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The Effects of Water/Cement Ratio and Cement Dosage Variables on the Performance of Shotcrete: Compressive Strength and Drying Shrinkage Perspective

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Shotcrete, Cement dosage, Water/cement ratio, Compressive strength, Drying shrinkage

Abstract: Shotcrete is a construction material that is applied by spraying under high pressure, and there are many factors that affect its properties. In this study, the effect of cement dosage and water-to-cement ratio on the compressive strength and drying shrinkage performance of shotcrete was investigated. For this purpose, shotcrete specimens were produced using three different water-to-cement ratios (0.40, 0.45, 0.50) and three different cement dosages (400 dsg, 450 dsg, 500 dsg). The unit weight, ultrasonic pulse velocity (UPV), compressive strength, splitting tensile strength, and drying shrinkage performance of the produced specimens were examined. As a result of the experimental studies, an increase in cement dosage resulted in an increase in unit weight values, with the amount of increase ranging from approximately 1% to 3%. When the UPV value was examined, an increase in cement dosage resulted in an increase in UPV values, with an increase of approximately 1% to 5%. An increase in cement dosage also resulted in an increase in compressive strength and splitting tensile strength values, with the increase ranging from approximately 12%-16%, 5%-9%, and 10%-12% for the 500, 450, and 400 dosage groups, respectively. The drying shrinkage values increased with increasing cement dosage, the highest shrinkage values occurred in the groups with 0.50 water/cement ratio and 500 dosage, and it was observed that 85-95% of the total shrinkage of the shotcrete specimens was completed within the first 1 hour. Furthermore, the data obtained can be used to determine the optimum water/cement ratio and cement dosage for the construction of shotcrete.

Püskürtme Betonlarında Su/Çimento Oranı ve Çimento Dozajı Değişkenlerinin Performansa Etkileri: Basınç Dayanımı ve Kuruma Rötresi Perspektifi

Anahtar Kelimeler
Püskürtme beton, Çimento dozajı, Su/çimento oranı, Basınç dayanımı, Kuruma rötresi

Öz: Püskürtme beton, yüksek basınç altında püskürtülerek uygulanan bir yapı malzemesidir ve özelliklerini etkileyen birçok faktör vardır. Yapılan bu çalışmada püskürtme betonda kullanılan çimento dozajının ve su/çimento oranının basınç dayanımı ve kuruma rötresi performansına etkisini incelenmiştir. Bu amaç kapsamında üç farklı su/çimento oranı (0.40, 0.45, 0.50) ve üç farklı çimento dozajı (400 dzj, 450 dzj, 500 dzj) kullanılarak püskürtme beton numuneleri üretilmiştir. Üretilen numuneler üzerinde birim hacim ağırlık, ultrases geçiş hızı (UPV), basınç dayanımı, yarmada çekme ve kuruma rötresi performansları incelenmiştir. Deneysel çalışmalar sonucunda, çimento dozajının artmasıyla birim hacim ağırlık değerlerinde artış meydana gelmiş olup meydana gelen artış miktarı yaklaşık olarak %1 ve %3 arasında değişmektedir. UPV değeri incelendiğinde ise, çimento dozajının artmasıyla UPV değerlerinde yaklaşık olarak %1 ve %5 değerlerinde artış elde edilmiştir. Basınç dayanımı ve yarmada çekme dayanımı değerlerinde de çimento dozajının artmasıyla artış meydana gelmiş olup, artış miktarı 500 dzj, 450 dzj ve 400 dzj için sırasıyla yaklaşık %12-16, %5-9 ve %10-12 arasında meydana gelmiştir. Çimento dozajının artmasıyla kuruma rötresi değerlerinde artış meydana gelmiş olup, en yüksek rötre değerleri 0.50 su/çimento oranı ve 500 dozlu gruplarda meydana geldiği, püskürtme beton numunelerinin toplam büzülmesinin %85-95'inin ilk 1 saat içerisinde tamamlandığı gözlemlenmiştir. Ayrıca, elde edilen veriler, püskürtme betonunun yapılandırılması için optimum su/çimento oranı ve çimento dozajını belirlemek için kullanılabilir.

