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The Effect of Aggregate Size and Cure Conditions On The Engineering Properties of Concrete

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Abstract: In this study, the effect of curing conditions and aggregate size on the engineering properties of concrete was investigated. Aggregates in the range of 0-8 mm and 0-16 mm were used in concrete production and then cubic samples of 100x100x100 mm were prepared. In the study, slump value of fresh concrete was determined as S3. Three samples were used for each experiment. Compressive strength, abrasion, porosity and carbonation tests were performed on 28-day concrete samples subjected to water and air curing. According to the results obtained, it is determined that concrete samples under the effect of water curing give better results. In addition, better results were obtained for compressive strength, abrasion, porosity and carbonation properties of concrete by increase in aggregate size. It has also been observed that there is an increase in compressive strength of concrete, a positively decrease for abrasion, porosity and carbonation properties.

Key words: Concrete, air cure, water cure, slump, aggregate size.

Agrega Boyutu ve Kür Şartlarının Betonun Mühendislik Özelliklerine Etkisi

Öz: Bu çalışmada, agrega boyutu ve kür şartlarının betonun mühendislik özelliklerine etkisi araştırılmıştır. Tane boyutu 8 ve 16 mm olan agregalar kullanılarak 100x100x100 mm' lik küp numuneler hazırlanmıştır. Çalışmada taze betonların slump değeri S3 olarak belirlenmiştir. Her bir deney için 3'er adet numune kullanılarak su ve hava kürüne tabi tutulan 28 günlük beton numuneleri üzerinde basınç dayanımı, aşınma, porozite ve karbonatlaşma deneyleri yapılmıştır. Elde edilen sonuçlara göre su kürü etkisindeki beton numunelerinin daha iyi sonuç verdiği belirlenmiştir. Ayrıca, agrega boyutunun artmasıyla betonun basınç dayanımında artış, aşınma, porozite ve karbonatlaşma özelliklerinde olumlu yönde azalma meydana geldiği görülmüştür.

Anahtar kelimeler: Beton, hava kürü, su kürü, slump, agrega boyutu.

1. Introduction

Although the first use date of concrete is not known precisely, the history of concrete technology goes back to about 1845. Concrete; It is a composite material that is produced by mixing fine aggregate, coarse aggregate, cement, water and mineral, chemical additives or fiber in certain proportions according to the requirement. In addition to, concrete is a composite material that initially has a plastic consistency that can take the desired shape and hardens as a result of the hydration of cement and water with the passing of time [1].

The concrete aggregate used in the production of concrete or mortar is a stack that is combined with the binding material formed by the hydration of cement and water to create concrete and broken or unbroken grains, naturally or artificially, whose maximum grain size does not exceed generally 100 mm [2].

The properties and performance of fresh or hardened concrete depends on the quality and proportion of the materials forming the concrete (water / cement, aggregate grain distribution, etc.). Some properties of high strength and economical concrete and aggregates used in the concrete production are directly related. Thanks to the appropriate aggregate, concretes with durability, strength and workability can be obtained [3].

The dimensional distribution of aggregates is determined by sieve analysis experiment. Aggregates are classified as fine-grained or coarse-grained aggregates according to the results of sieve analysis. Aggregates passing through 4 mm sieve are called fine aggregates, and aggregates with a diameter larger than 4 mm are called large aggregates. Aggregates have an important place in the materials that make up the concrete as they form carrier frame of the concrete. For a quality concrete, the grain distribution of aggregates in concrete mix design must be properly and in accordance with the standards. In this way, an economical and quality concrete can be produced by providing the maximum compaction of concrete. [4].

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Curing conditions of concrete are specified as the effects of humidity and temperature in the environment where the concrete is located. In order for the hydration reactions between cement and water to continue, there must be water in the environment where the concrete is located. If there is not enough water in the environment, hydration reactions either slow down or stop completely. As a consequence, concrete cannot gain strength [5,6]. Therefore, it is necessary to provide the curing conditions of the concrete in the best way to ensure the maximum level of hydration reactions [7].

In this study, the effects of different aggregate size and curing conditions on the engineering properties of concrete were investigated.

