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Effect of nano-materials on mechanical properties of cement and concrete

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Abstract
Cement is as an adhesive that binds pieces of solids together. In this research, the main materials used in construction such as cement, concrete and steel are described. After described that to what extent the nanomaterials of silicon, titanium nanoxide, polypropylene nanofibers, microsilica and nano calcium carbonate do the compressive strength of concrete and cement increase and prevent corrosion and erosion. Polypropylene nano-fibers are added, using titanium nanoxide to increase the compressive strength of concrete. NanoTiO_2, NanoAl_2O_3, NanoFe_2O_3, NanoFe_3O_4 and NanoSiO_2 have been compared in various studies. It has many effects on compressive strength, erosion resistance and permeability of concrete. This article reviews the research on the use of nanomaterials to improve the compressive strength, erosion and other properties of cement and concrete.

Keywords: Nano-cement; Nano-materials, Nano-fabrics, Nono-tubes, Pozolanic reaction, Compressive strength

Introductions

The changes that nano-cement has made in the industry include increasing the crack resistance of cement, increasing the curing time, increasing the ductility and also reducing its tensile strength. These changes, which are positive, have led to the use of nano-cement in most industries. When nanoparticles are combined with materials and particles such as TiO_2, Al_2O_3, ZnO_2, SiO_2, carbon nanotubes, nanofibers and carbon nanofibers, this can affect the mechanical and physical properties of cement. The effect of nanoparticles on the high quality of cement as mentioned before is composed of holes from a few micrometers to a few millimeters, which is one of the reasons for the low resistance of this substance. The use of nanotechnology has solved this problem so well that nanocrystals penetrate the pores of this material and cover the empty space of this material well. The effect of nanoparticles on nanocement is to increase porosity and permeability and on the other hand increases the resistance. Nanocrystals that fill nanopores well also affect and increase its viscosity. On the other hand, due to this property, nano-cement grains are suspended in liquids and water and do not precipitate. This feature allows you to prepare and use a suitable paste with nano cement.

Cement: Cement is a construction material, obtained by burning and grinding a mixture of clay and limestone up to the clinker in a kiln and hardens as a result of chemical reactions with water. The reaction of cement and water is called hydration. Hydration (the reaction of cement and water) produces a paste that acts as a glue. Paste binds to sand and gravel, resulting in concrete. So, the function of cement in concrete is to bind sand and gravel. Good concrete is one that does not lose its cement adhesive in the test of compressive strength, but rather breaks down the gravel grains. The primary materials for cement production are clay and limestone. To produce cement, first grind clay and limestone and mix them in appropriate proportions. Pour the ground mixture into the oven and heat from 1100 °C to 1500 °C until it turns into a green clinker. These grains range in size from 0.5-2 cm. Grinding green clinker in a mill. This fine material or powder is called cement. Gypsum is also added when grinding green clinker in the mill. This prevents the cement from hardening and setting quickly so that there will be enough time to use the concrete. There are different types of cement to meet different needs, so cement is produced in different ways, the most important are accordt with ASTMC150.

Concrete: Concrete is a construction material, obtained from a suitable mixture of cement, water, sand and gravel. Concrete is made up of cement paste (obtained from chemical reaction of cement and water) and aggregate (sand and gravel) where the paste acts as glue and binds the sand and gravel in consequently obtain concrete. Aggregates makes up to 60-70% of the volume and up to 70-85% the weight of the concrete and the rest is made up of 7-15% cement and 14-21% water. Admixtures are also chemicals that are added to concrete in small quantities as a percentage of the weight of cement as needed. Concrete is a heterogeneous material. It has two fresh and hard states

The proportions, properties, and quality of the composite components of concrete greatly influence the characteristics of both concrete states (fresh and hard). Concrete is the most widely used construction material in the world. Concrete is one of the most widely used building materials in the world due to its following properties: It has high compressive strength; good fire resistance (Can withstand fire up to 28 hours); requires less maintenance and oversight;; long life; Its components are easily obtained in the field of work' ability to take on different shapes; employees require a low level of skill. There are different types of concrete that can be used to suit the working and environmental conditions. As mentioned earlier, in some cases it is necessary to add certain chemicals called admixtures to the concrete in small quantities as a percentage of the weight of cement, some of them are nanomaterial, nano-materials are used in concrete to get some good properties such as to increase compressive strength and durability of concrete.