1. INTRODUCTION

Shotcrete is a construction technique used in underground construction worldwide due to its technical and economic advantages over conventional concrete [1-2]. Today, shotcrete is widely used in construction, mining and tunnel construction [3-4-5-6]. Since the introduction of shotcrete, great progress has been made in terms of improving the performance of materials, mix ratio, and concrete and dust control of the spraying process [7-8-9]. While shotcrete technology has recently made great progress in terms of equipment, ease of use and capacity, many basic principles remain unchanged [10]. The main components that affect the rheological properties of fresh concrete include: (1) binder formulations, including the type and content of chemical and mineral additives; (2) type, shape and gradation of aggregates; (3) water-cement ratio (w/c); and (4) are the properties of cement materials. Even similar mixtures can show quite different flow properties with small changes in these components [11]. Main components of shotcrete (1) properties and dosage of cement; (2) type, shape and gradation of aggregates; (3) water/cement (w/c) ratio and (4) type and content of chemical and mineral additives [12].

In this study, the effects of cement dosage and water/cement ratio, which are important main components affecting shotcrete properties, were investigated. The main objective of the study was to determine the mechanical properties and drying shrinkage characteristics of shotcrete produced using three different water/cement ratios (0.40, 0.45, 0.50) and three different cement dosages (400, 450, 500) considering the water/cement ratio and cement dosage limits specified in EFNARC standard.

2. MATERIAL AND METHOD

2.1. Materials

2.1.1. Cement

In the production of concrete mixtures, CEM I 42.5R Portland cement which conforms to the ASTM C 150 [13] and EN 197-1 [14] standard, was used for all concrete mixtures as a binder. Portland cement has the specific surface area and specific gravity of 4130 cm^2/g and 3.13 respectively. Characteristic properties of Portland cement are tabulated in Table 1.

Table-1. Physical and chemical properties of cement (CEM I 42,5 R)

Chemical Composition (%)		**Physical Properties of Cement**	
SiO_2(%)	19,16	Specific Gravity (g/cm3)	3,13
Al_2O_3 (%)	4,87	Bleine (cm^2/G)	4130
Fe_2O_3 (%)	3,76	Fineness (μ)	2,8
CaO (%)	63,03	İnitial Setting min	125
MgO (%)	1,65	Final Setting min.	210
SO_3 (%)	3,26	Le Chatelier min.	1
K_2O (%)	0,58	Compressive Strength (N/mm^2)	
Na_2O (%)	0,17	2 days	28,1
CI (%)	0,0102	7 days	40,4
loss on ignition	3,43	28 days	54,2
Insoluble residue	0,61		

2.1.2. Chemical Additives

Alkali containing, setting accelerator additive was used in the study. The setting accelerator additive was obtained from AKKİM Kimya A.Ş. and its properties are given in Table 2.

Table 2. Properties of Chemical Additives

COD	**Solids conte nt (%)**	**Density (gr/cm^3)**	**pH**	**Chloride Content**	**Alkali Amount (Na_2O equivalent , %)**
AK SHOT 150	35	1,47	13,0	<0,1	<25

2.2.3. Aggregates

In the study, crushed stone aggregate with a size between 0-7 mm was used and sieve analysis of the aggregates to be used was performed. As a result of the sieve analysis, granulometry curves of crushed stone aggregate were drawn and shown in Figure 1. The curve boundaries are based on EFNARC (1996) [15] limit values for shotcrete.

