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Tensile and Compressive Strength Investigations of Ordinary Concrete and Pozzolanic Concrete and the Effect of Polypropylene on Them

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Abstract

Fibers increase cohesion, increase tensile strength, reduce cracks, and increase the softness of concrete. The type of fibers used in concrete and their size depends on the type of concrete used and tensile strength. Fibers used in concrete can be glass, steel, or polymer fibers. Polypropylene fibers are economically efficient, and considering their favorable properties, in this research we examine the effect of these fibers on ordinary concrete and pozzolanic concrete. After preparing the necessary materials, which include cement, water, stone materials, and lubricants, it is necessary to prepare the additives required for concrete, which include polypropylene fibers and metakaolin pozzolan. The samples made in this research include control sample S and sample A1 with 0.2% by weight of polypropylene fibers and 5% by weight of metakaolin pozzolan, sample A2 with 0.2% by weight of polypropylene fibers and 10% by weight of metakaolin pozzolan, sample A3 with 2.2 0% by weight of polypropylene fibers and 10% by weight of metakaolin pozzolan, sample B1 has 0.5% by weight of polypropylene fibers and 5% by weight of metakaolin pozzolan, sample B2 has 0.5% by weight of polypropylene fibers and 5% by weight of metakaolin pozzolan, sample B3 has 0.5% by weight of polypropylene fibers and 15% by weight of metakaolin pozzolan, sample C1 has 1% by weight of polypropylene fibers and 5% by weight of metakaolin pozzolan, sample C2 has 10% by weight of polypropylene fibers and 10% by weight of metakaolin pozzolan, sample C3 has 1% by weight of polypropylene fibers and 15% by weight of metakaolin pozzolan. The use of polypropylene fibers reduces the compressive strength. It increases the tensile strength of the samples, and the use of high percentages of pozzolan improves the compressive strength and tensile strength.

Keywords: Compressive strength, Tensile strength, Pozzolan, Polypropylene fibers.

1 | Introduction

Concrete is currently one of the most widely used building materials in the world. Today, concrete is considered for some reasons, including the presence of some features such as high compressive strength, durability, availability of materials needed for construction and reasonable price.

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Due to the expansion of concrete consumption in various constructions, since the beginning of cement and concrete manufacturing, mankind has always tried to produce concrete with better properties. These efforts have been in different fields. In this context, it is possible to mention the complete replacement of other materials instead of cement to the replacement of different materials instead of a part of cement or aggregate [1].

But it can be said that the general axis of these experiments was in the field of concrete production with higher density and, of course more economical. According to estimates, the total amount of concrete consumed in the world in 2011 was more than three billion tons, which is one ton per person in the world. The only substance that humans consume in this amount is water. With the increasing progress of science, researchers have tried to take a step towards the production of concrete with high strength by using new technologies in the concrete industry and making special concretes [2].

In Iran, due to the high volume of construction projects and the availability of materials needed for cement production, the use of concrete is very popular, and engineers consider the durability of concrete as a fundamental factor in the useful life of concrete structures. On the other hand, studies have shown that cement production destroys amounts of natural resources such as limestone, fossil fuels, etc. For every ton of cement produced, about one ton of carbon dioxide gas, which is one of the environmental pollutants, is created. This amount of greenhouse gas production can have many effects on global warming and its effects. The increasing need for cement is very important for implementing various projects and achieving high-quality and durable concrete structures [3].

In addition, the necessity of using cement optimally and replacing part of it with materials that, despite having the properties of cement, do not endanger the performance of cement paste, either in terms of strength or durability, is felt. In this replacement, the economic issues of design and durability of concrete are decisive factors. A group of these materials are known as pozzolans. In general, pozzolans are materials that do not have the value of cement by themselves or have little cement activity. Still, if their particles are well separated and fine, they can chemically react with calcium hydroxide from the hydration of cement in the presence of moisture and produce compounds with the properties of cement [4].

Pozzolans are cheap and accessible mineral additives that reduce the production of cement and replace a part of cement, reduce energy consumption, and preserve natural resources and the environment. Pozzolans are divided into natural and artificial pozzolans in terms of their origin and type of formation. Natural pozzolan includes shales, volcanic ash tuffs, etc. The main sources of synthetic pozzolan production are metal extraction furnaces that produce crude iron steel and power plants that use coal as fuel. Using these materials and replacing their different percentages not only reduces the cost of concrete production but also improves the durability of concrete in destructive environments [5].