Steel: Steel is one of the most important and widely used building materials. Properties such as strength, corrosion resistance and weld ability are very important in design and construction. These capabilities have made steel a major player in the construction industry. The use of nanotechnology in steel helps to improve its physical properties. Today's design of steel to prevent fatigue or structural failure of steel, due to its periodic loading, apply three rules to reduce allowable stress, reduce service life and increase regular visits. The application of these restrictions has a significant impact on Costs - will extend the useful life of the structure and the useful use of materials. Increased stresses in the steel cause cracks that result in rupture and fatigue in the steel. Addition of copper nanoparticles to steel reduces its surface roughness and also limits the increase in stress and consequent fatigue cracks (2013, Abhiyan *et al.*) Studies and investigations to correct the cementite (Fe_3C) phase of steel the nanoparticles of vanadium (V) and molybdenum (Mo) solve the problems of delayed rupture associated with high-strength screws, reduce the brittle effect of hydrogen, and reduce the quality of steel microstructures. The addition of magnesium and calcium nanoparticles increases the weld hardness. Two relatively new products available today are the MMFX2 Nano-flex sandwich (Figure1). Both are resistant to corrosion, but have different mechanical properties, so they are different applications of nanotechnology. Forces in modern construction require high strength, while safety (especially in shaky areas) and stress redistribution require high ductility. This leads to the use of flexible materials with lower strength in larger sizes, otherwise materials with higher strengths may be used, and as a result it is a matter of sustainability and optimal use of resources. Nanoflex is a new stainless steel that can be even thinner and lighter than components made of aluminum and titanium due to its high strength and modulus of elasticity. May be resistance to corrosion and erosion increases its useful life and reduces construction and maintenance costs.

Application of nanotechnology in concrete: Application of nanotechnology in concrete finding a new generation of high-performance building materials with different properties than conventional materials is the ultimate goal of studying nanoscale concrete. The use of micron-sized silica particles has been widely used in concrete for many years. It has recently been proven that the use of particles on a smaller scale than micro-silica increases the compressive strength of concrete, and on the other hand, all the properties of a concrete are related to the processes that occur at the nanoscale. In fact, nanotechnology is a science related to measuring and describing molecular structure at the nanoscale and micro scale, to better understand behavior in It is large scale (macro). Nanotechnology includes nano-meter-scale restructuring techniques to create a new and suitable generation of cementitious composites with ideal mechanical behavior, with the help of which concrete with new properties such as low electrical resistance, intelligence, self-cleaning, self-repair formation, high ductility, etc.

In the cement industry, it is produced in powder form, the dimensions of which are generally in millimeters and microns. Recently, two methods for producing cement in nano-dimensions have been proposed: 1- Grinding cement particles (in this method, nanocomposites are made by crushing the main material). 2 - The use of chemical compounds (in this method, using chemical reactions, nanoparticles are formed).