2. Material and Method

2.1. Material

2.1.1. Cement

CEM I 42.5 R type cement was used as cement in the study. Cement properties are shown in Table 1.

Table 1. Cement properties

Properties	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Ignition Loss (%)
Value (%)	18.69	5.34	3.27	63.70	1.54	2,70	0,75	3.57

2.1.2. Aggregate

In the study, crushed stone aggregates of 0-8 mm and 0-16 mm grain sizes were used for concrete production. Sieve analysis results of 0-8 mm and 0-16 mm aggregate groups are given in Figure 1 and Figure 2, and physical properties are given in Table 2.

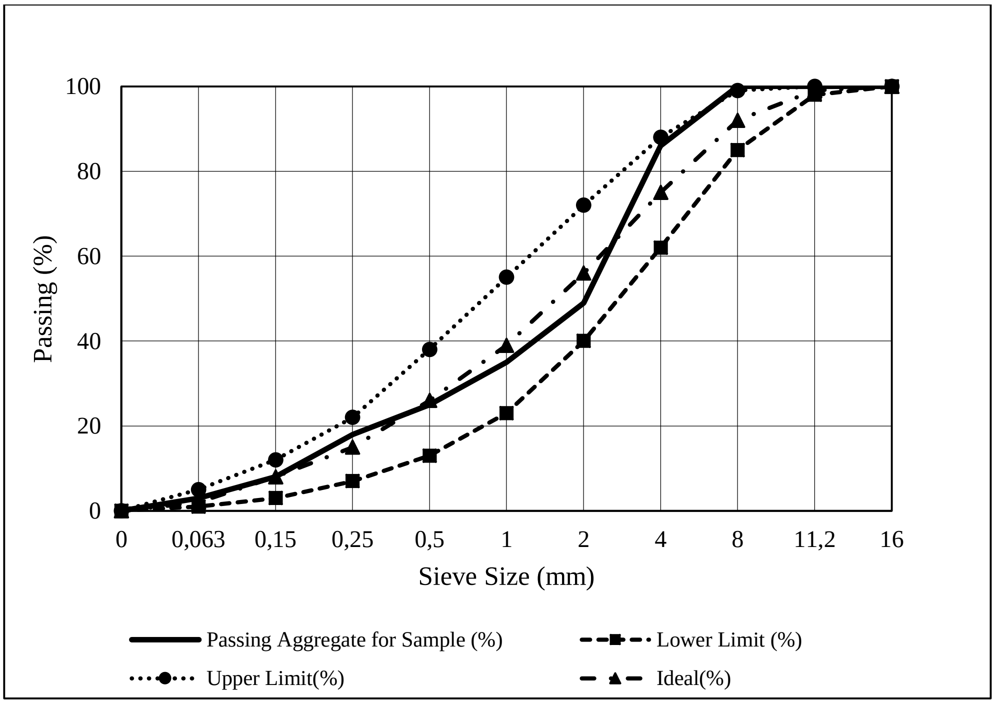


Figure 1. Limits of aggregate grain size distribution curve determined for concrete with the largest grain size of 8 mm aggregate and granulometry curve for 0-8 mm aggregate group