Other additives that can be used in concrete are fibers. The use of fiber reinforced concrete is increasing worldwide due to the improvement of mechanical properties and durability of concrete. Therefore, the use of this type of concrete in the construction industry requires more research on its properties and durability, which is the main factor in the design and construction of structures. Among the advantages of these concretes we can mention their high compressive strength and tensile strength, higher modulus of elasticity, and lower permeability [6].

One of the effective factors in achieving such high resistance in concrete is the use of resistant and well-shaped sand, increasing the amount of cement used, limiting the size of the largest aggregate, using sand with a suitable modulus of elasticity, reducing the ratio of water to cement and using the above the lubricant is for its greater homogeneity. Also, by using very fine-grained materials such as pozzolans, denser aggregates with very low porosity can be prepared. As a result, it leads to an increase in the compressive strength of concrete . Often, with the increase of concrete strength, its brittleness and fragility also increase. Adding fibers to concrete causes [7].

Fibers deal with cracks and increase the resistance of concrete against fatigue, impact, shrinkage and thermal stresses and have a positive effect on the mechanical properties of concrete in all modes of failure. It copes better and improves the mechanical properties of concrete by bridging microcracks. Polypropylene fibers, which are prepared through the polymerization of propylene in a linear form and are called pp for short, are used for a wide range of applications due to their cheap price compared to other fibers. The types of fibers used in concrete are steel fibers, glass fibers, polypropylene fibers, carbon fibers, etc. It is made of polypropylene fibers in concrete to control cracks and is one of the alternative materials for steel rebar to reinforce and strengthen concrete [8].

The addition of polypropylene fibers will increase mechanical and chemical resistance and reduce the damage caused by effective fire. Its use will have a positive effect on the properties of concrete. The lightness of polypropylene from water, as well as the non-absorption of water by these fibers, and as a result, the non-change of their mechanical properties due to contact with moisture, are its prominent features. When these fibers are mixed with concrete, they do not settle and increase the weight of concrete, and they do not destroy the alkaline environment of concrete. Polypropylene fibers can be added to concrete at any time; usually, these fibers are first mixed with aggregate, and then water is added to it.

2 | Pozzolan

Pozzolan is a siliceous material with siliceous-aluminate that alone has little or no adhesive properties, but its soft and homogenized powder reacts chemically with calcium hydroxide in the presence of humidity and normal temperature and creates compounds similar to cement mortar compounds. Iranian National Standard Organization No. 3433 (INSO No. 3433) has also provided a definition similar to American Society for Testing and Materials (ASTM): pozzolans are siliceous or siliceous-aluminum materials that have little or no adhesive properties on their own but form a soft round in the vicinity of moisture. At normal temperatures, they react chemically with calcium hydroxide and create compounds with the properties of cement. Therefore, pozzolan is a natural or synthetic material that contains active silica. The pozzolanic material must be in powdered form. Only then can the silica form stable calcium silicates with adhesive properties in the presence of water with lime (which can be formed by the hydration of Portland cement).

3 | Types of Pozzolans

In general, pozzolans are divided into two main groups: 1) natural pozzolans (materials that have been processed only for the production of pozzolans) and 2) synthetic pozzolans (industrial by-products or industrial waste materials). Of course, some researchers have considered natural materials that have been heat-treated to obtain pozzolanic properties as synthetic pozzolans.

Among these materials, metakaolin can be mentioned. Metakaolin is obtained by heating clays containing kaolin at temperatures of 600 to 900 degrees Celsius, and it is a white and amorphous aluminum silicate that strongly reacts with calcium hydroxide to form sticky and cement compounds. Classification of natural pozzolans is difficult because these materials rarely contain only reactive constituents. However, based on the main reactive constituent present, a classification can be volcanic glasses, volcanic tuffs, clays with calcined clay tones, and diatomaceous earth. The publication of their formation processes and relevant specifications are given below:

I. Volcanic glasses: the soil of Santorini, Utah, pozzolan with clay from Italy, and pozzolan from Shirasu, Japan, are examples of pozzolanic materials in which the characteristic of reactivity with lime mainly originates from modified aluminosilicate glass.