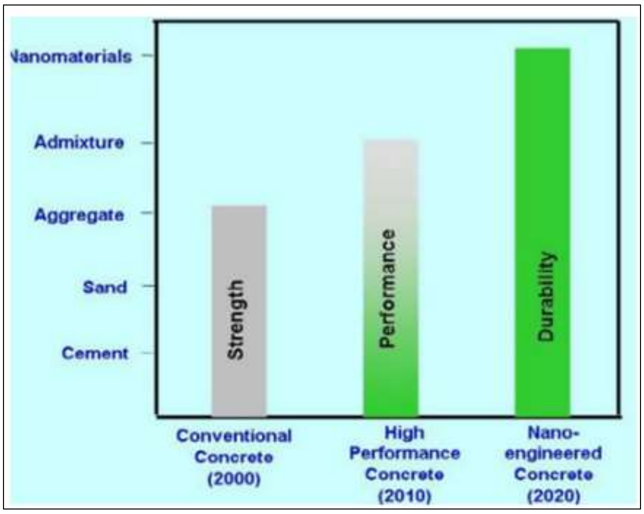

Fig 1: Moving towards durable concrete using nanotechnology

Nano-cement materials: Ordinary cements, which were mostly used in the past, have very brittle properties. Due to the emergence of new materials and achievements in various fields, today we see the addition of some materials to these materials. Nano-cement materials can be used as carbon nanotubes, silicon nanoparticles, iron oxide nanoparticles, zinc oxide nanoparticles, nano calcium particles, titanium nanoparticles and aluminum were considered. The problem with nano-cement materials is that each of these materials gives a special property to the cement. For example, by adding nano-calcium particles to the cement, the cement becomes more compressive and flexible, or zinc oxide nanoparticles can become porous and permeable. Zinc oxide nanoparticles can reduce the porosity and permeability of cement. The use of these nanoparticles in nano-cement has made this material known as one of the quality and basic materials in the construction industry.

Nanomaterials in concrete: There are different types of nanomaterials and the numbers of nanomaterials studied in concrete are also more. This article introduces the most important and the most widely used nanomaterials. These nanomaterials are generally made of cement itself, such as nano-iron, nano-alumina, nano-silica, etc. Generally, each of these nanomaterials has many advantages and disadvantages, and the main problem of using these nanomaterials in our country and in the world is their economic discussion and their effect is on the environment. For this reason, it is very important to find the optimal and effective amount of these nanoparticles in concrete and to find nanomaterials that do not have a harmful effect on the environment. In the following, a number of up-to-date researches will be introduced and reviewed.

Investigating the effect of nano-silica: Sun *et al*. conducted research on modifying the effect of nanosilica on the initial compressive strength of concrete containing large amounts of fly ash [2]. According to this research, the control sample of cement without nanosilica and fly ash had the highest compressive strength. The closest compressive strength to this control sample was 58% cement, 2% nanosilica and 40% fly ash. The results of uniaxial compressive strength test can be seen in Figure2. Adding large amounts of fly ash, especially more than 70%, significantly reduces the compressive strength of concrete. High performance has also been investigated by Jalal *et al*. [5].

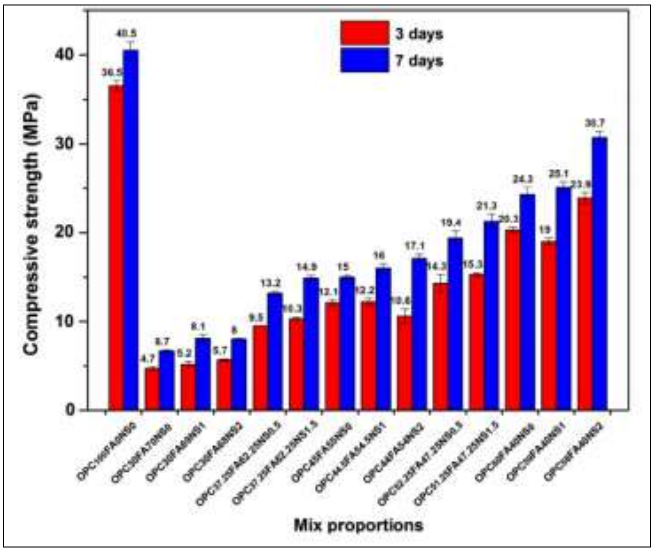

Fig 2: Investigation of the effect of nanosilica on concrete containing high levels of fly ash

The results of the above diagram have also been investigated in another study, in which the sample containing nano-silicane had higher strength than the sample containing nano-silicane fly ash [3, 4] The effect of fly ash to nano-silicane on the compressive strength of high performance compacted concrete [5] The results indicate a decrease in strength with the addition of fly ash and an increase in strength with the addition of nano-silica. However, the compressive strength for 15% of fly ash in concrete at 90 days of age has increased slightly compared to the control sample. Rahim *et al*. investigated the effect of adding nanosilica in concrete containing cement with wood ash on its compressive strength [6]. It contains a sample containing 2% nanosilica in the presence of wood ash ($0.WA_{10}NS_2$). The results of this example can be seen in Figure 2. According to this chart, the effect of nanosilica is low in the early ages, but we see an increase in resistance at older ages. This increase is due to better pozzolanic reactions. However, in this study, the optimal amount of nanosilica is 1.5%.

