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# Effect of Natural Pozzolan on Concrete's Mechanical Properties and Permeability in Various Grades of Cement

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**ABSTRACT**

Pozzolan is an additive to cement clinker that if added to the high quality cement and concrete, it can be effective in enhancing the quality of cement and concrete resulting from high quality controlled precision and repeated sampling and continuous testing. Concrete creates the cement-free concrete without any additives. Documentary reports and rigorous scientific studies have shown that good pozzolan can, in addition to increasing the chemical resistance of concrete, eliminate the defects caused by the use of conventional cement in concrete and due to the diversity of water and soil use in different areas. In this study, the effect of natural pozzolan in different grades of cement on the mechanical properties and permeability of concrete at 7 and 28 days of age is investigated. It was found that with increasing cement grade, the water absorption rate of concrete increased. Also, the effect of pozzolan on the permeability of concrete samples is increased by increasing the pozzolan water absorption rate. Also, the effect of cement grade on the compressive strength of concrete was found to decrease with increasing concrete grade. Today using alternative sources in concrete productions is important, due to its economical and environmental considerations. Pozzolans are one of these resources which decrease the environmental pollutions and production costs of concrete structures.

## 1. Introduction

Today, pozzolanic materials are enjoying a renaissance as supplementary cementing materials in Portland cements pastes and may replace part of the clinker in order to enhance the performance of the hydrated cement. When Portland cement clinker is produced there is a significant amount of CO2 emitted from the calcination of the limestone (Bajare et al., 2013). In order to reduce the emission of CO2, reduction of the cement amount in concrete production and usage of pozzolans is an advantage (Dunstan, 2011). Pozzolans are materials that consist predominantly of silica and alumina (Cook, 1980) and are able to combine with portlandite in the presence of water to produce new reaction products exhibiting a binding character (Martinez-Ramirez et al, 2006; Martens et al., 2009). The amount of portlandite produced during the cement hydration will be reduced relatively to the percentage of pozzolans used in the mixture, and it will vary depending on the type of cements. Amount of portlandite is also related to the ratio of cement hydration.

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It will depend upon the amount of $C_3S$ and $C_2S$ in the cement. Each of these compounds react with water to form C-S-H (calcium silicate hydrate) and portlandite – $Ca(OH)_2$. A small portion of portlandite enters into reactions with alumina and sulphates to form compounds such as ettringite. Therefore not all of the portlandite produced is available or free to react with pozzolans (Toropovs et al., 2014; Popovic et al., 1998). It has been noted in the research by Massazza, that approximately 22% of free portlandite is available in the system. (Massazza, 2010). Moreover, it has been found that adding calcium to pozzolan, which has a low calcium /silica ratio, enhances the hydration reaction for the formation of calcium silicate hydrate (C-S-H) gels and improves the mechanical strength of high-performance concrete (Isaia et al.,2003).

Materials that exhibit pozzolanic activity can decrease the hydration heat by means of cement substitution, which increases the heat generated during hydration due to the pozzolanic reaction (Frias et al., 2000). Pozzolans are known to increase the durability, lower the hydration heat, increase the resistance to sulphate attack and reduce the energy cost per cement unit (Malathy and Subramanian, 2007). Consequently, the present study focuses on examining the effects of pozzolanic materials on the concrete properties, the optimal percentage of each pozzolan in the mixing scheme and its effect on the concrete properties were compared and presented in graphs and tables.

## 2. Material and Methods

### 2.1. Consumables

*Aggregates*: The stone material used in this project consists of three sections as sand, pea gravel and almond sand. The mace is up to 8 mm in size from the mines around Shabestar. Grading Fig. 1 shows the results of the grading test for the sand sample. The sand softness modulus was set at 3.99, which by comparison, common in the country's sand, compared to the range of grading mentioned by references such as ASTM C33 (Valipour et al., 2103). Pea sand grading has been selected to be within the range of grading as recommended by the authoritative authorities as far as possible.

*Cement*: In this research, concrete type 2 Sufian cement with a softness of 2974 $cm^2$ was used to make concrete samples. As the results show, the chemical composition and physical-mechanical properties of the cement used are in accordance with ASTM C125 standard requirements for Type 2 cement (ASTM C125).

*Water*: Testing of water consumption in concrete prior to the concrete preparation operation is necessary as water containing carbonic gas, high sulfate and chlorine (saline water) reduces the concrete strength. In the process of concrete preparation, water is the main factor in the cement hydration and directly affects the cement retention time and the strength of the concrete. The water used in the preparation of concrete mixes for this project was drinking water in Tabriz (National Iranian Standard, 1-12284).

*Pozzolan*: The pozzolan used in this study was a light green watermelon pozzolan from a light group that is well-watered. The following is the physical and chemical properties of these pozzolans. The Pozzolani mine of the Abike Cement Plant, one kilometer northeast of Abike, is the subject of this article. The area is geologically part of central Alborz and is affected by the Alborz orogenic phases. The exploitable materials of the mine are volcanic-sedimentary rocks of Karaj Formation with Eocene age which in these places are in layers with gentle slope to the south west (Dahir et al., 2006).

