Challenge Journal of Structural Mechanics 6 (2) (2020) 73–83

Challenge Journal of Structural Mechanics

Research Article

# The effect of different fineness values of Afşin Elbistan fly ash on permeability in concrete

Demet Demir Şahin [a,*], Mustafa Çullu [b], Hasan Eker [c]

[a] Department of Mining Technology, Gümüşhane University, 29000 Gümüşhane, Turkey
[b] Department of Civil Engineering, Gümüşhane University, 29000 Gümüşhane, Turkey
[c] Department of Mining Engineering, Gümüşhane University, 29000 Gümüşhane, Turkey

**ABSTRACT**

Too much $CO_2$ is released during cement production. In many researches, the use of natural or recycled compounds plays an important role in the cement composition. The use of these components contributes both to reducing the amount of waste and to protecting the environment in nature. It is possible to produce an environmentally friendly concrete, thanks to its being a fly ash thermal power plant waste and its use as mineral additive in terms of its composition. In this study, it is aimed to produce impermeable concretes with the use of C type fly ash as substitutes for cement in concrete composition in substitution rates of 10 %, 30 % and 50 %. In order to reduce the permeability of concrete in this direction, as a result of grinding the fly ash in the ball mill for 0, 10, 20, 30, 45 and 60 minutes, concrete samples were prepared with and without admixture (Reference). Capillarity test was performed to determine the permeability at the end of cure periods of 28 and 90 days on concrete samples. According to the results obtained at the end of 28 days, the best impermeability was achieved in the mixture with 50 % fly ash replacement and 60 minutes grinding time. In 90 days, the best impermeability was obtained in the mixture with 30 % fly ash replacement and 0 minutes of grinding time. As a result, it was seen that permeability decreased with increasing thinness and substitution rate of fly ash in concrete composition.

**ARTICLE INFO**

*Article history:*
Received 15 November 2019
Revised 6 January 2020
Accepted 20 January 2020

*Keywords:*
Fly ash
Concrete
Cement
Permeability
C type

## 1. Introduction

The presence of rich lignite deposits in our country, easy to supply, short-term and low-cost operation in terms of electrical power generation is one of the most preferred reasons for thermal power plants. The increase in electricity production in the 21st century is an indicator of economic and social development and is one of the factors facilitating human life (Özcan et al., 2014). As of the end of July 2017, the number of power plants generating electricity in our country increased to 3,098 (including unlicensed plants). 613 of the existing power plants are hydroelectric, 40 are coal, 186 are wind, 33 are geothermal, 288 are natural gas, 1,773 are solar and have other sources. Afşin Elbistan thermal power plant has the highest electricity generation capacity among these power plants and the installed capacity was determined as 2795 MW in total A and B plants (MENR, 2018). In our country, the amount of fly ash released in these plants and other coal-fired thermal power plants is calculated as 18 million tons annually (Bilir et al., 2015). In the world, this amount is 780 million tons annually (Toniolo and Boccaccini, 2017).

The waste material, which is not involved in the act of burning as a result of the burning of coal in thermal power plants, which is inorganic and small in size, is transported by flue gases and collected with the help of electron filters and cyclones is termed fly ash. The formation mechanism of this product is brought to fine grain structure by the grinding of coal in ball or roller mills during electricity production. The carbon in the coal starts to ignite in the combustion chambers, which

* *Corresponding author*. Tel.: +90-456-233-2937 ; E-mail address: demetsahin@gumushane.edu.tr (D. Demir Şahin)
ISSN: 2149-8024 / DOI: https://doi.org/10.20528/cjsmec.2020.02.004

have a temperature of 1037-1482°C and are fed by continuous air. Subsequently, as a result of the continuous combustion of the coal, the volatiles evaporate and the carbon is heated in the pipes in the boiler. Inorganic materials such as clay, quartz and feldspar melt and slag is formed in the combustion chambers. Hardened melts in the flue gas are separated from the combustion chambers and spherical grained fly ash particles are formed (Hoffman, 2006).

With the increase in the need for energy and the supply of energy from coal in our country, the amount of fly ash released from thermal power plants has increased. The increase in the amount of ash led to the idea of evaluating waste in other areas. It is considered as a suitable material for use in the construction sector. However, it is more widely used in cement and concrete construction due to its composition and many other properties. Especially the fly ashes' having pozzolanic properties leads to energy saving in concrete and cement technology and to an increase in the strength and durability of concrete by the introduction of new features in fresh and hardened condition. Afşin Elbistan increases the ultimate pressure of concrete by increasing the cohesion by using fly ash with high CaO content such as fly ash. In addition, large masses such as dam structures reduce thermal shrinkage in concrete. Fly ash is collected in the chimneys and used as it can be of fine grain thickness without any treatment. Occasionally, when grain fineness is not suitable for use in concrete and cement composition, it is rendered suitable by sieving and grinding processes. In particular, the use of fly ash with fine grain structure in the composition of concrete makes a great contribution to the production of impermeable concrete (Binici et al., 2009). In addition, environmental problems and consumption of natural resources will be reduced by the use of fly ash in concrete and will contribute to the national economy with the efficient use of waste products.