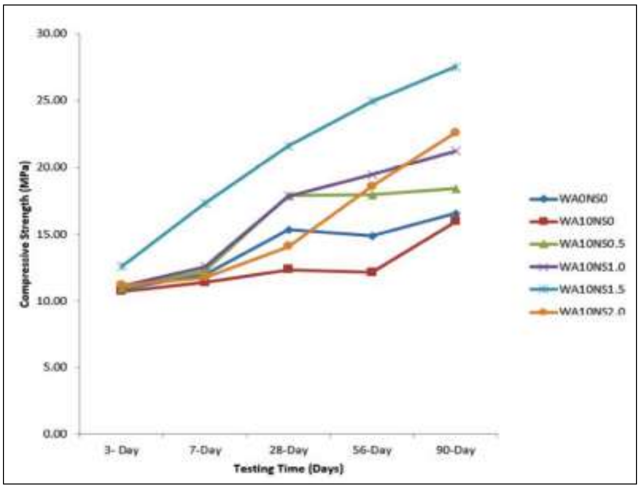

Fig 3: Diagram of the effect of nanosilica on cement concrete containing wood ash.

Windhian and Vapilay also investigate the effect of nanosilica [7]. According to their research, increasing nanosilica increases the compressive strength and then decreases. According to their results, it achieves the highest compressive strength of 1.5%. The reason for this increase is that the hydration process of tricalcium silicate (c3s) is faster in the presence of nanosilica as shown in Figure4.

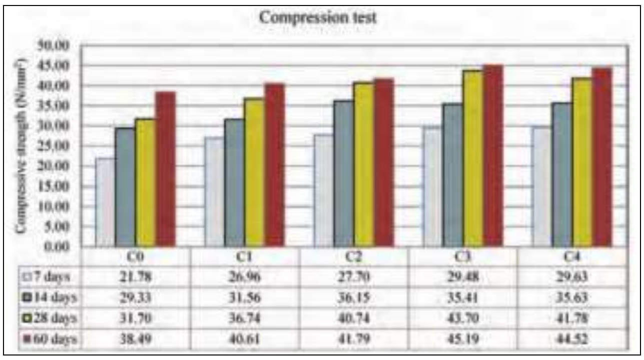

Fig 4: Evaluation of compressive strength results of concrete in the presence of nano-silica

Investigation of the effect of nano-calcium carbonate: Research has been done on the use of calcium carbonate nanoparticles and the results have included improved good mechanical strength, improved impact strength and flexural strength [1]. In another study by Ehsani *et al*., combined calcium carbonate particles with a carbon coating and investigated its effect on the compressive strength of concrete [1]. This carbon coating is the result of soot combustion materials that are combined in solution by a reactor with lime milk. According to the observations, it can be seen that the concrete containing calcium carbonate with nano-carbon coating in its 3-day strength shows a decrease in strength compared to the normal sample. So that in the amount of 10% by weight of cement, it experiences a decrease in strength of about 15.6%. As the age of concrete increases, as seen in the research, the 7-day strength of concrete experiences an increase in compressive strength compared to normal concrete samples. This increase occurs up to 3% by weight of cement, but if the percentage of this nano increases, the sample will undergo a process of decreasing compressive strength at the age of 7 days.

Titanium Nano Oxide: Research has shown that the use of titanium dioxide nanoparticles, in addition to the self-cleaning properties of concrete, increases the rate of hydration and reduces the setting time of concrete (2009, al et. Jayapalan.) Also, the use of these nanoparticles increases flexural strength and compressive strength of concrete (2007. *et al*.). 2006., *et al*. Li. show the effect of adding titanium oxide nanoparticles to the concrete itself. As it turns out, the addition of titanium oxide nanoparticles improves the microstructure of the concrete and makes the internal cavities of the concrete smaller. This improves the mechanical properties and durability of concrete (2013., *et al*., Fathi, Jalal)

Aluminum Nano Oxide: The addition of aluminum oxide nanoparticles to the concrete mix significantly increases the modulus of elasticity of the concrete. Experience has shown that with the addition of 0% aluminum nanoparticles, the modulus of elasticity of concrete increases by 153%, but has no significant effect on the strength of concrete (2006., *et al*. Li. Z.). Theoretical and mathematical effect of adding nanoparticles aluminum oxide was studied on the hydration of concrete and found that the addition of these particles reduces the heat release and accelerates the peak release time of this heat. By adding 3% by weight of aluminum oxide nanoparticles to concrete, the amount of heat released will have the greatest drop (Rashad, 2013). Theoretically and mathematically, the effect of workability of modified concrete with aluminum oxide nanoparticles for weight ratios of 0.5, 1.5, 0.5 and 2% and the results showed that increasing the amount of aluminum oxide nanoparticles reduces the workability of concrete.