### 2.2. The laboratory steps performed in this paper are step by step

The test performing can be discussed as following stages:

- Wash sand (to remove silt and increase concrete strength) and dry by drying and flattening,
- Weighting of materials based on percentages of mixing ratio,
- Mixing materials, lubricating molds and pouring concrete into molds for vibration,
- Smooth the surface of the molds, labeling and pasting in the right place,
- Remove the samples from the mold in the water tank After two days, the samples are removed from the mold and placed in a water tank at a temperature of +20 °C,

It should be noted that the mixing of materials is such that a paste is obtained from one hand of concrete. The specimens were broken by hydraulic jack at 7 and 28 days of age and their compressive strength was measured.

### 2.3. Calculate the mixing ratio

Concrete mix design is the process of determining the proportion of concrete components so that the concrete becomes as cost-effective as possible and meets the requirements including physical, mechanical and durability properties. The concrete mix design method will create a common language for those involved in the industry. Mix design is the process by which the proper composition of concrete components is determined according to the given technical specifications. The mix design mechanism is complex because changing a variable may affect the properties of the concrete in the opposite way. Therefore, the mixed design is the art of balancing these contrasting effects. However, in the mixed design other criteria such as reduction of creep, creep and so on may be considered.

The basics of the Iranian mixed design method are derived from the German method. The proposed method is considered as the national method of concrete mix design, in accordance with the standard of concrete aggregates

(National Standard of Iran No. 302) as well as the Iranian concrete code (National Standard of Iran No. 389) and the properties of Portland cement (Poon and Lam, 2008).

To obtain the mixing ratio, first calculate the percentage of aggregate in one cubic meter of concrete, and then calculate the volume of mold and the number of samples: Specific gravity of concrete is 2300 kg/m$^3$. In this study, the amount of Cement grade is 320-340-360-380-400 kg/m$^3$. It is known that the maximum nominal size of the aggregate mixture is 19 mm because more than 90% of it passes the 19 mm sieve. Therefore, due to the pumping of the concrete, it is attempted to have a grain curve between A19 and B19 and closer to B19. In this case, n appears to be 0.4 to 0.5. In the first place, the share of sand is 50%. It is observed that the resulting agglomeration is a bit coarse, so it seems to be 40% sand and 60% sand. However, if sand grading, especially in the case of particles smaller than 0.6 mm, was coarse-grade, we might not be able to obtain proper grading. It should be said that the sand in Iran often loses its fine particles due to repeated and repeated washing, which will not solve the problem with increasing sand share (Keykha and Najmaddini, 2020).

By the way since the maximum actual size of the aggregate not 25 mm in the first sieve, 19 mm may not be a good match, which is reasonable. It should be noted that the sand share values can be between 45 and 40 and the sand share 55 to 60. For sand the resulting 45% and 55% sand blend seems a bit coarse, especially in the upper part. So the same share of sand is 40% and sand 60% more desirable. The amount of free water in concrete depends on several factors such as desired performance, maximum aggregate size, aggregation and type of aggregates consumed in terms of texture and shape. Water content is the most important factor affecting concrete performance. Increasing the amount of water makes it easier to pour concrete and make it compressible. However, increasing water, in addition to decreasing resistance, results in the separation of particles and water drop. The amount of water in the mixture should be sufficient to absorb the aggregate particles and then occupy the space between the aggregate particles to create a lubricating state by creating a layer of cement slurry on the aggregates. Therefore, smaller particles need more water. On the other hand, in the absence of fine particles (filler or filler), the concrete cannot be pasty, so the amount of water in the mixture cannot be considered independent of aggregate aggregation (Hajiani Boushehrian, 2020).

If more cement grade is used, it is necessary to increase the water content by about 1 to 2 kg/m$^3$ of 10 cements per 10 kg. In cases where the lubricant or super-lubricant chemical is used in the concrete mixture, the water content of the mixture can be reduced by about 5 to 30%, without altering the amount of slip desired. The amount of water needed to bring the moisture content of the aggregates from dry to wet to saturate with dry surface should be adjusted to free water. Also, the intentional air bubble in concrete generally reduces free water to provide efficiency. For each percent of intentional air bubbles (excess unwanted air), 2.5 percent of the free water required in the mixture is reduced. After determining the amount of cement, it is necessary to correct the amount of water according to the previous step and to determine the amount of cement again. This correction is done only once and there is no need to repeat it. The value of the cement calculated from the above formula shall be compared with the maximum or minimum stated in the specifications or durability requirements. If the value of the calculated cement is more or less than the desired value, that value must be selected. If cement substitute mineral additives (silica fume or fly ash) are used, the amount of water required and the cementations material should be calculated taking into account the effective factor K (ACI 237R-07).