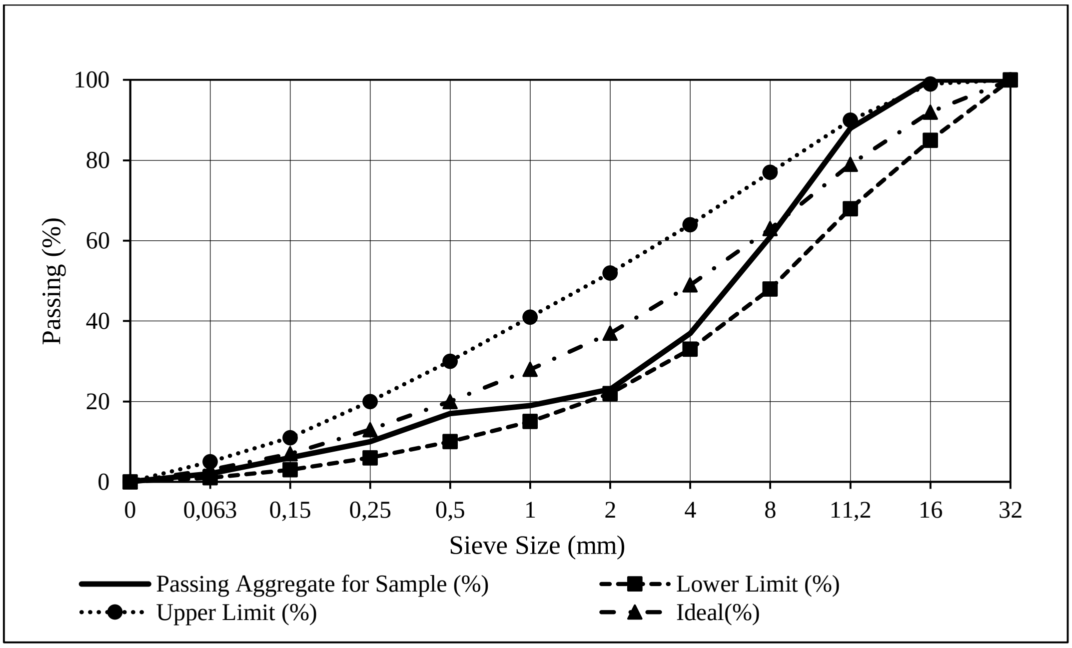


Figure 2. Limits of aggregate grain size distribution curve determined for concrete with the largest grain size of 16 mm aggregate and granulometry curve for 0-16 mm aggregate group

Table 2. Physical properties of aggregate

Physical properties of aggregate			
Aggregate Type	Water Absorption (%)	Specific Weight (gr/cm^3)	Abrasion Loss (%)
Crushed Stone (0-8 mm)	3.34	2.78	-
Crushed Stone (0-16 mm)	0.744	2.71	23.1

2.1.3. Mixing water

Tap water of Ankara was used as mixing water.

2.2. Method

2.2.1. Preparation of concrete samples

Aggregate used in concrete production is crushed stone aggregate. The aggregate used in the preparation of samples has a maximum grain size of 8 and 16 mm respectively. In the study, slump value was kept constant (6-9 cm) in all concrete series. The total amount of binders in all concrete series has been selected as 400 kg/m^3. Mix ratios of concrete samples prepared in this way are given in Table 3. In the study, 100x100x100 mm cube sample molds were used for compressive strength, abrasion, porosity and carbonation tests. Concrete mixes are prepared in the mixer and placed in the molds by considering the recommendations given in the standards (TS EN 12390-3 [8] and ASTM C944 / C944M [9]). After the prepared mixes were placed in the molds with 25 times rodding in 2 stages, the samples were removed from the molds after waiting 1 day under laboratory conditions. Then, half of the samples were kept in air curing and the other half of samples were kept in water curing for 28 days.

Table 3. Mixing ratios of the samples tested

Mixing ratios of Samples			
Aggregate Size (mm)	Water (kg/m^3)	Cement (kg/m^3)	Aggregate (kg/m^3)
0-8	238	400	1708
0-16	230	400	1716

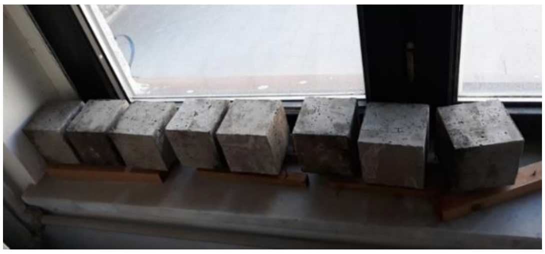
2.2.2. Tests

Compressive Strength Test

For each group of concrete samples produced with a maximum aggregate size of 8 and 16 mm, a total of 12 samples of 100 mm cubes (3 samples both cured in air and water for each group) were subjected to compressive strength test on the 28th day. Compressive strength tests were carried out in accordance with TS EN 12390-3-2010 [8]. The mold where samples are poured and samples are given in Picture 1. Samples subjected to water curing were kept at a temperature of 20 °C and all surfaces were left in water (Picture 2) and samples that were subjected to air curing (Picture 3) were cured by standing in a laboratory environment.