Cement is an important and integral component in concrete composition. However, producing excess cement and using it in concrete composition increases the heat of hydration, shrinkage and cost. Fly ash is a waste product that form spontaneously in thermal power plants and is used instead of cement. The use of fly ash in concrete is very common and serves to reduce the heat of hydration and the microcrack structure. Thus, greenhouse gas emissions stemming from cement production are reduced. Particularly, fly ashes' having fine-grained, spherical grain structure and smooth surface characteristics, reduces the need for water in concrete and increases processability. However, the fly ashes' having pozzolanic properties also helps to regulate the gap structure (Qiu et al., 2014).

The bearing property of the concrete depends on the durability and service life of the concrete. Permeability of water is an important factor for concrete durability. As it activates the acid mechanical reaction together with chlorine, sulfate ions and water in the concrete, it accelerates the deterioration of the concrete structure. Permeability of concrete depends on the permeability of cement paste. The void structure of the concrete is the most important factor controlling the transport properties of the hydrated cement paste.

The pores of the aggregates in the concrete composition have no effect on the permeability of the concrete because the pores in the aggregate are wrapped with cement paste and permeability in concrete is affected by the porous structure of the cement paste (Neville, 1995). Permeability in cement paste is provided by capillary voids. Capillary void size is between 0.0110 m and 10 μm and voids less than this size are called gel voids. In addition to the capillary gaps, the other gap parameters, gap size and the interconnection of gaps also affect the permeability (Sant et al., 2011).

Fly ash is used to change the properties of concrete. The grain size in fly ash affects the performance of cement and concrete. For example, it increases strength, abrasion and freeze-thaw resistance in fly ash added concrete. The optimum grain size of fly ash has an effective role in the development of pozzolanic activity and in the compaction of concrete (Sevim and Demir, 2019).

In this study, fly ash taken from Afşin Elbistan thermal power plant was milled into fine grained material. Fly ash, of which different fineness values were obtained through grinding was substituted for cement in ratios of 10%, 30% and 50% by weight and reinforced concrete samples were produced. The effect of different fineness values and substitution ratios of fly ash used in concrete on the permeability of concrete was investigated. In this context, 28 and 90 days of capillary tests were performed to determine the permeability. As a result, it was found that the increase in the fineness of the fly ash and substitution rate decreased the permeability property.

## 2. Material and Method

### *2.1. Material*

In this study, concrete samples were produced by using limestone aggregate, cement, fly ash and city water of Gümüşhane Municipality.

#### *2.1.1. Aggregate*

The aggregates used in the concrete composition were grouped as 0-4 mm, 4-11.2 mm and 11.2-22.4 mm. These aggregates were composed of limestones specific to Gümüşhane region (Fig. 1). Granulometry curves of the limestone aggregates used in the study are given in Fig. 2.

According to granulometry of the aggregate used in the study, curve A forms the representative curves showing the particle size distribution of aggregates with a dimension range of 11.2-22.4, curve B with a dimension range of 4-11.2 mm and curve C with a dimension range of 0-4 mm (Fig. 2).

#### *2.1.2. Cement*

CEM I 42.5 R type cement was used for the concretes produced in the study. This cement was supplied from Gümüşhane Aşkale cement factory. The specific physical, chemical and mechanical properties of the cement are given in Table 1.