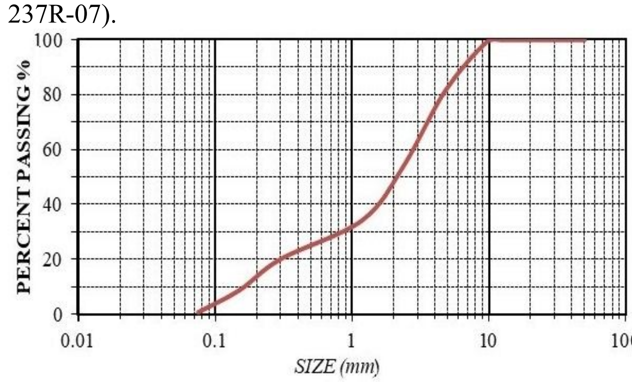


**Figure 1.** Report of sand grading experiment

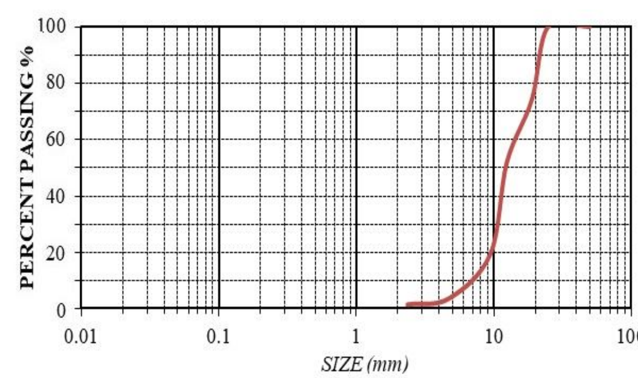


**Figure 2.** Report of the pea sand aggregation experiment

**Table 1.** Results of Sufian Type 2 Cement Mechanical Experiments

| Parameter | Unit | Value |
|---|---|---|
| Specific gravity | gr/cm$^3$ | 3.11 |
| Specific surface area | gr/cm$^2$ | 2974 |
| 7-day compressive strength with standard sand | kg/cm$^2$ | 237 |
| 28-day compressive strength with standard sand | kg/cm$^2$ | 462 |
| Initial Reception Time, IRT | minutes | 116 |
| Final Reception Time, FRT | minutes | 175 |

**Table 2.** Chemical composition of utilized cement

| No. | Chemical composition | Percentage (%) |
|---|---|---|
| 1 | CaO | 63.13 |
| 2 | $SiO_2$ | 21.77 |
| 3 | $Al_2O_3$ | 4.53 |
| 5 | $Fe_2O_3$ | 3.66 |
| 6 | MgO | 2.17 |
| 7 | $SO_3$ | 2.22 |
| 8 | $Na_2O$ | 0.32 |
| 9 | $K_2O$ | 0.83 |

**Table 3.** Physical and chemical properties of pozzolanic abic

| No. | Main composition | Unit | Pozzolan abic |
|---|---|---|---|
| 1 | CaO | % | 64.45 |
| 2 | $SiO_2$ | % | 13.39 |
| 3 | $Al_2O_3$ | % | 3.89 |
| 5 | $Fe_2O_3$ | % | 3.59 |
| 6 | MgO | % | 1.83 |
| 7 | $SO_3$ | % | 1.10 |
| 8 | $Na_2O$ | % | 1.00 |
| 9 | $K_2O$ | % | 1.67 |
| 10 | IOL | % | 4.06 |
| 11 | Specific weight | $gr/cm^2$ | 2.55 |
| 12 | Blain | $gr/cm^2$ | 3400 |

**Table 4.** Component values of 320 $kg/m^3$ concrete mixes

| Parameter | Unit | Value |
|---|---|---|
| Slump | - | 10.5 - 12.5 |
| Gravel | Kg | 6.121 |
| Sand | Kg | 9.21 |
| Pozzolan content | g | 50 - 382 |
| Pozzolan percentage | % | 2 - 15 |
| Cement | Kg | 2.29 - 2.54 |
| Water | Kg | 1.14 - 1.33 |
| W/C | - | 0.5 |

**Table 5.** Component values of 340 $kg/m^3$ concrete mixes

| Parameter | Unit | Value |
|---|---|---|
| Slump | - | 10.5 - 12.0 |
| Gravel | Kg | 6.035 |
| Sand | Kg | 9.053 |
| Pozzolan content | g | 57.3 - 429.9 |
| Pozzolan percentage | % | 2 - 15 |
| Cement | Kg | 2.43 - 2.86 |
| Water | Kg | 1.21 - 1.43 |
| W/C | - | 0.5 |

**Table 6.** Component values of 360 $kg/m^3$ concrete mixes

| Parameter | Unit | Value |
|---|---|---|
| Slump | - | 9.5 - 12.5 |
| Gravel | Kg | 5.934 |
| Sand | Kg | 8.902 |
| Pozzolan content | g | 60 - 455 |
| Pozzolan percentage | % | 2 - 15 |
| Cement | Kg | 2.57 - 3.04 |
| Water | Kg | 1.28 - 1.54 |
| W/C | - | 0.5 |

**Table 7.** Component values of 380 $kg/m^3$ concrete mixes

| Parameter | Unit | Value |
|---|---|---|
| Slump | - | 9.0 - 11.5 |
| Gravel | Kg | 5.833 |
| Sand | Kg | 8.750 |
| Pozzolan content | g | 64.1 – 480.4 |
| Pozzolan percentage | % | 2 - 15 |
| Cement | Kg | 2.72 - 3.20 |
| Water | Kg | 1.36 - 1.60 |
| W/C | - | 0.5 |

**Table 8.** Component values of 400 $kg/m^3$ concrete mixes

| Parameter | Unit | Value |
|---|---|---|
| Slump | - | 8.5 - 11.0 |
| Gravel | Kg | 5.732 |
| Sand | Kg | 8.598 |
| Pozzolan content | g | 67 - 505 |
| Pozzolan percentage | % | 2 - 15 |
| Cement | Kg | 2.37 - 2.86 |
| Water | Kg | 1.43 - 1.68 |
| W/C | - | 0.5 |

## 3. Results and Discussions

After the laboratory steps (mixing ratios - preparation of materials - making samples), breaking samples and obtaining compressive strength the above results are presented in the following diagrams. The compressive strength of the specimens is written in two quantities:

- Quantity F which represents the force recorded in the concrete crushing machine,
- The $f_c$ value, which represents the compressive strength in $kg/cm^2$ and is obtained by dividing the force by the sample area.

