete

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Abstract

Due to the use of concrete structures in climatic conditions, the problem of damage to these types of structures and, as a result, their repair and maintenance is one of the main issues of experts. Nanop articles have shown unique physical and chemical properties compared to other materials. Self-Compacting Concrete (SCC) is a new technology in world construction. It fills the form without external and internal vibrators and only uses the force of weight to maintain its uniformity simultaneously. Also, in the advanced industry, nanotechnology has created tremendous changes in the concrete industry, and with the production of nanomaterials, significant changes are seen in increasing the strength and durability of concrete. This research has tried to investigate the effect of adding nanomaterials on the properties of concrete while achieving specific mixing plans for making SCC. These tests were performed on the obtained mixing designs, and the samples were examined at ages 7, 28, 90, and 180. The results showed that adding these materials increased compressive and tensile strength. Also, it was observed in other studies that with the increase of nanomaterials, water absorption by concrete decreased a lot, and it was also observed in the study of electrical resistance that these nanomaterials played a significant role in increasing the electrical resistance of concrete. The increase in electrical resistance and, as a result, the decrease in conductivity prevents the corrosion and loss of round rods and other metals used in concrete.

Keywords: Self-compacting concrete, Compressive strength, Tensile strength, Water absorption, Electrical resistance.

1 | Introduction

Concrete is one of the most common and widely used construction materials, and the optimization and elimination of its defects have been considered essential by many researchers. Since 1983, the durability of

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concrete has been one of the main concerns of many large construction companies. The construction of concrete structures with proper density and high durability requires the use of efficient and efficient forces. As we know, concrete is shaken to remove the air inside the concrete, reduce its porosity, and increase the resistance due to compression.

Problems that can exist in the implementation of ordinary concrete, such as shaking of concrete and as a result of heterogeneous compaction of concrete, separation of concrete grains, and cracking of parts of the concrete surface due to high vibration of concrete or unavailability of parts of concrete and problems of setting up equipment and labor to shake concrete, it made the researchers produce concrete without the need of shaking and at the same time maintaining the proper granularity and having the desired density. As a result of this research, Mr. Okamura from Japan produced this type of concrete prototype in 1988 [1], which became known as Self-Compacting Concrete (SCC).

SCC includes a wide range of mixing designs with fresh and hardened concrete properties required for specific uses. Although resistance is still the main criterion for this concrete's success, fresh concrete's characteristics are much wider than ordinary concrete compacted by vibrators. These desirable properties must be maintained at the time and place of concreting. SCC is a desirable option in cases where the rebar network is compact. Despite the favorable characteristics, the mixing plan and implementation of this type of concrete depends on several factors, such as the granulation of stone materials, the type of additives, and the fillers used [2].

2 | Nanotechnology

Nanotechnology is the ability to make, control, and use matter in nanometer dimensions, which is one billionth. The size of nanotechnology particles is significant because, at the nanoscale, the dimensions of matter are very influential in their properties, and the physical, chemical, and biological properties of individual atoms and molecules are different from the properties of the mass of matter. This size varies in different cases. However, nanomaterials are usually referred to as materials with at least one of their dimensions smaller than 100 Nm [3].

The high surface-to-volume ratio of nanomaterials is one of the most important characteristics of materials produced at the nanoscale. In this scale, the surface behavior dominates the mass behavior of the material. In the nano dimensions, the laws of quantum physics make it possible to change the properties of matter, such as melting temperature, magnetic properties, and color. The methods of making nanomaterials can be classified into two general methods.

I. Top-down method: this method consists of reducing the size of the structure from micrometer to nanometer, so it is possible to analyze things so much that they reach the nanometer level. Today, this process is done by physical and chemical failure.

II. Bottom-up method: this method can only be used to fabricate materials at the nanometer scale, but top-down manufacturing methods are used to fabricate both nano and micro materials [4].

2.1 | Applications of Nanotechnology

Considering the novelty of this technology, new applications of it are introduced in different industries every year. Regarding the applications of nanostructures in concrete, we can mention their use in high-performance concrete and SCC.

2.2 | Improving the Properties of Cement and Concrete

The addition of nano-silica materials improves the density of particles, increases the strength of concrete, and prevents water penetration into the concrete. Using titanium dioxide creates self-cleaning and disinfecting properties of concrete and gives white color and shine to concrete. Carbon nanotubes are one of the other concrete additives; although their density is about one-sixth that of steel, their Young's modulus is five times, and their strength is eight times higher than steel. This nano additive can be used as a suitable reinforcement, bridging cracks and reducing the size and shape of cracks [5].