II. Volcanic tuffs: the Sinian pozzolans of Latium (in Italy) and the Rhineland and Bavarian terraces (in Germany) represent conventional volcanic tuffs. Zeolite tuffs, with their compact texture, are relatively strong; they achieve compressive strengths of about 100 to 200 kg/cm2. The main Zeolite minerals are mentioned as fabricate and herschlite. After the compacted mass is ground to a soft particle size, xenolithic minerals show significant reactivity with lime, producing cementitious properties similar to those of pozzolans containing volcanic glass.

III. Tiflised clays or shales: volcanic glasses and tuffs do not need heat treatment to increase their pozzolanic properties. However, clays and shales do not show appreciable reactivity with lime unless the crystalline structures present in formal minerals are destroyed by heat treatment. Temperatures of around 600 to 900 in rotary kilns with oil, gas, or coal fuel are considered sufficient for this purpose. The pozzolanic activity of this product is basically due to the formation of an amorphous or irregular aluminosilicate structure as a result of thermal processing. Historically, pozzolans made in India by pulverizing fired clay bricks belong to this group. In other words, pulverizing fired clay bricks made from any clay may not yield suitable mineral admixtures for concrete.

4 | Properties of Pozzolanic Concrete

Many properties of concrete are favorably affected by adding pozzolanic materials. The physical effect of pozzolan particles causes some of these effects and chemical reactions of pozzolan cause some others. Pozzolans generally have a stabilizing effect on the deformation of fresh concrete in such a way that adding small pozzolan particles to the concrete mixture reduces water loss and segregation. Also, published reports show that the addition of pozzolans to ordinary cement mixtures generally increases the adhesion of the mixture and reduces the flowability of the mixture [9].

5 | Pozzolanic Reaction in Cement

A pozzolanic substance, when mixed with water, does not have any value or properties of adhesion and hardening, but the pozzolanic interaction between the silica or aluminized silica components of a pozzolan occurs with calcium hydroxide exposed to moisture and shows the properties of adhesion and cementation [10].

6 | Polypropylene Fibers

In the experiment, polypropylene fibers made in Iran were used, and all its technical specifications are given in accordance with the standards presented in *Table 1*.

One of the important applications of fibers in concrete is to increase fire resistance. It has been seen that concrete members, especially high-strength concretes, suddenly ruptured after being exposed to fire and exposure to high temperatures, or their resistance parameters were significantly reduced.

Scientists consider the high density of the texture of hydrated products and the lack of empty spaces in these concretes as effective factors in this field. As the concrete temperature increases, the water in the capillary spaces that did not participate in the hydration reaction evaporates. Due to the lack of sufficient space, the pressure inside these holes increases. A temperature of 300 degrees Celsius causes internal stresses of about 8 MPa, which almost doubles when the temperature increases to 350 degrees Celsius, which easily destroys concrete. In concrete containing polypropylene fibers, the existing fibers are melted at 160 degrees Celsius to produce additional empty spaces in the concrete and reduce its internal pressure by transferring the excess pressure to the outside [11].

Basically, all cement mixtures tend to shrink naturally. Therefore, the use of the mentioned fibers in the mentioned mixtures has a significant effect in preventing the occurrence of such phenomena. In the early ages (from the time of concreting to the first 24 hours), the resistance gained by the concrete is insignificant, and the smallest action can lead to cracking. Cracks are caused by the beneficial effect of temperature change (cooling of concrete after the temperature of concrete has risen due to hydration of cement and by evaporation of water from the concrete surface. The high tensile strength of polypropylene fibers at this time prevents the concrete from cracking.

Using polypropylene fibers to prevent shrinkage and cracking of concrete at early ages (plastic shrinkage) seems to be more effective than any other solution. A very large number of fibers per cubic meter means a very wide flat connection of the fibers to the concrete, and the small distances of the fibers prevent the formation of cracks. Polypropylene fibers prevent the concrete from losing water and prevent the transfer of water to the surface of the concrete, which results in the homogenization of the concrete and the same ratio of water to cement in all the concrete and the continuation of the hydration process [12].

These fibers reduce the permeability of the concrete surface increase the life of concrete and increase the wear resistance of concrete. Watering is associated with the formation of a layer of thin slurry on the concrete surface, which has a negative effect on the resistance of the concrete surface. Preventing water leakage means preventing the creation of weak points in concrete [13].