**Fig. 1.** Limestone aggregate.

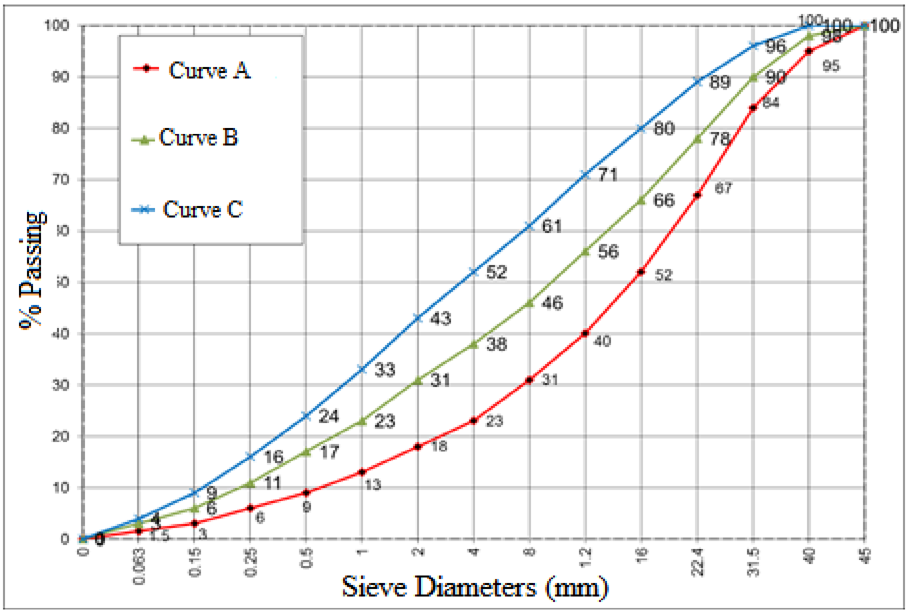


**Fig. 2.** Granulometric curves of aggregates according to TS 802 standard (TS 802, 2016).

**Table 1.** Properties of CEM I 42.5 R type cement.

| Chemical Analysis (%) | | Physical Tests | |
|---|---|---|---|
| $SiO_2$ | 18.59 | Thinness (45 µ over the screen, %) | 8.58 |
| $Al_2O_3$ | 4.69 | Specific Gravity (gr/cm$^3$) | 3.08 |
| $Fe_2O_3$ | 3.04 | Blaine (cm$^2$/gr) | 4145 |
| CaO | 60.34 | Initial Setting (lllehour-min) | 2hrs-33min |
| MgO | 1.92 | Final Setting (hour-min) | 3hrs-18min |
| $SO_3$ | 2.89 | Volume Expansion (mm) | 0.7 |
| Loss of ignition | 7.19 | Water Requirement (%) | 29.9 |
| $Na_2O$ | 0.11 | | |
| $K_2O$ | 0.64 | | |
| CI | 0.0189 | Compressive Strength ( N/mm$^2$) | |
| Unmeasurable | 0.57 | 2. day | 23.9 |
| Total | 100 | 28. day | 51.1 |
| Free CaO | 0.38 | | |
| Additive Content % | 17.87 | | |

The specific weight of the cement used was 3.08 gr/cm$^3$, its specific surface area was 4145 cm$^2$/gr and 8.58% over 45 μ sieve. According to the results of chemical analysis, ignition loss is 7.19%, free CaO 0.38%, $SiO_2$ 18.59%, $SO_3$ 2.89% (Table 1).

### *2.1.3. Fly ash*

Fly ash was obtained from Afşin Elbistan thermal power plant in Kahramanmaraş Province. It is composed of unburned carbon grains in fly ash as shown in Fig. 3 and is dark brown. The physical and chemical properties of Afşin Elbistan fly ash were determined by performing the relevant experiments in the Gümüşhane Aşkale Cement Plant laboratory (Table 2).

According to ASTM C 618 standard; S+A+F ($SiO_2$ + $Al_2O_3$ + $Fe_2O_3$) sum was ≥70% and CaO<10% it was termed as class F (low level of lime), and if S+A+F ($SiO_2$ + $Al_2O_3$ + $Fe_2O_3$) sum was ≥50% and CaO>10% it was termed as C class (high level of lime) fly ash. According to this, Afşin Elbistan fly ash was S+A+F: 47.40%, CaO: 37.84%, and the amount of S+A+F in it was less than 50%, but since the CaO content was greater than 10% it was termed C class fly ash. Ignition loss was obtained as 2.31%, free CaO as 4.51% and 45 μ oversize as 50.68% (Table 2).

**Fig. 3.** A view of Afşin Elbistan fly ash.

**Table 2.** Chemical and physical properties of fly ash.

| Chemical Analysis | | Physical Tests | |
|---|---|---|---|
| Component,% | Fly Ash | Physical Properties | Components |
| $SiO_2$ | 29.24 | Thinness (45 μ over the screen, %) | 50.68 |
| $Al_2O_3$ | 11.49 | | |
| $Fe_2O_3$ | 6.67 | Specific Gravity ( gr/cm$^3$) | 2.54 |
| CaO | 37.84 | | |
| MgO | 1.86 | Specific Surface (cm$^2$/gr) | 1834 |
| $Na_2O$ | 0.38 | | |
| $K_2O$ | 0.69 | Initial Setting (hour-min) | 2hrs-30 min |
| $SO_3$ | 4.70 | | |
| $Cr_2O_3$ | 0.054 | Final Setting (hour-min) | 3 hrs-15 min |
| $Mn_2O_3$ | 0.059 | | |
| $P_2O_5$ | 0.494 | Volume Expansion (mm) | 0 |
| $TiO_2$ | 0.49 | | |
| ZnO | 0.001 | Water Requirement (%) | 27.4 |
| KK | 2.31 | | |
| Total | 96.27 | Water Content (gr) | 137 |
| Free CaO | 4.51 | | |

### *2.1.4. Mixing water*

The water used for the construction of concrete samples consisted of city water belonging to Gümüşhane Municipality.

## ***2.2. Method***

In this study, concrete samples of C25 strength class were produced. Impermeability and capillarity values of these concrete samples were determined by being kept in curing pool up to 28 and 90 days.

The concrete produced in this study was designed according to the TS 802 standard and the samples given in Fig. 4 were produced.