For example, for example with the composition of micro silica we have:

$F = 59470$ kgf

$A = 15\times15 = 225$ $cm^2$

$f^c = 59470/225 = 264.3$ $kg/cm^2$

### 3.1. Effect of Pozzolan Concrete Treatment with 400 grade Cement

In the study of the processing of concrete with ABC pozzolan in 400 grade cement, it is shown in Figure 3 that with increasing of pozzolan percentage at early age (7 days) the amount of compressive strength decreases so that in 15% pozzolan cement replacement. The control sample decreased the compressive strength by 9%. Further, in the study of cementitious application of pozzolan to 400 grade cement at 28 days of age, it was found that up to 8% increased with increasing pozzolan 2% resistance, but in 12 and 15% samples, pozzolan replaced cement.

### 3.2. Influence of Pozzolan Concrete Treatment with 380 Cement Concrete

In the study of the processing of concrete with ABC in 380 grade cement it was observed that in Fig. 5 the percentage of compressive strength decreases with increasing of pozzolan at early age (7 days), so that in 15% of pozzolan cement replacement compared to cement. The control sample decreased compressive strength by 7%. 2.5% resistance but in 12 and 15% samples, pozzolan replaced cement. Compared to the control sample, it decreased.

### 3.3. Effect of Pozzolan Concrete Treatment with 360 Degree Cement

In the study of cementitious treatment with aqueous pozzolan in 360 grade cement, it is shown in Fig. 7 that with increasing the percentage of pozzolan at an early age (7 days), the amount of compressive strength decreases as compared to 15% pozzolan cement replacement. The control sample decreased the compressive strength by 6%. Further, in the study of cementitious treatment of pozzolan with 360 grade cement at 28 days of age, it was found that up to 8% increased with increasing pozzolan 3% resistance, but in 12 and 15% samples, pozzolan replaced cement. The control sample has decreased.

### 3.4. Effect of Pozzolan Cement Concrete Treatment on 340 Cement

In the study of the processing of concrete with ABC in 340 grade cement, it was observed that in Fig. 9 the compressive strength decreases with increasing of pozzolan at early age (7 days), so that in 15% of pozzolan cement replacement compared to cement. The control sample had a compressive strength of 5.8%. Further, in the study of cementitious treatment with pozzolan, 340 grade cement was observed at 28 days of age, which increased by almost 8% with increasing pozzolan 3.5% resistance, but in 12 and 15% samples, cozy substitute cement was observed. Resistance to the control sample decreased (Sajedi and Jalilifar, 2019).

### 3.5. Influence of Pozzolan Cement Concrete Treatment 320

In the study of cementitious treatment with aqueous pozzolan in 320-grade cement, it was observed that in Fig. 4-9, the increase in the percentage of pozzolan at an early age (7 days) reduced the amount of compressive strength to 15% of cement substituted pozzolan. The control sample had a compressive strength of 5.7%. Further, in the study of cementitious treatment of pozzolan with 320 grade cement at 28 days of age, it was observed that up to 8% increased with increasing pozzolan 4% resistance, but in 12 and 15% samples, pozzolan cement replacement was observed. The control sample decreased.

### 3.6. Water absorption percentage

The water absorption test was performed in accordance with (BS 1881-Part 122). The test method is that at 28 days of age, each of the concrete samples, with different percentages of pozzolan, were dried in the incubator at a temperature of approximately 45 °C for 5 days. After the samples were removed from the incubator, the samples were weighed in a dry state and then placed in a water container. This was done so that the water height above the specimens was 25+5 mm. The specimens were left in water for 24 h and then extracted and weighed in saturation with dry surface. The results show that with increasing cement grade, the water absorption rate of concrete increases. Also, the effect of pozzolan on the concrete samples can be observed by increasing the amount of water absorbed by pozzolan (Heydari Mofrad and Hoseini-Azar, 2017).