Also, the fibers are effective on shrinkage after hardening and reduce it. If the amount of consumption is 2 square meters per kilogram or more, they prevent concrete shrinkage and prevent the formation of thermal cracks to a large extent. Polypropylene fibers significantly increase the resistance of concrete against impact loads. This is important in dynamic loading, such as strong wind, earthquakes, vibration of heavy machinery, and impact caused by rocket explosions.

Table 1. Characteristics of polypropylene fibers.

Diameter (mm)	Length (mm)	Specific Gravity (gr/cm³)	Maximum Percent Change in Length	Modulus of Elasticity (Kg/cm²)	Tensile Strength (Kg/cm²)	Type of Fiber
0.02	18.12.6	0.9	25	35.16	7734-5625	Polypropylene

Fig. 1. Polypropylene fibers after separation by hand.

Fig. 2. Fibers before separation.

7 | Metakaolin

Kaolinite soils are a group of types of natural pozzolans that can be a good substitute for part of cement due to their fineness, amorphous structure, and high pozzolanic activity. To strengthen the pozzolanic purposes and increase the reactivity of kaolin, it is heated in the temperature range of 600 to 900 degrees Celsius to form materials called metakaolin with an aluminosilicate structure in an amorphous form. Kaolin is a very fine-grained natural mineral soil, white and with plate-shaped particles. Chemically, the common molecular formula for kaolin is the kaolinite supergroup [14].

Table 2. Physical and chemical characteristics of metakaolin pozzolan.

Chemical Compounds	Metakaolin
SiO_2	52.1
Al_2O_3	42.8
Fe_2O_3	1.6
CaO	0.2
Mgo	0.21
So_3	0.00
K_2O	0.32
Na_2O	0.11
Physical Characteristics	
Specific Surface (m^2/g)	2.54
Special Mass	2.6

8 | Compressive Strength Test

This test is the most common test that is performed on the quality of hardened concrete. The test to determine the compressive strength has been carried out according to EN 3-12390 standard. 150 mm cubic specimens were used to determine the compressive strength of the mixtures. After taking these samples out of the mold, they were transferred into the water pool at a temperature of approximately 20 degrees Celsius. At the desired ages of 7, 28, and 60 days, they were taken out of the water and tested to determine the compressive strength. In order to determine the compressive strength, a concrete breaker jack produced by Tek Azma company with a capacity of 200 tons and a loading speed of three kilonewtons per second was used according to the standard. *Fig. 3* shows the image of the concrete breaker jack for the test to determine the compressive strength.

Fig. 2. Fibers before separation.

9 | Test to Determine the Tensile Strength by the Brazilian Method

This test is performed based on the ASTM C496 standard method according to *Fig. 4* on cylindrical specimens. The conditions for preparation and storage of these samples are the same as for pressure samples. The test method is to measure the diameter and height of the sample, mark the two levels of the base of the sample with two perpendicular lines, and place the sample between the plates of the concrete breaker jack. For the balanced distribution of pressure, we use two wooden blades at the top and bottom of the samples. The load is gradually increased, and as a result of the pressure in the direction perpendicular to the tensile stress, the sample breaks. The increase in load will be uniform and at a rate equal to 7 to 14 kilograms of force per square centimeter per minute until the sample breaks. At this time, the maximum incoming load is read and recorded by the device.

Fig. 4. Cylindrical samples for testing tensile strength.

Fig. 5. Testing to determine the tensile strength of cylindrical specimens using the Brazilian method.

10 | Conclusion

Fiber concrete is a type of concrete in which fibers are used in its construction, and cement, water, aggregates, and additives are mixed with fibers. Fibers increase cohesion, increase tensile strength, reduce cracks, and increase the softness of concrete. The type of fibers used in concrete and their size depends on the type of concrete used and the desired tensile strength. The fibers used can be glass, steel, or polymer fibers. Since polypropylene fibers are economical and due to their desirable properties, in this research, we examine the effect of these fibers on ordinary concrete and pozzolanic concrete. The secondary objectives pursued in this research include the effect of polypropylene fibers on the compressive strength and tensile strength properties of pozzolanic and ordinary concrete, the use of pozzolan in different percentages on the compressive strength of concrete samples, the use of polypropylene fibers in different percentages and its effect on the strength properties of concrete. The combined use of pOzzolanic materials and polypropylene fibers in concrete is to achieve high strength and measure the economic efficiency of this work.

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