### *2.2.1. Capillarity determination*

100 x 200 mm cylinder concrete samples were removed from the curing pool at the end of the curing period of 28 and 90 days and allowed to dry for 3 days in an air circulation oven at 50±5°C. The lateral surfaces of the samples were then placed in a water-filled container with liquid-tight material (silicone), with 2±1 mm soles touching water. These samples were kept in water for 1, 5, 10, 20, 30, 60, 120, 180, 240, 300, 360, 600, 1440, 2280, 4320, 5760, 11520" min and their mass gains were determined by weighing up with a sensitivity value of 0.01 g. Capillary water absorption (CWA) values of concrete samples were calculated according to Eq. (1). The cumulative capillary water absorption values were plotted according to the square root of time. The amount of water absorbed by the

capillary concrete is directly proportional to the surface area and the square root of the elapsed time. The number $K$, which is proportionality constant and is also called the capillarity coefficient, is a property of the cavities of the concrete. The weight differences of the samples were calculated according to their initial weights and their CWA values were determined. Eq. (2) shown below was utilized used to calculate the capillarity coefficients. The capillarity coefficient was calculated to interpret the volumes of water leaking from each unit area (ASTM C 1585, 2013).

$$I = \frac{mt}{a/d} \quad (1)$$

In this equation;
$I$ : Capillary water absorption (mm),
$mt$ : the change in mass of concrete, for example, in time (t) grams
a : area of sample (mm$^2$) of concrete exposed to the test,
d : density of water (gr mm$^3$).

$$K = \frac{Q^2}{A^2 t} \quad (\text{cm}^2/\text{sec}) \quad (2)$$

In this equation;
$K$ : Capillarity coefficient (cm$^2$/s),
$a$ : Area in contact with water (cm$^2$),
$t$ : Elapsed time (s),
$Q$ : The amount of water absorbed is (cm$^3$).

Siliconization of the lateral surfaces of concrete samples used for capillarity testing (Fig. 5).

Examples of concrete dried in a drying oven and placed in a water-filled container for the capillarity test are shown in Fig. 6.

Measuring the mass changes as presented in Fig. 7 by removing the samples from the water-filled container at the end of the specified periods.

**Fig. 4.** Examples of fly ash added concrete.

**Fig. 5.** Siliconization of the samples to be tested for capillarity.

**Fig. 6.** Holding the concrete samples in the water filled container in the installed order.


**Fig. 7.** Measurement of mass changes at the specified time in the capillary test apparatus.

## 3. Results and Discussion

Capillarity test was performed in order to determine the permeability properties of reinforced concrete samples, produced by substituting Afşin Elbistan fly ash materials generated with different grinding times for cement. The results of the capillarity test performed on 28-day concrete samples with 10%, 30% and 50% fly ash substitution and the obtained capillarity coefficient values are given in Fig. 8.

It was observed that the increase of fly ash fineness in 10% fly ash added concrete samples reduces the permeability in concrete. The lowest water absorption rate of concrete with a substitution rate of 10% was determined as 0.76 mm for 60 min ground fly ash added concrete samples. The maximum amount of water absorption was calculated as 1.45 mm in the reference concrete sample. The concrete sample with a 60 min grinding time reduced the water permeability by about half by reducing it to -47% relative to the reference concrete (Fig. 8a). As a result of the refining of fly ash by grinding, it was seen that it forms more impermeable concretes by filling the gaps in concrete. Capillarity coefficient values decreased with increasing the grinding time according to the capillarity test result by filling the gaps in concrete. As shown in Fig. 8d, the lowest capillarity coefficient value among the 10% fly ash substitute concrete samples, i.e. the impermeable concrete sample, was determined as 8.45E-09 in the concrete sample having 60 min grinding time compared to the reference sample. The permeability value relative to the reference sample showed a decrease of -72.3%.

When the amount of fly ash substitution in concrete was increased to 30%, it exhibited a similar behavior with 10% fly ash substituted concrete and decreased the permeability value. The lowest water absorption rate was 0.75 mm in 60 min ground fly ash reinforced concrete samples and the maximum water absorption rate was 1.45 mm in reference concrete samples (Fig. 8b). 30% fly ash ground according to the reference sample reduced permeability by -46% in concretes. As shown in Fig. 8e, as the fly ash substitution rate and grinding time increased, the amount of water absorbed through the capillary channels in concrete decreased by about half.

When the fly ash substitution rate in concrete was increased to 50%, the amount of water absorbed by capillary channels was determined as 0.50 mm in the highest grinding time concrete sample and 1.4 mm in the reference sample (Fig. 8c). The fly ash reinforced concrete sample contributed to the formation of more impermeable concrete by absorbing - 66% less water than the reference sample. As shown in Fig. 8f, the capillarity coefficient value contributes to a significant reduction in permeability of approximately 80% and above in all milling time samples, except for a 50% unsaturated ash added concrete sample with respect to the reference sample. Fig. 9 shows the capillarity test results at the end of the 90-day curing period.

Capillary water absorption and capillarity coefficient values of Afşin Elbistan volatile reinforced concretes after 90 days curing period are given in Fig. 9. After the 90-day curing period, the highest water absorption value in Fig. 9a was observed in the concrete sample having a grinding time of 20 min as 3.24 mm. The water absorption value of the reference sample was determined as 1.94 mm, and the 67% fly ash added concrete sample had a higher water absorption value. The capillarity coefficient value was found to be 179.2% higher than the reference sample. The lowest water absorption value was observed in the concrete sample with 60 min grinding time, and the capillary water absorption value decreased by-3% and the capillarity coefficient value by -5,2% compared to the reference sample, causing the permeability to be reduced.