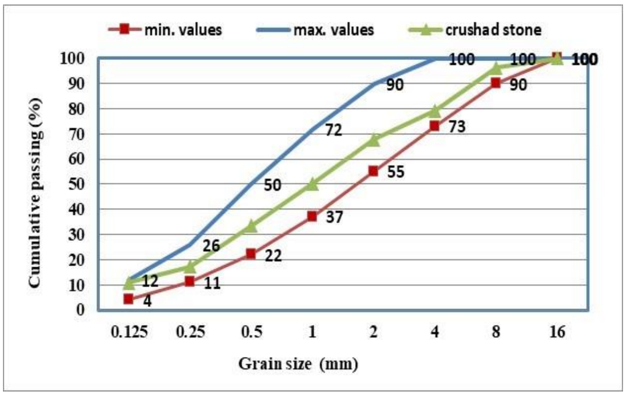

Figure 1. Granuometry curve of crushed stone aggregate

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2.2 Methods

2.2.1. Production of mixtures

In this study, shotcrete specimens were produced to investigate the effect of water/cement ratio and cement dosage on the compressive strength and drying shrinkage performance of wet mix shotcrete. Three different water/cement ratios (0.40, 0.45, 0.50) and three different cement dosages (400, 450, 500) were used during the production of the specimens, considering the water/cement ratio and cement dosage limits specified in the EFNARC standard. The amount of setting accelerator admixture used in shotcrete production was kept constant at 4% by weight of cement. The mixture ratios used in shotcrete are given in Figure 2.

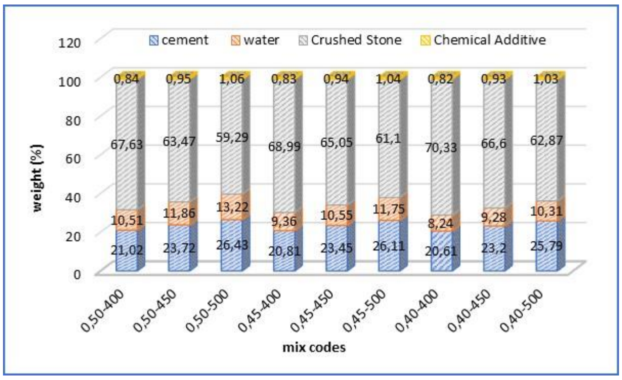

Figure 2. Shotcrete mixing ratios (%)

During the spraying process, 45x45x10 cm wooden molds placed at a 45o angle were used. After the spraying process was completed, the molds were kept for 24 hours and then the concrete blocks were cured for seven days under suitable conditions. After the curing process was completed, 10x10 cm core samples were produced from the concrete blocks and 4x4x16 cm rectangular samples were produced during the spraying process to determine the drying shrinkage performance. Shotcrete production stages are given in Figure 3.

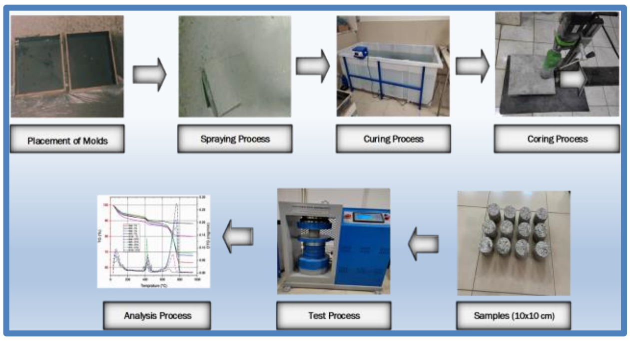

Figure 3. Shotcrete production stages

3. RESEARCH FINDINGS

Unit volume weight, utrase transition rate, compressive strength and tensile strength at splitting properties of the specimens produced as a result of the study were analyzed. The data obtained are given below.

3.1. Density and UPV values

The unit weight test was performed according to TS EN 1015- 10 (2001) [16] The ultrasound transmission rate test was determined according to ASTM C 597, (1997) [17]. Test results are given in Table 4.