2.3 | Nanocoatings

Among the nanocoatings, we can mention stone and wood coatings, brick, ceramic, and tile coatings, concrete surface coatings, and fiber coatings. The most important advantages of using nanocoatings are the creation of a suitable insulating cover, the non-penetration of corrosion factors into these covers, increased resistance to heat transfer, increased resistance to corrosion, wear and decay, and the self-cleaning properties of these surfaces [6].

2.4 | Nano Waterproofs

Water absorption causes numerous and irreparable damages to an unprotected building. Dandruff, flaking of the wall and flaking of paint, formation of molds and fungi, absorption of pollution and dirtiness, creation of cracks and premature wear, reduction of concrete strength, and corrosion of iron and steel are among the external and structural damages to the building. Waterproofers are a suitable solution to prevent damage caused by water infiltration into the building.

Waterproof materials made of nanoparticles provide long-term protection for surfaces with proper penetration into materials. The construction uses of waterproofers include new buildings, old buildings, cement and concrete parts, tiles, and stones. It is worth mentioning that waterproofing the building is possible in different parts such as foundation and columns, internal walls, external walls and covers, sanitary services, built-in wiring and channels, underground and aerial water storage tanks, and roofs [7].

2.5 | Nano Glasses

Among the applications of nanotechnology in the glass manufacturing industry, we can mention products such as self-cleaning glass, energy-controlling glass, and fire-protection glass. Titanium dioxide nanoparticles are used to make self-cleaning glasses. These glasses have anti-stain and disinfection properties. Fire-protective glasses are made by placing a transparent layer containing silica nanoparticles between two glass plates. Energy-controlling glasses reduce the passage of ultraviolet and infrared waves, regulate the passage of visible light, and prevent energy wastage inside the building [8].

2.6 | Nano Asphalts

The structural elements and constituents of bitumen and asphalt are on the micro and nanoscale, and nanotechnology can improve these materials' properties. Among the applications of nanomaterials in improving the properties of asphalts, we can include things such as resistance to damage caused by moisture, increasing strength and life span, saving maintenance and repair costs of asphalts, improving the critical properties of asphalt such as compressive strength, tensile strength and stability to bear loads. Imported at high temperature, pointed out [9].

2.7 | Clay Nanocomposites

The advantages of using clay nanocomposites in different materials include improving mechanical properties, increased hardness without reducing the degree of plasticity, resistance to heat and chemical factors, suitable applicability, recyclability, and fire resistance. The ability to delay the effects of flame has led to using these materials in fireproof coatings in products such as flooring, insulation, building panels, foams, and various parts of cars, ships, airplanes, and military industries. Reducing the permeability of various gases such as oxygen, water vapor, and carbon dioxide is also one of the advantages of using nano composites. These materials are optically transparent and almost colorless.

3 | The Evolution of Self-Dense Concrete

SCC was used for the first time in 1988 in order to achieve durable concrete structures. Since then, various research studies have been carried out. Construction companies mainly used concrete in practical structures in Japan. For the first few years in 1983, the probability and stability of concrete structures were the main topics for building durable concrete structures; it is necessary to have sufficient density along with experienced workers. In comparison, the gradual decrease in the number of skilled workers in the construction industry in Japan led to a similar decrease in the quality of construction work.

One solution to achieve durable concrete structures regardless of the quality of the construction work is using SCC, which can be vibrated in every corner of the mold by its weight without needing a compaction device. The necessity of using this concrete by a person named Okamura in 1986. It was revealed. The research for developing this type of concrete included basic research on the performance [10] of Ozawa and Maekawa at the University of Tokyo. The first sample of SCC was completed for the first time in 1988 using the materials shown in the figure (*Fig. 1*). The mentioned sample was performed satisfactorily with respect to dryness and shrinkage [1], heat of hydration, no compaction after hardening, and other properties. This concrete was called Kara (with high efficiency). It was defined as follows in 3 stages of concrete (triple stages of concrete).

I. New: self-consistent.

II. At a young age: avoiding primary defects.

III. After hardness: resistance against external forces.

The frequency of collision and contact between the particles of granular materials can increase when the relative distance of these particles decreases. Then, internal stresses can increase when the concrete changes its shape, especially near obstacles. The amount of coarse aggregate, especially in energy consumption, is lower than normal ratios.