Capillary water absorption and capillary coefficient values of 30% substituted concrete samples are given in Figs. 9b and 9e. In Fig. 9b, the highest water absorption value is seen in the concrete reinforced sample with a grinding time of 45 min. The water absorption change in mm was 22% and the capillarity coefficient was 49.7% higher than the reference sample and it was found to be a more permeable concrete. The lowest water absorption value was -1,3% lower in the original fly ash reinforced concrete compared to the reference sample and it was more impermeable concrete.

Capillary water absorption and capillarity coefficient values of 50% substituted concrete samples are given in Fig. 9c and Fig. 9f. The highest water absorption value was 141% and capillarity coefficient increase was 483% higher in the concrete sample ground for 20 minutes compared to the reference sample and showed more permeable concrete properties. The lowest water absorption value was determined as the reference concrete sample.

Using Afşin Elbistan fly ash in concrete at different grinding times and substitution rates has greatly reduced the permeability after 28 days of curing time. In the 90-day concrete samples, water absorption values of concrete samples with some grinding times were calculated as higher than the reference. In general, according to the results of the capillarity test, fly ash contributes to decrease in the permeability of concrete. Shaikh and Supit (2015), in their study, maintained that fly ash reinforced concrete samples decreased permeability value by 6-11% compared to the unmixed samples. The properties revealed that the use of fly ash in concrete as high as 40% contributed greatly to reducing the permeability volume. As a result of the capillary water absorption test applied on concrete samples, the capillary water absorption coefficient of volatile ash concrete was found to be lower than those of unmixed concrete samples. As a result of their study, they concluded that fly ash reduces the permeability of cement paste and the transition zone around the aggregates and minimizes the permeability value of concrete. The effect of fly ash fineness and substitution rate on the permeability of concrete increases due to the increase in the fly ash's fineness, resulting in the formation of a tighter or gapless material by filling the voids. A gap-free material absorbs less water (Naganathan and Linda, 2013). It provides higher specific surface area compared to cement by fly ash grinding. In fly ash reinforced concretes with high specific surface area, the capillary cavities of the fly ash concretes were less and showed less water absorption properties since it reduces the volume of the binder and the thickness of the transition zone between the binder and aggregate (Saha, 2017). Fly ash reduces the risk of exiting calcium hydroxide with the C-S-H gels they form due to their pozzolanic properties and also reduces permeability. Fly ashes the porosity of concrete, regulates grain distribution by micro-aggregate effect and provides optimum compaction. Thus, they increase the resistance of concrete against external effects. In addition, due to its spherical and smooth surface structure, they increased the processability of fresh concrete (Unal and Uygunoglu, 2004).

That in the 90-day concrete samples reinforced with fly ash, capillarity value was higher compared to the reference sample stemmed from the fact that it had larger grain sizes than the cement. Since the pozzolanic activity in fly ashes develops in the long term, the grinding time up to 60 min for the development of pozzolanic activity was not sufficient to improve the pozzolanic activity of the fly ash. Furthermore, due to the grinding of fly ash, the round grain structure was disrupted and caused the formation of irregular grain structure. The deterioration of grain structure decreased the effect of filling the cavities and consequently caused an increase the porosity and permeability (Sinsiri et al., 2010).

Slowly filling the cavities with the hydration products during the hydration of the cement reduces the water permeability. Regarding the use of fly ash in the concrete composition and the development of pozzolanic reaction in the concrete, while fly ash reinforced concretes with the same water/binder ratio have more permeability in a short curing time compared to unmixed concrete, they have less permeability in a long curing time (Naik et al., 1994).

The permeability of concrete varies depending on water / cement ratio, crack structure, curing conditions and the type, fineness and quantity of mineral admixture. The effect of fly ash, which is one of the mineral additives and is widely used in concrete, on the permeability property varies according to grain size, grain shape, fly ash type and usage amount. Since the processability of the fly ash reinforced concretes formed of round grain structure increased, the water requirement of the mixture was reduced. However, due to the grain structure of the concretes prepared with the admixture of Afşin Elbistan ash having irregular grain structure, permeability in 28 days curing time was lower than that of reference concrete but permeability values of 90 days due to substitution rate and fineness were also higher (Bıparve, 2012).