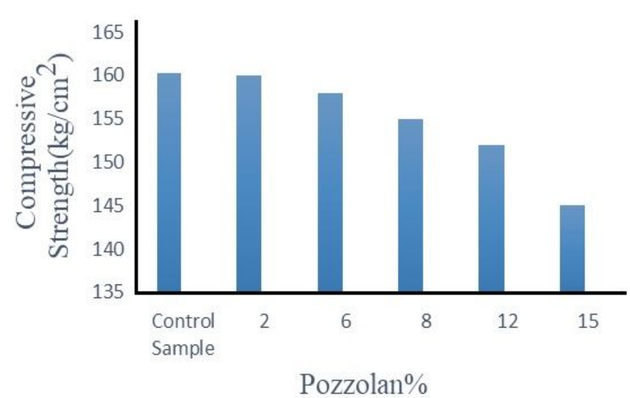


**Figure 3.** Concrete strength with different percentages of pozzolan with 400 grade cement at 7 days old concrete

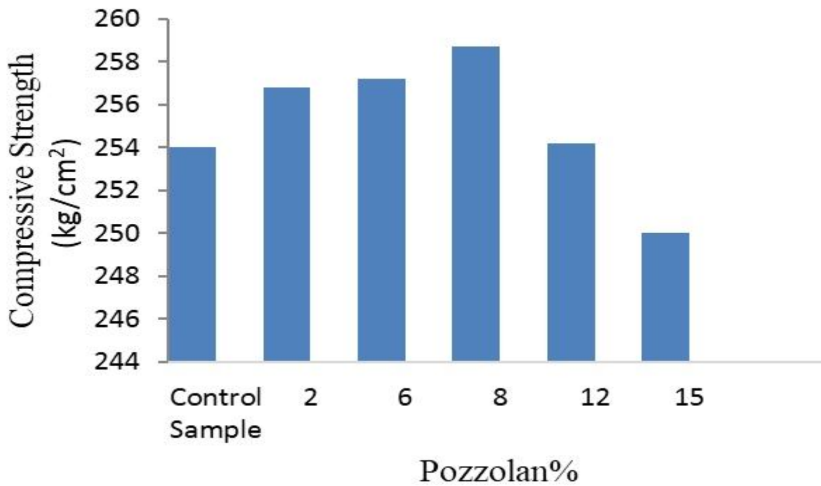


**Figure 4.** Concrete strength with different percentages of pozzolan with 400 grade cement at 28 days old concrete

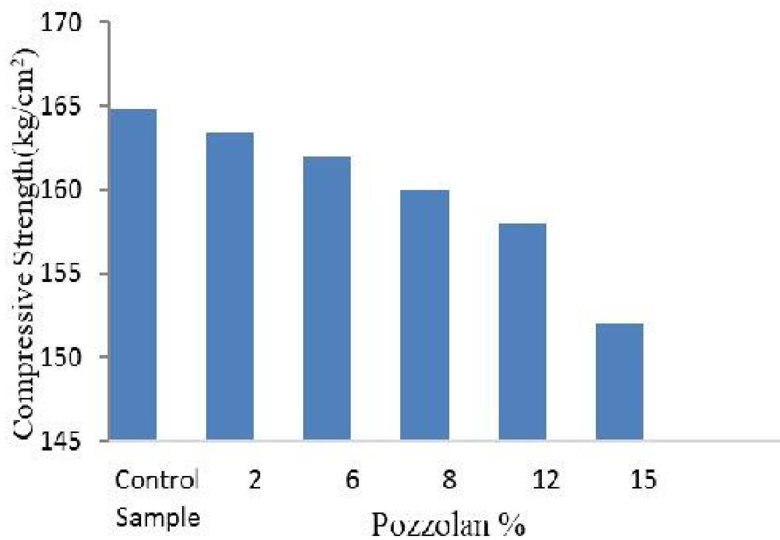


**Figure 5.** Concrete strength with different percentages of pozzolan with 380 grade cement at 7 days old concrete

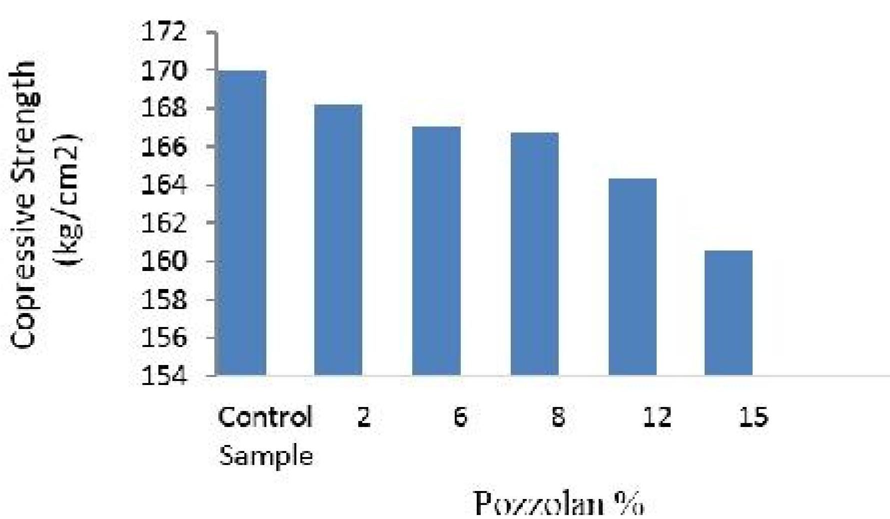


**Figure 6.** Concrete strength with different percentages of pozzolan with 380 grade cement at 28 days old concrete

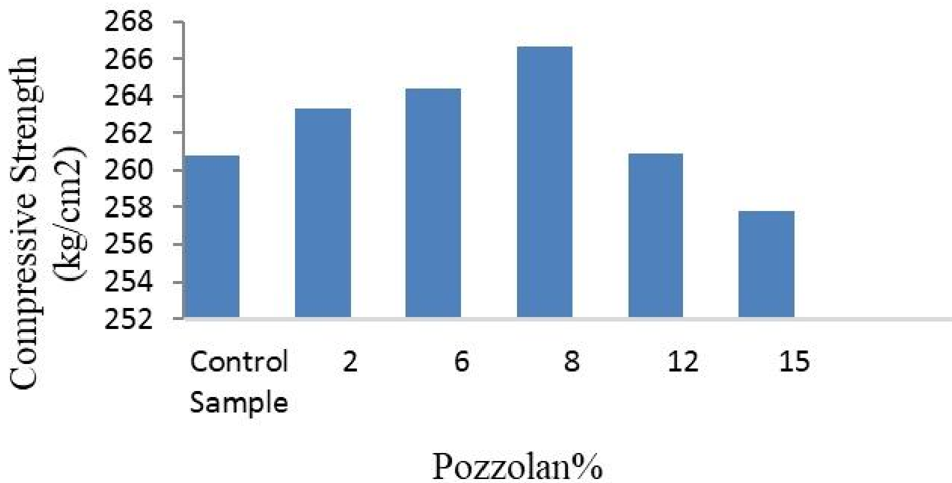


**Figure 7.** Concrete strength with different percentages of pozzolan with 360 grade cement at the age of 7 days of concrete