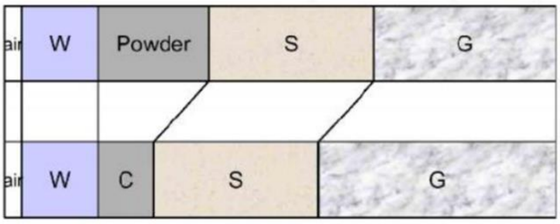

Fig. 1. Comparison of proportions between SCC and common concrete [11].

4 | Tensile Strength Test

The tensile strength of concrete is determined using the 2/5 method for molded or cored cylindrical samples. In general, the tensile strength of concrete in an indirect way (2/5) is greater than the direct tensile strength and smaller than the bending strength (modulus of rupture). Determining the tensile strength of concrete using the 2/5 method is used to design lightweight concrete structural members to evaluate the shear strength and determine the elongation of the rebar inside the concrete. In general, concretes have lower tensile strength than compressive strength. Because of this issue, reinforcements are essential in bearing tensile force in structural members.

In *Fig. 2* shown image of the concrete sample in the testing machine.

Fig. 2. Image of the concrete sample in the testing machine.

In this method, a diagonal compressive force is applied at a certain speed along the length of the cylindrical concrete test piece until rupture occurs. This loading causes tensile stresses on the surface subjected to relatively high compressive loads and stresses. Tensile rupture occurs earlier than compressive rupture because the load application surfaces are triaxial in compression. As a result, they bear much more compressive stresses than the uniaxial compressive strength test. For loading, thin support strips made of plywood are used to spread the applied load along the length of the cylinder.

The method of carrying out the tensile test of concrete using the 2/5 method (Brazilian)

Using a suitable tool, draw diagonal lines at the end of the test so that the lines are located on the plane that passes through the axis of the test. Calculate the diameter of the test piece with an accuracy of 0.25 mm by calculating the average of three diameters at the cylinder's beginning, end, and middle. Determine the length of the test piece with an accuracy of 2 mm by calculating the average of at least two lengths measured on the plane of the lines marked at both ends. Align the center of one of the plywood boards with the center of the bottom support. Place the test piece on the wooden strip so that the marked lines on both ends of the cylinder are perpendicular to the axis of the wooden strip and in its center.

These conditions must be met after taking the exam

The plane obtained from the two lines marked at the two ends of the test piece must pass through the center of the upper support. In the case of using auxiliary support plates, the center of the test piece should be located directly below the center of the load application of the spherical support block. Apply loading continuously and at a uniform rate of about MPa/min (1.4 to 0.7) until the tensile stress causes the specimen to break. Record the maximum applied load calculated by the device and pay attention to the fracture type.

The maximum tensile strength of the specimen is obtained through the following equation.

$$T = \frac{2P}{\pi l d}. \qquad (1)$$

T: tensile strength of halving in Mpa.

P: the maximum load applied by the device in Newtons (N).

L: is the length of the object in mm.

d: diameter of the object in mm.

5 | Compressive Strength Test

Using the proportions determined in the mixing plan, the amounts of sand, cement, and water are weighed in the same amount, and the sand and cement are mixed into the concrete mixer. Then, water is added and stirred well until the micro and coarse grains are mixed. After the concrete mixture is prepared, it is tested as follows: first, in order to prevent the concrete from sticking to the mold wall, its inner walls should be coated with a thin layer of mineral oil. A compressive strength test of concrete is required to calculate the strength of members. Concrete samples are made and tested under compressive force to obtain their compressive strength.

The compressive strength is calculated by dividing the failure load by the area of load application, usually at different ages of storage and processing of concrete. The strength of concrete is controlled by the proportion of cement, fine aggregate, water, and various additives. The lower the ratio of water to cement, the higher the compressive strength. Concrete strength is reported in psi per square inch in US units and megapascals in SI units. For common uses, the compressive strength of concrete is between 0.1 and 60 MPa. Mixed concrete with more than 500 MPa compressive strength can be obtained for special cases and buildings, usually high-strength concrete or reactive concrete powder.