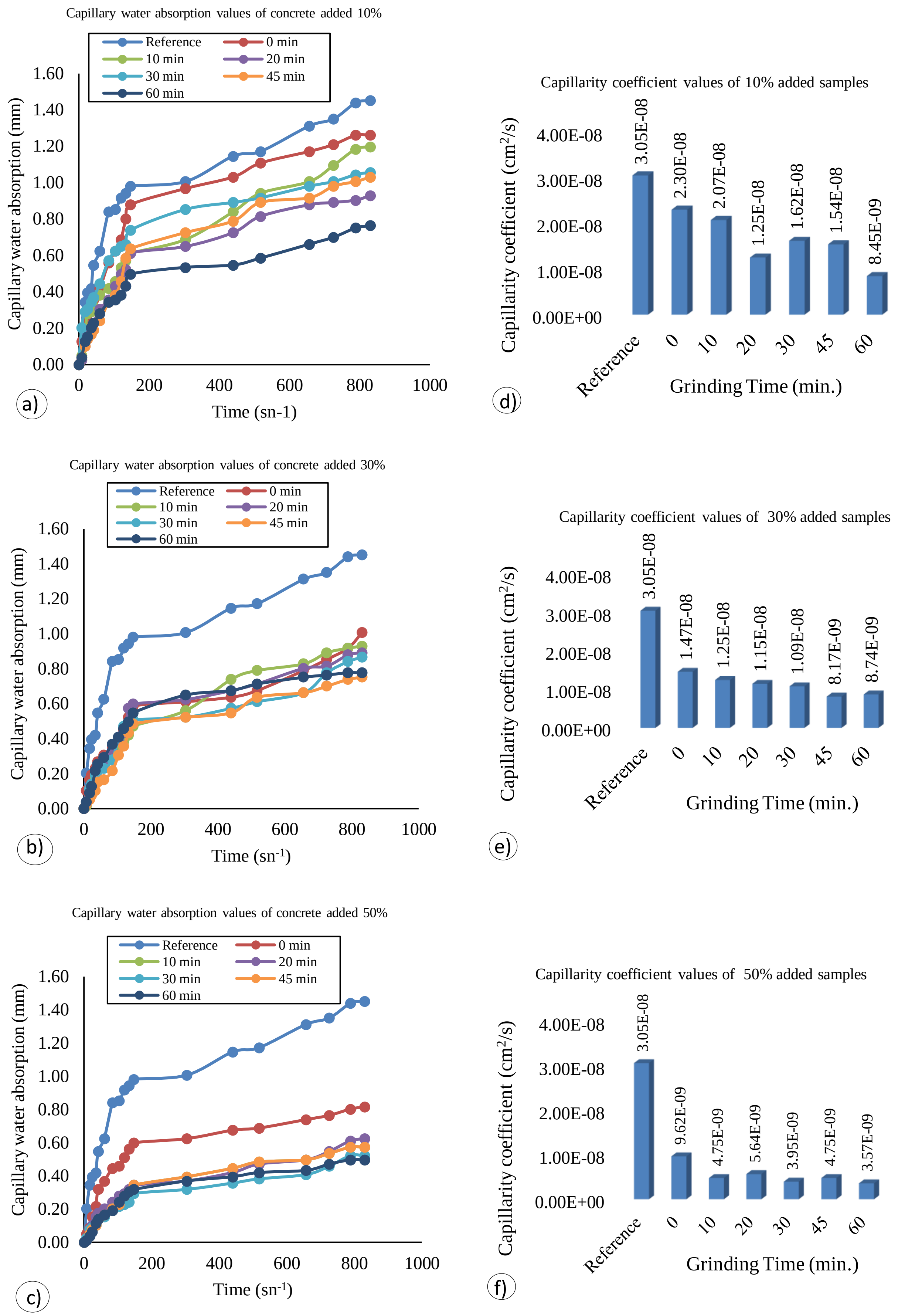


**Fig. 8.** Capillary water absorption and capillarity coefficient values of 28 days varying fly ash and substitution rate fly ash admixtures.