Picture 1. Molds where samples are poured and their appearance after pouring

Picture 2. Samples left on the water cure



Picture 3. Samples left on air curing

Abrasion Test

12 samples in total including 6 samples for each group from 100 mm cubes produced with aggregates with 0-8 mm and 0-16 mm grain sizes were subjected to the abrasion test. Abrasion test was carried out in accordance with ASTM C944 / C944M [9]. Half of the samples were kept in air curing and the other half were kept in water curing for 28 days and then they were subjected to abrasion test. The samples, which have completed the curing period for the abrasion test, were subjected to abrasion for 6 minutes with abrasive wheels having a speed of 200 rpm. The abrasion test apparatus and samples after abrasion are given in Picture 4 and Picture 5.

Picture 4. Abrasion Test Aparatus

Picture 5. Samples after abrasion test

Porosity Test

For the determination of porosity, the dry weights of the samples were determined first and the value found was recorded as Wo. Samples with dry weights were kept in water during the period of 1 day so that all surfaces were kept in water to absorb water. Then all surfaces of the samples taken from the water were dried. After the samples were dried, they were weighed and the value found was recorded as W_1. Then, the weight of the samples under water was found by the Archimedes scale (Picture 6) and the value found was recorded as W_2. All the required values were calculated and replaced with the Equation 1 and porosity (P) value was found.

$$P = \frac{(W_1 - W_0)}{(W_1 - W_2)} * 100 \qquad (1)$$

Picture 6. Archimedes scale

Carbonation Test

For each group of concrete samples produced with a maximum aggregate size of 8 and 16 mm, a total of 12 samples of 100 mm cubes (3 samples both cured in air and water for each group) were subjected to accelerated carbonation tests on the 28th day. The gas tightness of the accelerated test apparatus was first tested for carbonation test. After the samples were placed in the carbonation tank, 1 bar of CO_2 gas was given to the tank. Sodium dichromate was used to adjust the humidity inside the apparatus to approximately 55%. The appearance of the accelerated carbonation tank prepared is given in Picture 7. The concretes removed from the carbonation tank were subjected to the splitting tensile test [10] to be split in two pieces to samples, and the phenolphthalein solution was sprayed into the divided pieces and color change was observed in the sample. Fenolftalin which reacts with the hydration product, calcium hydroxide, creates a color that turns pink in the sample, and no color change occurs in the carbonation zone. The appearance of the phenolftaline sprayed sample is as in Figure 3, and the carbonation depth is measured by measuring the values A1, A2, B1, B2, C1, C2, D1, D2 and placing the values found in the Equation 2 below [11, 12]. Carbonation test samples are given in Picture 8.

Picture 7 Carbonation test apparatus

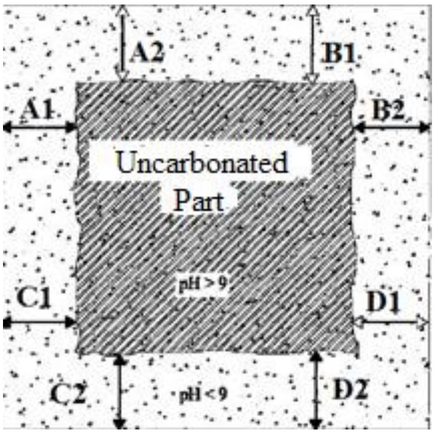
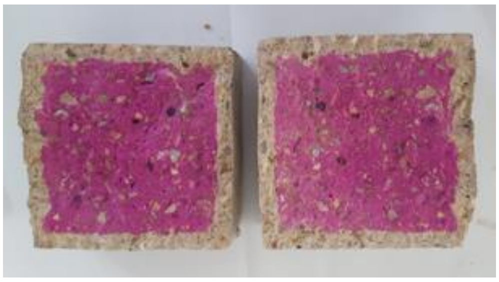


Figure 3. Sample for the carbonation test [11, 12].

$$\text{Carbonation Depth} = \frac{(A_1+A_2+B_1+B_2+C_1+C_2+D_1+D_2)}{8} * 100 \quad (2)$$



Picture 8. Fenolftalin sprayed samples

3. Findings

3.1. Compressive strength test

The results of the compressive strength test performed on the hardened concrete samples (28 days) are shown in Figure 4.