Nanotechnology challenges in the concrete industry: Nanotechnology is a vast and dynamic field of research around the world, which has been used in various fields such as electronics, medical engineering and composites after the invention of nanocarbon tubes. Recently, various researchers have turned to the use of nanotechnology in the cement industry. Using nanoparticles in cement, and achieving new properties, cement can replace conventional cements as a high-tech material. Like many new technologies, nanotechnology needs to be justified. It is economical, but at present, due to the high costs of this technology, the increasing development of these products and their use in industry is limited. Uniform distribution of nanoparticles in concrete another challenge is the use of these particles. Usually these particles become a piled mass when added to concrete and are not well distributed in the mixture. Of course, strong mixers can be used to compensate for this defect. Because nanoparticles have a large specific surface area, it is possible for them to absorb large amounts of water and, as a result, have a negative impact on the performance of concrete.

Compressive strength: Based on the studies, it can be said that Nanosilica (NanoSiO_2) is the most common nanomaterials used in cement matrices, but other nanomaterials such as NanoAl_2O_3, NanoTiO_2, NanoFe_2O_3, NanoFe_3O_4, NanoClay and NanoZrO_2 have also been used. Addition of 1, 3 and 5% NanoSiO_2 and NanoTiO_2 to ordinary concrete indicates a 12% increase in compressive strength in a sample containing 1% nano-silica and an 18% increase in the sample containing 1% nanotitania [4, 5]. In another study Zr, Fe, Ti and Al nano-oxides were used in the amount of 1.5% by weight of cementitious materials in super-reinforced concrete and the best improvement in compressive strength of 55% was reported in samples containing nano-alumina [6] Addition of nano-silica and nano-alumina by 0.5 to 2% and curing in both water and lime water showed that in both cases nano-silica had a better effect than nano-alumina and also the results of the treated samples. In lime water, they showed a better improvement than 7 [7]. Nanosilica and micro silica were used in another study with percentages of 1, 3, 5 and 7 in porous concrete and the effect of nanosilica was much better. A 48% improvement in compressive strength was obtained in a sample containing 7% nano-silica [8]. The use of NanoFe2O3 with percentages of 1 to 5 indicates the best improvement in compressive strength (72% increase (4% by weight) [9]. Nano-silicon dioxide and aluminum are used in ordinary concrete. The optimum percentage of these nanomaterials to improve the maximum compressive strength of concrete, 3% by weight of nano-aluminum oxide and 5% by weight of nano-silicon cement) 8% and 30%, respectively [10]. In another study, in addition to nano-silica and nano-aluminum, polypropylene (PP) fibers were also used, the highest improvement is related to 5% nano-silica, in which 2% by volume of concrete, PP fibers Has been used and the amount of this improvement is 31%, which is slightly more than the improvement of 5% silicon nano dioxide without fibers [11]. Addition of silicon nano dioxide in the amounts of 0.3 and 0.9% by weight of cementitious materials, improved the compressive strength by 9% and 12%, respectively [12]. In another study, 10% by weight of nano-silicon cement was used, which showed an improvement of about 30% in compressive strength [13]. Also, by using 1 and 2% nano-silicon dioxide, the highest compressive strength of concrete containing 2% nano-silica with a water-to-cement ratio of 0.39 has been improved by 11% [14] in a review article [15]. The application of nanosilica is mentioned.

The use of nano-silica in HPC (high performance concrete) concrete containing body ash in percentages of zero, 1, 3, 5, 7 and 9 has been shown to improve the compressive strength of the samples by increasing the amount of nano-silica to 5%) 22% improvement for the sample with age 3 days (and by passing 5% and using 7% and 9% nano-silica, the rate of this improvement will decrease [16].