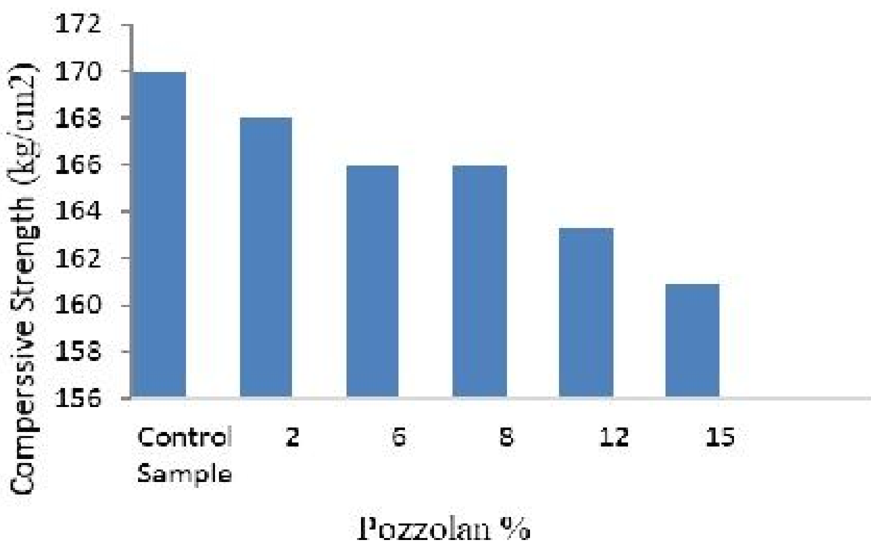


**Figure 8.** Concrete strength with different percentages of pozzolan with 360 grade cement at 28 days of age

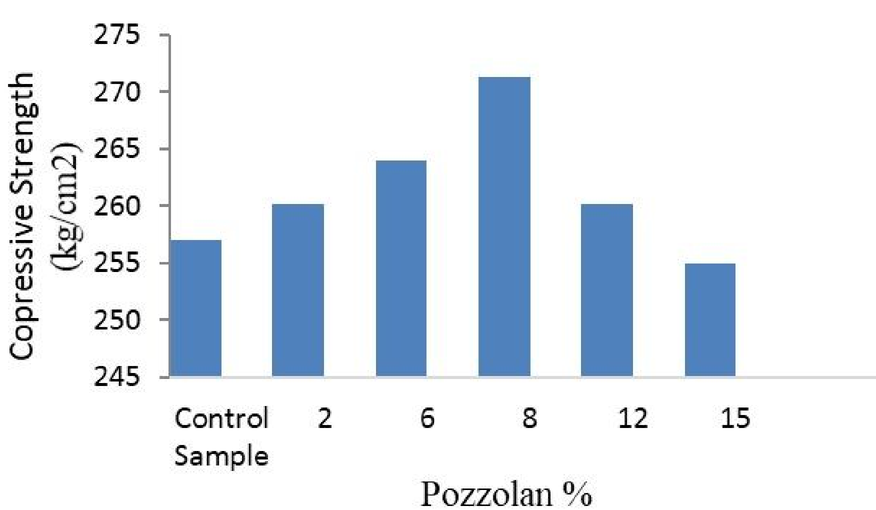


**Figure 9.** Concrete strength with different percentages of pozzolan with 340 grade cement at 7 days old concrete

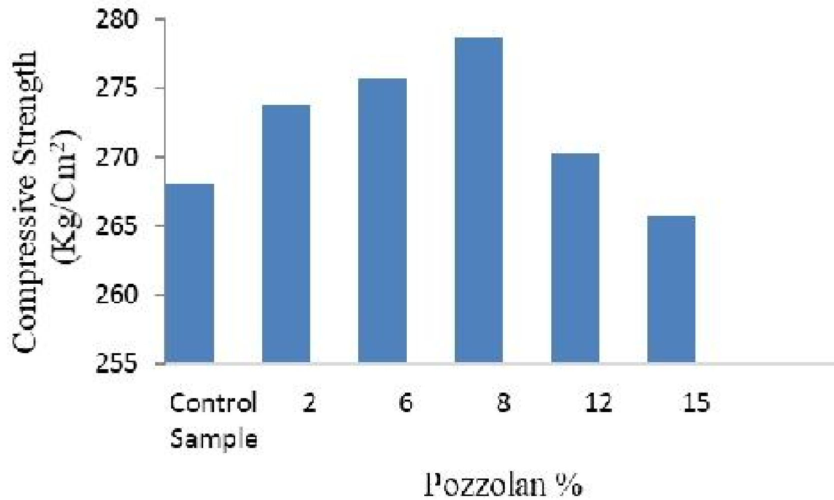


**Figure 10.** Concrete strength with different percentages of pozzolan with 340 grade cement at 28 days old concrete

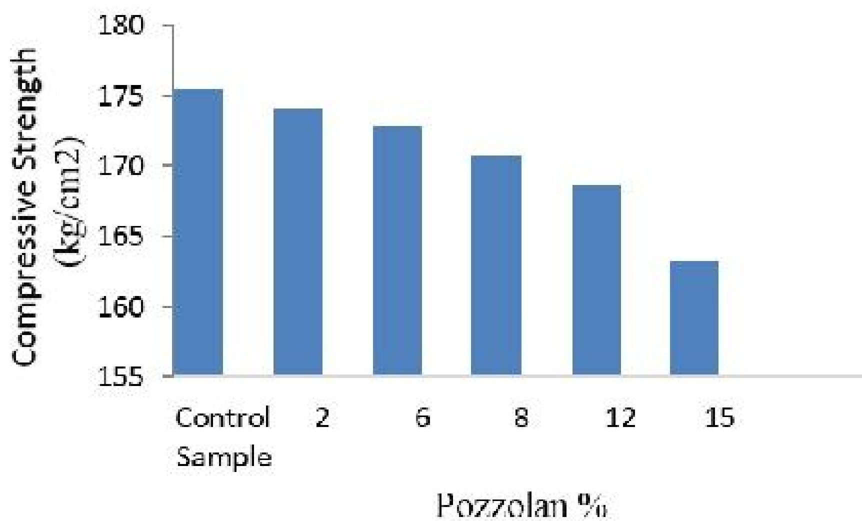


**Figure 11.** Concrete strength with different percentages of pozzolan with 320 grade cement at the age of 7 days of concrete