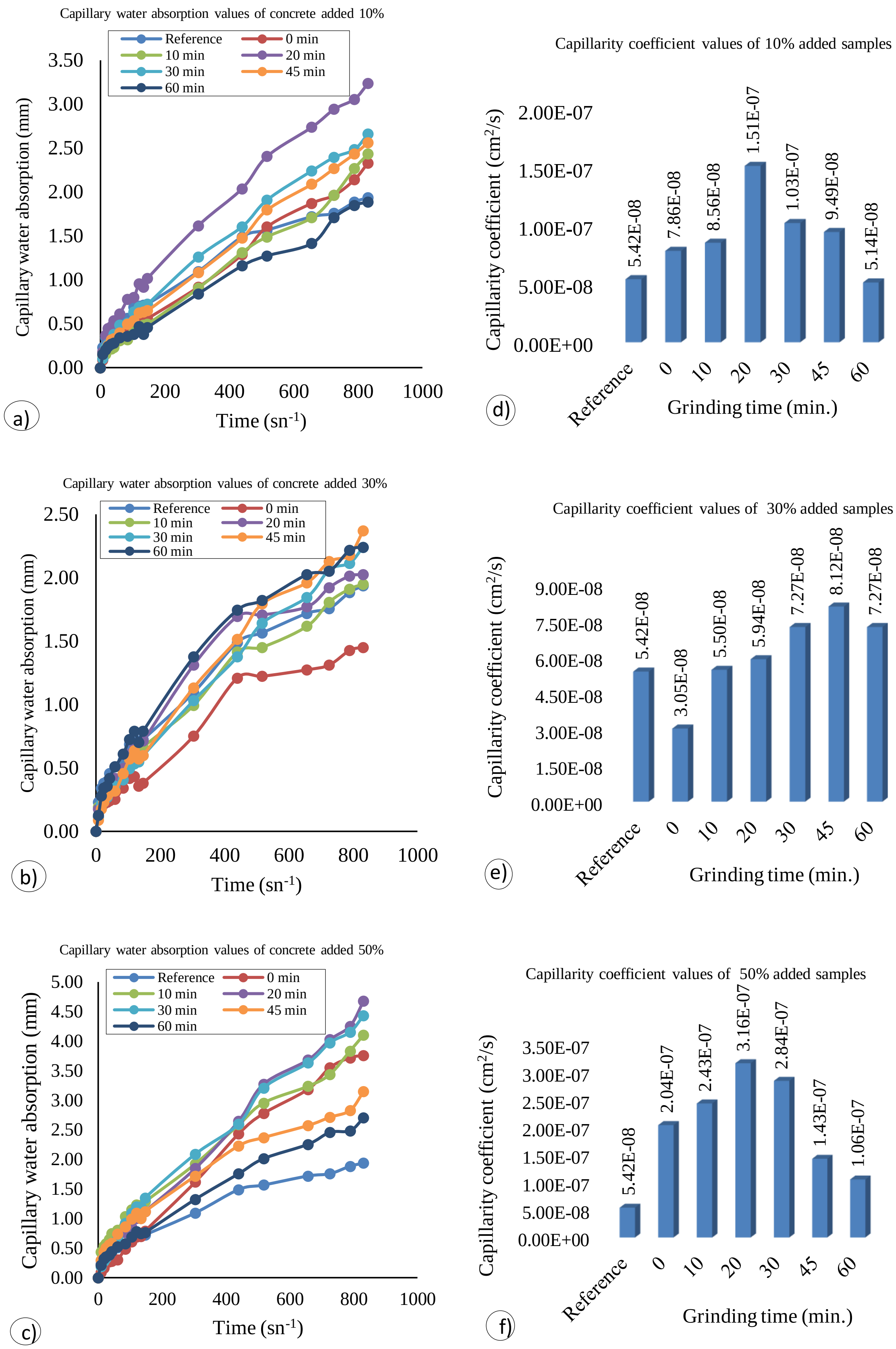


**Fig. 9.** Capillary water absorption and capillarity coefficient values of 90 days different fly ash and substitution rate fly ash admixtures.

In the study, after the curing period of 28 and 90 days, the differences between the samples obtained with different grain sizes of fly ash and the permeability value of the reference concrete showed differences from the connected cavities in the cement paste, micro cracks in the concrete, and the difference of the paste-aggregate interface. In particular, the voids and associated voids in the concrete are influenced by the water / cement ratio, the degree of hydration and the degree of compression. The different sizes of fly ashes caused a difference in the permeability properties of concrete samples since they affected the water / cement ratio, hydration degree and compression ratio. It consists of macro and micro crack system in concrete. In particular, the water permeability is determined by the capillary cavities. A cake's water / cement ratio and degree of hydration determine the total capillary voids (Mehta, 1990).

The particle size and distribution of aggregate in the concrete, the inner surface of the cement, the water / cement ratio, the degree of compaction of the fresh concrete, the curing condition, the humidity of the environment and the thermal history of the concrete are the factors affecting the micro-crack system of the concrete. With the use of fly ash of different Blaine fineness in concrete, it was aimed to change the microcrack structure of the concrete and to produce more impermeable concrete. Because permeability in concrete is determined by total porosity and distribution. In particular, permeability in concrete is associated with correlated voids. The fact that the concrete has a high void structure does not mean that it will have a high permeability; on the contrary it can show a low permeability. Sometimes concrete with low void structure can exhibit high permeability. The main reason for this situation is that the gaps are dependent and independent from each other. Therefore, the lack of void structure associated with fly ash reinforced concretes with a different fineness of 28 days caused low permeability compared to the reference. However, after 90 days curing period, that fly ash fineness was not effective on permeability stemmed from the formation of the correlative cavity structure (Chia and Zhang, 2002).

## 4. Conclusions

In this study, fly ash taken from Afşin Elbistan thermal power plant was milled into fine grained material. In the fly ash concrete, of which different fineness values were obtained by grinding was substituted for cement, in ratios of 10%, 30% and 50% by weight and reinforced concrete samples were produced. The effect of different fineness values and substitution ratios of fly ash used in concrete on the permeability property of concrete was investigated. In this context, 28 and 90 days of capillary tests were performed to determine the permeability. As a result;

- The amount of water absorbed by concrete samples prepared through capillary channels decreased as a result of the increase in the amount of fly ash in the concrete and the fineness with the effect of grinding.
- The reason for the decrease in capillary water absorption amount due to increase of fly ash ratio and fineness, decreased the amount of water absorbed by fly ash particles clogging the capillary channels.
- At the end of the 28-day curing period, the permeability values between the ground fly ash reinforced concrete samples and the reference sample were discussed more clearly. However, at the end of the 90-day curing period, the permeability values were close to each other in the ground concrete samples and the reference sample.
- In the 90 days fly ash reinforced concrete, $Ca(OH)_2$ and Si and Al compounds of fly ash formed as a result of cement hydration with fly ash reacted to form CSH and CAH structures. In these structures, they filled the gaps in the concrete and decreased permeability.
- Permeability in concrete changed, depending on variables such as the amount of binding material, water content, aggregate and grain distribution, curing conditions.
- Capillary cavities are not the only factors affecting water permeability in fly ash added concrete. However, the connection of capillary cavities is a critical factor in water permeability in unmixed and fly ash reinforced concretes.
- As a result of thinning of fly ash in terms of grain size, it decreased permeability by increasing pozzolanic activity and making the matrix more dense as a result of forming additional hydration products and increasing compressibility.
- Filling effect of fine-grained fly ashes, the development of pozzolanic activity due to fineness and cement hydration reduced the porosity and permability of the concrete thanks to the triple combination.
- The porosity and permability curing time of fly ash reinforced concretes were found to change in line with the fineness and substitution rate of the material. According to these parameters, the ideal substitution rate and fineness value of fly ash was at a level of 10% and 60 min grinding time, thus reducing permeability.
- That fly ash did not provide a significant reduction in permeability, especially during the 90-day curing time was associated with its not reaching the fineness of cement until 60 min of grinding time and not providing the ideal grain size. In addition, it did not contribute to the significant development of pozzolanic activity in the long cure period since it did not have the appropriate fineness value.