6 | Hardened Concrete Water Absorption Test

This test tries to obtain the absorption amount of water poured on the horizontal surface of a concrete sample or a part of prefabricated parts while there is not much water height to exert pressure, and it is limited to 200 mm. In this experiment, the amount of absorbed water is reported in grams or milliliters per unit area (m2) at different time intervals. The permeability of concrete and the transfer speed of materials through concrete depends on the concrete structure. The concrete permeability coefficient must be determined to determine the concrete permeability of a structure. The coefficient of permeability of concrete is the flow rate of liquid or passing gas (usually in liters) per unit of time through a unit of cross-sectional area under a unit hydraulic gradient (the ratio of head, one meter of water, to the passage, unit of concrete thickness in meters) which Usually, the permeability of concrete is determined quantitatively by the coefficient of liquid (fluid) leakage, which is determined and calculated by gas or water penetration factors with a contractual index.

7 | Conclusion

Increasing the compressive strength of concrete in the samples and using the conventional relationships of reinforced concrete, it can be seen from the percentage of reinforcement in the cassette section, in the investigation of the behavior of reinforced concrete, the compressive strength of SCC can be considered the same as ordinary concrete. The researchers, in examining the ductility in the final state of the joint in members made of SCC, showed that the behavior of SCC in reinforced concrete structures is the same as normal concrete, and the final compressive strain of concrete can be considered to be around 0.0035. Therefore, according to the usual relations of reinforced concrete, the savings in steel consumption can be calculated using the structural calculations of piles.

This value will be proportional to the increase in the characteristic strength of concrete. In terms of durability, in the underground environment and exposed to groundwater, SCC with suitable properties is expected to have less weakness due to low permeability and relatively high uniformity. This property varies in relation to the amount of stone powder used. Therefore, in presenting the mixture design, it should be noted that despite the uncertainty of the negative effects of using high amounts of limestone in this type of concrete, its amount is limited. The cement consumption has intentionally increased (despite the increase in the amount of cement in SCC, this amount is still around 13. The percentage was lower than the consumption of cement in ordinary concrete).

One of the goals of this research is to investigate the feasibility and economic justification of using SCC in domestic projects. The advantages of SCC in terms of quality compared to ordinary concrete are clearly understandable. Time, especially the production and implementation cost, requires more investigation, control, and precision. The working method is such that first, the necessary comparisons are made in the implementation dimension of SCC and ordinary concrete to evaluate the amount of changes in the cost of implementation and, as a result, the overall cost of the project according to the influencing factors such as manpower. The next step is the cost of the materials required for mixing normal and SCC. The high quality of SCC structures is more favorable than ordinary concrete structures. Although SCC has a higher cost than ordinary concrete from the point of view of primary materials, from the implementation aspect and by eliminating human factors, in addition to increasing the quality of the concrete structure, it will have a lower implementation cost than ordinary concrete.

With the calculations and research in the text of the research, for each cubic meter of concreting in one working day, a significant reduction of 21.2% in the cost of manpower was observed while using regional materials and suitable additives to achieve compressive strength similar to and even higher than Normal concrete, the increase in production cost will be 11% on average. In addition to this estimate, we should not forget the ability to implement SCC on sloping surfaces and the necessary arrangements for its implementation. The main drawback to SCC is the molding and sealing of the molds. Also, most of the sensitivity of this concrete against separation can be solved by adding a small amount of viscosity modifier. In this research, the effect of adding different materials and nanoparticles and nano oxides was studied to improve the performance of SCC.

The results are as follows:

I. Adding nano-silica to concrete increases the compressive strength, and increasing the replacement percentage of nano-silica improves the compressive strength.

II. The addition of nano-silica effectively reduces water's permeability and capillary absorption, and by increasing its amount in the mixing plan, a further decrease in permeability is observed. This improvement can be attributed to the high pozzolanic activity of nano silica and the production of C-S-H gel, the pore-filling property of concrete, and the removal of fine holes in the structure of silicate gel.

III. Adding nano-silica to concrete increases the electrical resistance and resistance to chlorine ion penetration in the samples, and this increase continues with the increase of substitution level.

IV. In general, by adding silica nanoparticles to SCC, the amount of compressive, tensile, and bending strength will increase, the time taken by concrete will decrease, and the permeability of water inside the concrete will decrease.

Using nano-silica particles in SCC should be according to existing standards because adding too many nano-silica materials can have the opposite result or be ineffective, which causes costs.

Author Contributions

Farshid Parvareh was solely responsible for the conceptualization, experimental design, data collection, analysis, and manuscript preparation for this study.

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Data Availability

The data supporting the findings of this study are available from the author upon reasonable request.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this research.

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