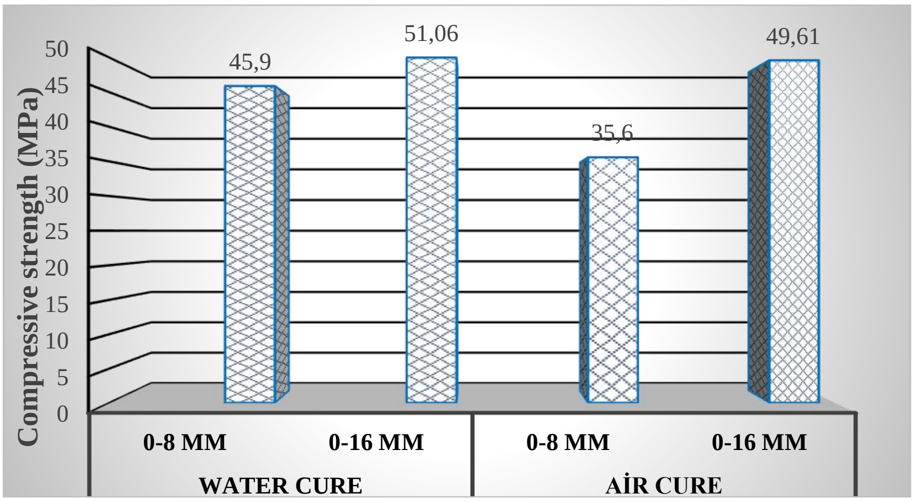


Figure 4. Results of compressive strength test on 28th day

When Figure 4 is analyzed, it is seen that compressive strength of concrete samples cured in water gives better results than the aired cured ones. In the samples produced with 0-8 mm aggregate group, it is seen that the compressive strength of the samples cured with water was 45.9 N/mm^2, the compressive strength of the samples cured with air was 35.6 N/mm^2. Concrete samples produced with 0-8 mm aggregate group cured with water gave approximately 29% more compressive strength than air curing. In the samples produced with 0-16 mm aggregate group, it was observed that those that were cured with water have a compressive strength of 51.06 N/mm^2, and those that were cured with air have a compressive strength of 49.61 N/mm^2. It has also been seen that concrete samples produced with 0-16 mm aggregate group cured with water give approximately 3% more compressive strength than air cured samples. Therefore, it has been observed that concrete samples cured with water give better results than concrete samples cured with air. When the results are examined in terms of aggregate size, increases in compressive strength have occurred with increasing aggregate size. The most important feature affecting compressive strength is the compactness of the sample. The amount of water in the mixture and the amount of void will increase as the aggregate size decreases. Therefore, the compaction and compressive strength of the sample is reduced. The compaction and compressive strength of the sample increases with increasing aggregate size [4].

3.2. Abrasion test

When Figure 5, which gives the results of the abrasion test of the concrete samples according to the curing conditions, was examined, it was seen that the abrasion resistance of the samples that were subjected to water curing gave better results similar to the results of the compressive strength. In addition, when the aggregate grain size is taken into consideration, it was observed that the abrasion percentage decreased with increasing aggregate size.