Abrasion resistance: The use of NanoSiO_2, NanoTiO_2 and polypropylene (PP) fibers has shown that the application of lower percentages of these nanomaterials has a better effect on abrasion resistance, so that the addition of 1% titanium dioxide was better than 3 and 5%. 181, 148 and 90% improvement respectively, and also the application of 1% nano-silica had a better effect on abrasion resistance than 3% nano-silica respectively [5]. In another study by $NanoSiO_2$ and $NanoAl_2O_3$ 0.5 to 2% by weight used in water and lime water and improved abrasion resistance of nano-silica was better than nano-alumina. The optimum amount of these materials is 2% by weight of cementitious materials [7]. Addition of $nanoSiO_2$ in colloidal solution containing different percentage (of 4, 8 and 12%) and also as a spray in different quantities (of 25 and 50% in different times and numbers) 1 to 3 times used. Either processed in colloidal solution for 28 days and then tested or treated in water and sprayed on the cleaned surface, in all cases, a larger amount of nano-silicon dioxide) Spray 50% three times or colloids containing 12% (showed better improvement in abrasion test and 42 and 32% improvement in abrasion resistance were obtained for processing in colloids containing nanomaterials and spraying, respectively [3]. Addition of $_{NanoSiO2}$ and Nano SiC in percentages of 1, 2 and 3 separately and in combination shows that the optimal amount to improve the abrasion resistance in concrete is 2 and 3% by weight of cementitious materials for $NanoSiO_2$ and Nano SiC, respectively (49 and 68% improvement, respectively) and the combined mode is the answer better (75% improvement) compared to the separate state [17]. Comparison of the use of 40% fine nano-porous or 5% nanosilica or a combination of 5% nanosilica and 25% fly ash as an alternative to cement showed that improved concrete wear resistance of 20, 16 and 13% and mortar wear resistance of 82, 73 and 68%, respectively [18].

Resistance to permeability and water absorption: The use of silica and titanium nanoparticles and PP (polypropylene) fibers in concrete showed a 31 and 18% improvement in chloride penetration resistance in samples containing 1% titanium nano dioxide and 1% nanosilica, and PP fibers had a negative effect on resistance to chloride penetration; also in this study, samples containing low percentages of nanomaterials) showed 1% (better improvement than samples containing higher percentages) 3 and 5% (against chloride penetration [4]. Nanoparticles of $NZrO_2$, NFe_3O_4, $NTiO_2$ and NAl_2O_3 were used in 1.5% HPC concrete, 80% improved in water absorption of samples containing NFe_3O_4 and $NTiO_2$, and 70% improved in the penetration of $NZrO_2$ chloride with NAl_2O_3 (70%) [6]. In a study on porous concrete, nano-silica with values of 1, 3, 5 and 7% and micro-silica with 3, 5 and 8% were used separately. Micro-silica had a better effect than nanosilica on permeability. Addition of 8% micro-silica showed an improvement of about 25% and addition of 7% nano-silica also showed an improvement of about 20% in permeability [8]. Nano-hematite is equal to 4%, which shows about 74% improvement in water absorption [9]. Nano acids of Al_2O_3, Fe_2O_3, Fe_3O_4 and Nano Clay showed positive effect on absorption of water of cement mortar and the writers have been stated different optimal amounts (from 0.5% to 4%) which depends on the type of processing as well as other materials used in concrete mixing [19]. Nano-silica, nano-alumina and nano-hematite in two types of mortars containing fly ash and silica foam separately and the compound used and their permeability and water absorption have been investigated and the addition of 1.25% of nano-aluminum oxide in mortar containing silica foam has improved 29% of the permeability [20]. Also using 1.25% of combination of 3 mentioned nano-materials, in mortar containing fly ash, there is a 14% improvement in mortar water absorption [21].The use of 0.3% and 0.9% $NanoSiO_2$ can also show a good improvement in water permeability, so that the addition of 0.3% nano-silica improves 56% in concrete permeability [12]. In a study of two types of nanosilica, one with a fine particle size of 15 nano-meters (and the other with a large particle size) of 80 nano-meters (and 4% of each different) (0.5, 1, 1.5 and 2) have been used and water permeability has been tested, which in the long run, larger nanoparticles have a better effect on improving permeability (nearly 23% using 2% weight of coarse-grained nanosilica cement) but in the short term the effect of finer nanomaterials has been better [22]. Nano-silicon colloid has been used in two different ways (spraying or processing in nano-silica colloid) to improve the permeability, which is the best result for the case where samples were applied in colloids containing 12% nano-silica and 31% improvement in Water permeability is shown. Also, by spraying a solution containing nano-silica twice with a concentration of 50%, a 12% improvement in permeability has been achieved [3]. In one study, the effect of $NanoSiO_2$ on the mechanical properties and durability of concrete was reviewed in various researches [23]. Colloidal and powder modes have been used that the addition of 3.8% by weight of nano-silica has improved the permeability of water by 88% [24].