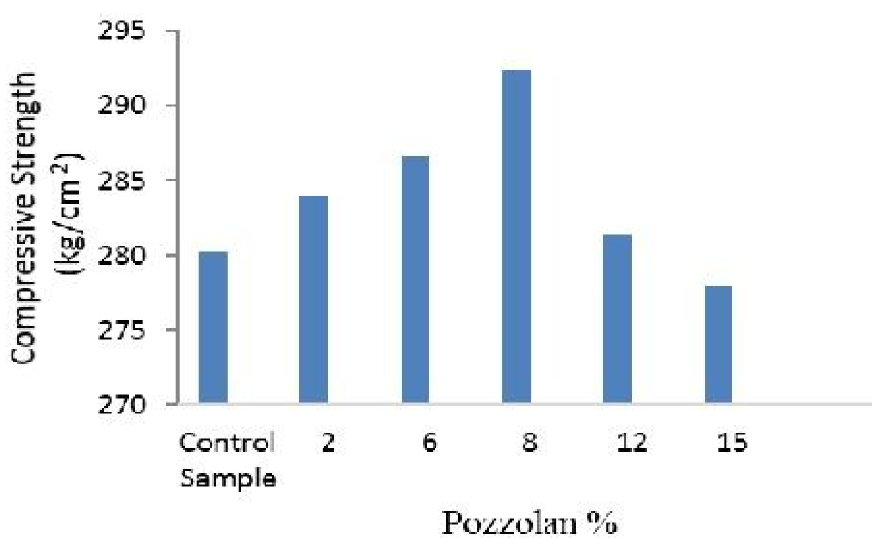


**Figure 12.** Concrete strength with different percentages of pozzolan with 320 grade cement at 28 days of concrete

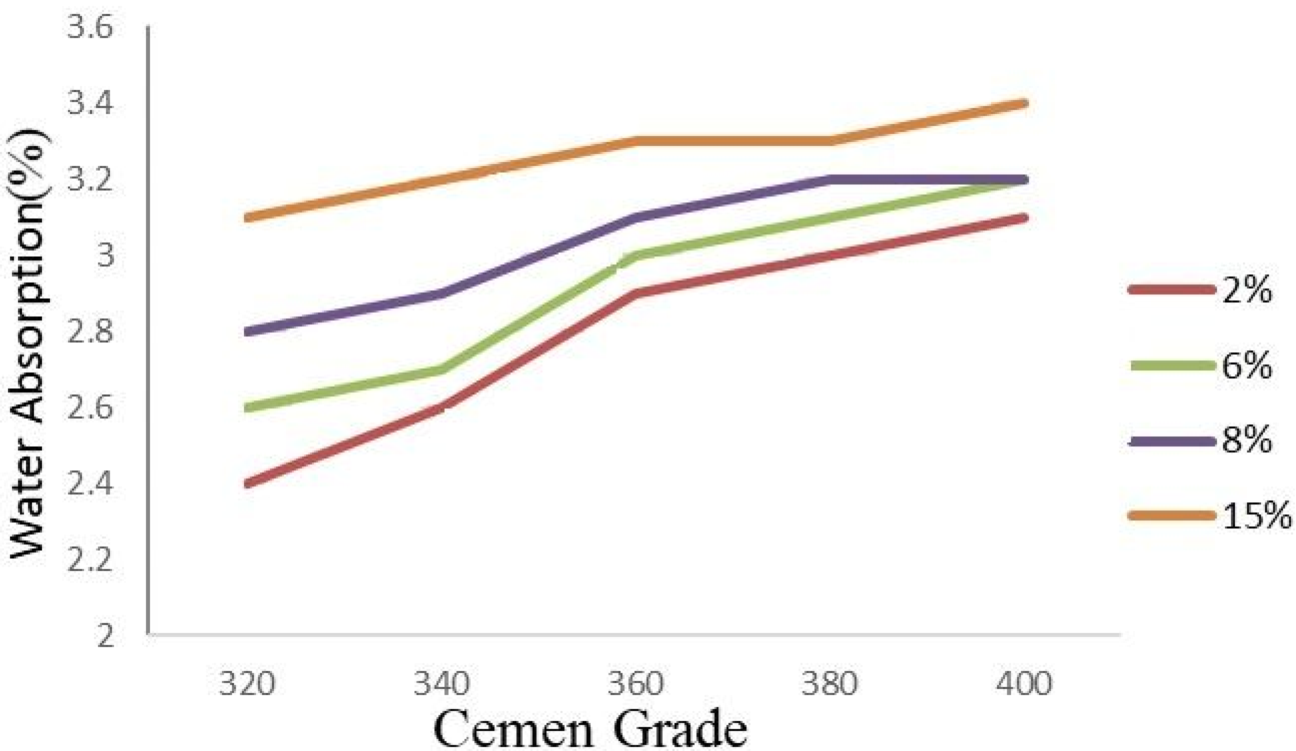


**Figure 13.** Diagram of water absorption percentage of concrete containing abiotic pozzolan to cement grade

## 4. Conclusion

The results of this study indicate that with increasing percentage of pozzolan replacement at low ages the compressive strength of concrete decreases but at higher ages with increasing percentage of pozzolan replacement the compressive strength increases. This increase persists to 8% of pozzolan, but decreases thereafter. These results are detailed below:

A) In the study of processing of pozzolan concrete in 400 grade cement it was observed that increasing the percentage of pozzolan at early age (7 days) decreases the amount of compressive strength. Compressive strength of 9% was decreased in 15% of pozzolan replacement cement compared to the control sample. Concrete Concrete processing with pozzolan was observed in 400 grade cement at 28 days of age, which increased by almost 8% with increasing pozzolan 2% resistance. However, in 12 and 15% of pozzolan cement replacement samples, resistance to control was reduced.

B) In the study of processing of pozzolan concrete in 380 grade cement, compressive strength decreases with increasing percentage of pozzolan at early age (7 days). In 15% of pozzolan replacement cement, the compressive strength decreased by 7% compared to the control. Concrete processing with pozzolan was observed in 380 grade cement at 28 days of age, which increased by almost 8% with increasing pozzolan 2.5%. However, in 12 and 15% of pozzolan cement replacement samples, resistance to control was reduced.