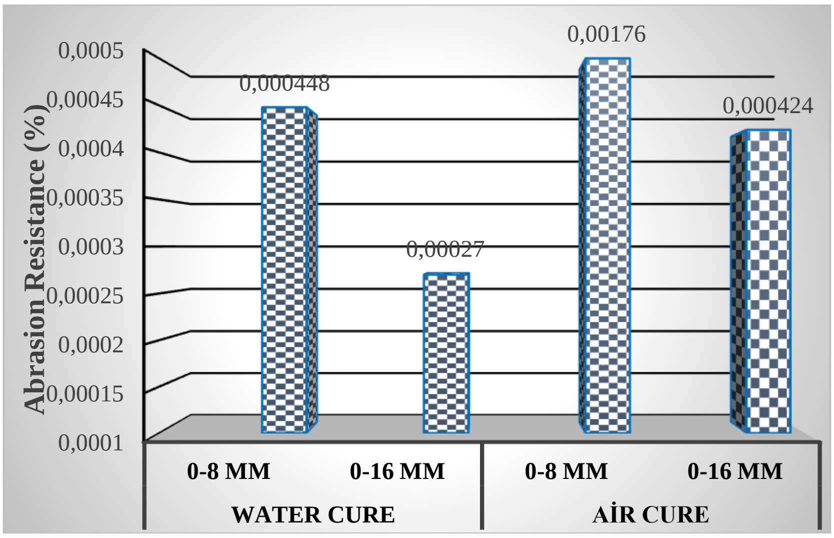


Figure 5. Abrasion Test Results

3.3. Porosity test

It is determined that the percentage of porosity in concrete samples gives better results in water-cured samples when Figure 6, which gives the results of the porosity test, is analyzed. It has been observed that the porosity of concrete samples produced with 0-8 mm aggregate group cured with water is 6.26%, and those cured with air are 13.13%. Thus, it can be said that concrete samples produced with 0-8 mm aggregate group cured with water are less void than air cured samples. In the concrete samples produced with 0-16 mm aggregate group, it was observed that the porosity of those cured with water was 4.13%, and those cured with air were 8.05%. Therefore, it can be said that water cured concrete samples have a more void-free structure than air cured samples. As a result, in terms of porosity, the cure made with water gave better results than the cure made with air. When Figure 6 is examined in terms of aggregate size, it is seen that porosity decreases with increasing aggregate size. As the grain size in the sample decreases, the number of grain in the unit volume increases and the space volume between these grains increases and the porosity in the mixture increases [4].

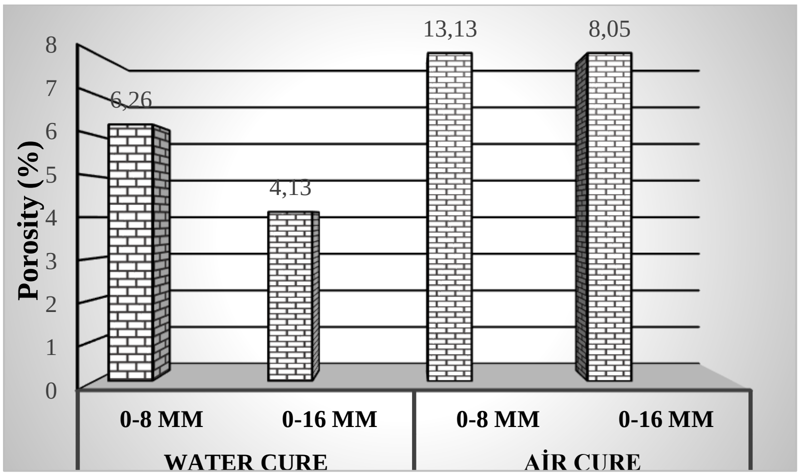


Figure 6. Porosity test results of concrete samples under different curing conditions

3.4. Carbonation test

The results of the carbonation test of the concrete samples according to the curing conditions are given in Figure 7.

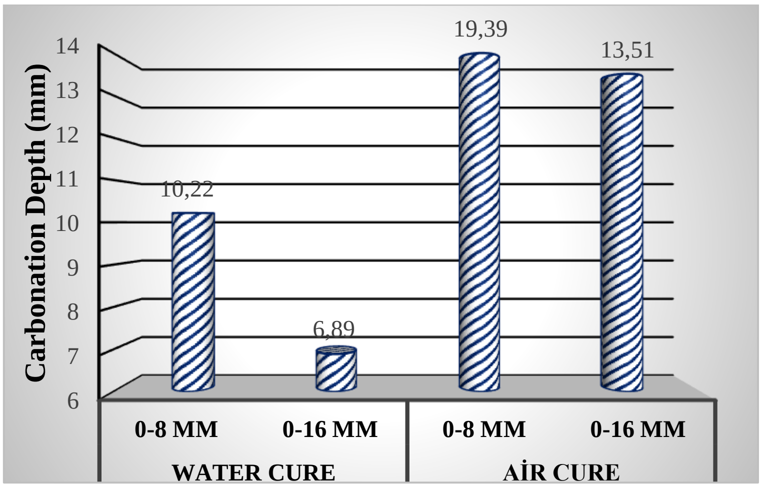


Figure 7. Carbonation test results of concrete samples in different curing conditions