Result: In this study, the effect of different types of nanomaterials ($NanoTiO_2$, NanoAl2O$_3$, $NanoFe_2O_3$, $NanoFe_3O_4$ and $NanoSiO_2$) on compressive strength, abrasion resistance and permeability of concrete were investigated and the general results are as follows. In general, nanomaterials can have a positive effect on the compressive strength of concrete. However, the same can be said for nanomaterials; Nano silica and graphene nano oxide have a great effect on the compressive strength properties of concrete and always increase the compressive strength up to a percentage of its addition to various types of concrete. In some studies, this amount of 1.5% and in others 3% for nanosilica and for graphene nano oxide 08.0% by weight of cement has been introduced. For nanosilica values higher than the mentioned cases, we will see a decrease in the compressive strength of concrete. The reason for this reduction can be considered as separation between particles and porosity in the concrete microstructure. Also, in relation to increasing the compressive strength of concrete by adding the mentioned amount of graphene nano oxide, it can be considered the positive effect of this nano in increasing the production of calcium silicate hydrate compared to calcium hydroxide and also reducing pores in concrete microstructure. Regarding the addition of nano-alumina, the results showed a decrease in compressive strength in old age and in small amounts of this nanomaterial in young age, an increase in compressive strength. In fact, nano-alumina will increase the setting speed of concrete at an early age. Finally, this initial entrapment increases resistance at a young age and decreases resistance at an older age.

In connection with the addition of carbon nanotubes to concrete, in addition to increasing the compressive strength of concrete, this nanomaterial has a great impact on other parameters of concrete and is known as a very useful nanomaterial. Titanium nano oxide also increases the compressive strength of concrete, but compared to other nanomaterials mentioned, it creates a lower percentage in increasing the compressive strength of concrete. This nanomaterial is also economically more expensive than nanosilica. In discussing the harmful effects of cement on the environment, a large part of cement can be replaced with fly ash and its strength can be strengthened with nanosilica. Of course, the use of carbon materials may be appropriate if it does not interact with the environment. Because carbon materials can be contaminated in the long run anyway. Finally, considering the price, impact and volume of research that has been done on nanosilica on the compressive strength of concrete so far, this nanomaterial can be distinguished and more effective than others.

Nano materials can be improved by improving the microstructure of concrete through The pozzolanic reaction as well as by filling the small pores in the concrete structure have a great impact on improving the mechanical properties and durability of concrete. Overall, increasing the compressive strength increases the abrasion resistance and decreases the permeability of the samples. Addition of some nano materials especially nano magnate in concrete, when mixed with self-compacted concrete causes air voids in it as a result increases empty spaces and empty volume which increase the porosity. Obviously, increasing the porosity has reduced the compressive strength and abrasion resistance and increased the penetration. In case the nanoparticles spread by the optimal amount, appropriate distances and uniformly in concrete, they must be placed as a core in the production of cement hydration, by creating a homogeneous and dense environment and by filling the empty spaces of the concrete structure, they improve the mechanical properties. Also, some nanoparticles, such as nanosilica, in addition to their filling properties, can increase the production of hydrated calcium silicate by pozzolanic reaction, which will have a direct effect on improving the mechanical properties of concrete. This pozzolanic reaction is faster in nanoparticles due to the higher specific surface area than in micro-scale materials. While the addition of nanomaterials more than the optimal amount by interfering with the proper distribution and also by reducing the efficiency of concrete and on the other hand by preventing the sufficient growth of calcium hydroxide crystals and reducing the ratio of these crystals to hydrated calcium silicate, leads to insufficient compaction of concrete microstructure. Deterioration of mechanical properties.

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