## Publication Note

This research has previously been presented at the 3rd International Conference on Advanced Engineering Technologies (ICADET'19) held in Bayburt, Turkey, on September 19-21, 2019. Extended version of the research has been submitted to Challenge Journal of Structural Mechanics and has been peer-reviewed prior to the publication.

## References


ASTM C618-19 (2019). Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete. *ASTM International,* West Conshohocken, PA.

ASTM C1585-13 (2013). Standard test method for measurement of rate of absorption of water by hydraulic-cement concretes. *ASTM International,* West Conshohocken, PA.

Bıparve A (2012). Permability and Durability Volume Fly Ash Concrete under an Applied Compressive Stress. *M.Sc thesis*, Shiraz University, Shiraz, Iran.

Bilir T, Gencel O, Topcu IB (2015). Properties of mortars with fly ash as fine aggregate. *Construction and Building Materials*, 93, 782-789.

Binici H, Görür EB, Durgun MY (2009). The use of Afşin-Elbistan fly ash and textile factory waste ash as pozzolanic admixture in concrete. *KSÜ Journal of Engineering Sciences*, 12(1), 10-19.

Chia KS, Zhang MH (2002). Water permeability and penetrability of high strength lightweight aggregate concrete. *Cement and Concrete Research*, 32, 639-645.

Hoffman GK (2006). Pozzolans and supplementary cementitious materials. *In Kogel JE, Trivedi NC, Barker JM and Krukowski ST*, *eds*. Industrial Minerals and Rocks 7th Edition, Society for Mining, Metallurgy and Exploration, Inc., Littleton, CO, 1161-1172.

Mehta PK (1990). Concrete: Structure, Properties, and Materials. Prentice Hall, New Jersey, USA.

Ministry of Energy and Natural Resources (MENR) (2018). Coal. Info Bank>Energy>Coal 2017. (http://www.enerji.gov.tr) (06.03.2018).

Naganathan S, Linda T (2013). Effect of fly ash fineness on the cement mortar. *Jordan Journal of Civil Engineering*, 7(3), 326-331.

Naik TR, Sing SS, Hossain MM (1994). Permeability of concrete containing large amounts of fly ash. *Cement and Concrete Research,* 24(5), 913-922.

Neville AM (1995). Properties of Concrete. 4th and final Ed., Longman's, London, UK.

Özcan İ, Bahadıroğlu C, Bozdoğan H (2014). Research on the reasons for the drying of planted saplings in the excavation areas around Afşin-Elbistan thermal power plant. *Nevşehir Journal of Science and Technology*, 3(1), 8-16.

Qiu JLQ, Xing F, Pan D (2014). Permeation properties and pore structure of surface layer of fly ash concrete. *Materials (Basel),* 7(6), 4282–4296.

Saha AK (2017). Effect of class F fly ash on the durability properties of concrete, *Sustainable Environment Research*, 28(1), 25-31.

Sant G, Bentz G, Weiss J (2011). Capillary porosity depercolation in cement-based materials: measurement techniques and factors which influence their interpretation. *Cement and Concrete Research*, 41(8), 854-864.

Sevim Ö, Demir İ (2019). Physical and permeability properties of cementitious mortars having fly ash with optimized particle size distribution *Cement and Concrete Composites*, 96, 266-273.

Shaikh FUA, Supit SWM (2015). High volume fly ash (HVFA) concretes containing ultrafine fly ash (UFFA), compressive strength and durability properties. *Construction and Building Materials*, 82, 192-205.

Sinsiri T, Chindaprasirt P, Jaturapitakkul C (2010). Influence of fly ash fineness and shape on the porosity and permeability of blended cement pastes. *International Journal of Minerals, Metallurgy and Materials,* 17(6), 683-690.

Toniolo N, Boccaccini AR (2017). Fly ash-based geopolymers containing added silicate waste. A Review. *Ceramics International*, 43(17), 14545-14551.

TS 802 (2016). Design concrete mixes. Turkish Standardization Institute, Ankara, Turkey.

Unal O, Uygunoğlu T (2004). Soma Termik Santral atığı uçucu külün inşaat sektöründe değerlendirilmesi. Turkey 14th Coal Congress, Zonguldak, Turkey (in Turkish).