C) In the study of the processing of concrete with ABC pozzolan in 360 degree cement, it was observed that by increasing the percentage of pozzolan at an early age (7 days), the amount of compressive strength decreased. In 15% of pozzolan cement replacement, the compressive strength decreased by 6% compared to the control sample. Concrete processing with pozzolan was observed in 360 degree cement at 28 days of age, which increased by almost 8% with increasing pozzolan 3% resistance. However, in the 12 and 15% samples of pozzolan, cement replacement was observed, which decreased with respect to the control sample.

D) Concrete processing with pozzolan and cement with 340 grade cement was observed by increasing the percentage of pozzolan at an early age (7 days) the amount of compressive strength decreased, with 5.8% decrease in compressive strength of 15% pozzolan as compared to the control sample. The study of the processing of concrete with pozzolan and cement with 340 grades at 28 days of age showed that almost 8% increased with increasing pozzolan 5.3% resistance. However, in 12 and 15% of pozzolan cement replacement samples, resistance to control was decreased.

E) Concrete processing with pozzolan in 320-degree cement transplanting decreases compressive strength by increasing the percentage of pozzolan at an early age (7 days). In 15% of pozzolan cement replacement, compression strength decreased by 7.5%. Concrete processing with pozzolan and cement with 320 grade C at 28 days of age showed that almost 8% increased with increasing pozzolan 4% resistance, but in 12 and 15% cozy substituted cementitious samples, resistance to control sample was observed.

F) The results show that with increasing cement grade, the water absorption rate of concrete increases.

G) Investigation of the effect of pozzolan on concrete specimens is observed with increasing pozzolan water absorption rate.

H) Compressive strength analysis showed that increased pozzolan reduced concrete strength.The effect of cement grade on the compressive strength of concrete was found to decrease with increasing grade of concrete.

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