When Figure 7 was analyzed, it was observed that carbonation in concrete samples gave better results in water-cured samples. It has been determined that the carbonation depth of the concrete samples produced with 0-8 mm aggregate group is 10.22 mm in water cured ones and 19.39 mm in air cured ones. Concrete samples produced with 0-8 mm aggregate group cured with water showed approximately 47% less carbonation than air cured samples. In the concrete samples produced with 0-16 mm aggregate group, the carbonation depth of those cured with water is 6.89 mm, and those cured with air are 13.51 mm. It has been observed that water cured concrete samples have approximately 49% less carbonation than air cured concrete samples. When Figure 7 was analyzed in terms of aggregate size, it was seen that the carbonation depth decreased with increasing aggregate size. Therefore, carbonation reactions are less in low porosity concretes [13].

Overall, by looking at Figure 8, it can be concluded that the compressive strength, porosity and carbonation depth of a concrete sample are related eachother.

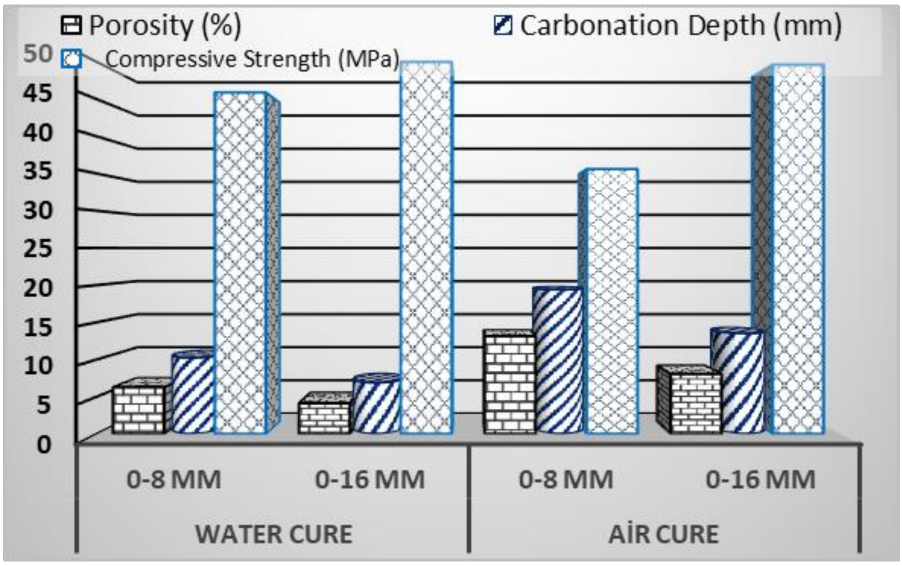


Figure 8. The results of porosity, carbonation and compressive strength tests.

4. Results

When we interpret our experimental data in terms of water cure and air cure, it was seen that the samples that were subjected to water curing performed better in terms of engineering properties compared to the air cured samples. The compressive strength of concrete samples subjected to water curing was higher. As a result of more voids in the samples that were cured in the air, the compressive strength has decreased and the abrasion, porosity and carbonation values have increased. In short, it was concluded that the water curing makes the concrete more resistant to external influences.

When the effect of aggregate size on the engineering properties of the samples was examined, it was observed that the compressive strength of the samples having 0-16 mm aggregate diameter range was higher than that of 0-8 mm aggregate grain size samples. We can conclude that when the aggregate granulometry grading of the samples is more balanced, it gives higher strength value.

It has been observed that samples having 0-16 mm aggregate diameter have lower porosity, abrasion and carbonation depth values. The use of larger size aggregates in conrete results in higher strength, in other words larger aggregate will create a lower surface area and lower water requirement. Therefore, a lower water cement ratio can be used, resulting in higher strength. As a result, it was observed that 0-16 mm aggregate group improved the engineering properties of the samples compared to 0-8 mm aggregate group.

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