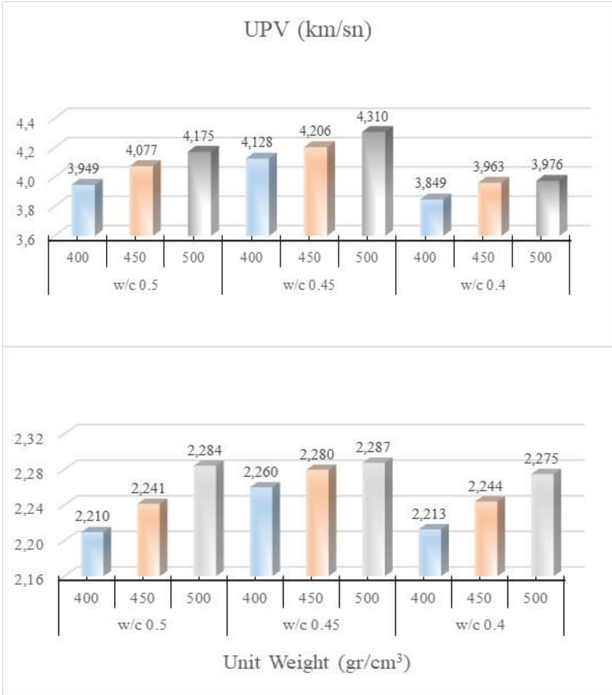

Figure 4. UPV and Unit weight values

When the unit volume weight values were analyzed, no significant change was observed in the unit volume weight values with increasing water/cement ratio. However, there was an increase in the unit weight values with the increase in cement dosage. The amount of increase varies between approximately 1% and 3%. When the UPV value was analyzed, UPV values increased by approximately 1% and 5% with increasing cement dosage, while compressive strength values decreased with increasing water/cement ratio. The lowest values were obtained from the specimens produced at a water/cement ratio of 0.40 and were due to the workability problem that occurred during placement.

3.2. Compressive strength values

The compressive strengths of the produced shotcrete concrete groups have been determined according to TS EN 12390-3 (2010) [18], and the compressive strength values are given in Figure 5. When the compressive strength values given in Figure 5 are analyzed, compressive strength values increased with the increase in cement dosage in all groups. The amount of increase was between 12%-16%, 5%-9% and 10%-12% for 500 dsg, 450 dsg and 400 dsg, respectively. Although compressive strength values increased up to a certain point with decreasing water/cement ratio, compressive strength values decreased due to the decrease in workability at 0.40 water/cement ratio. When all groups were analyzed, the highest values were obtained from the 0.45 water/cement group. The relationship between water/cement ratio and compressive strength is given in Figure 6. When the relationship is analyzed, the highest coefficient of determination (R^2= 9786) was obtained from 0.45 water/cement ratio.

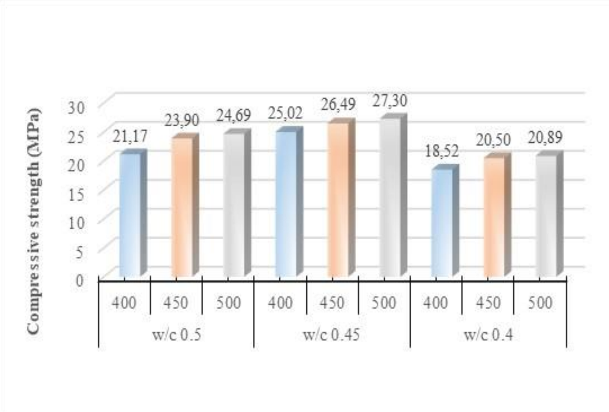

Figure 5. Compressive Strenght Values (MPa)

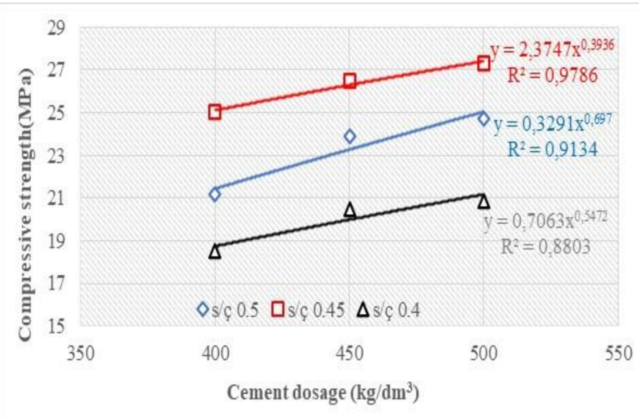

Figure 6. Compressive Strenght and cement dosage relationship (MPa)

3.3. Splitting tensile strenght values

The splitting tensile strength of the shotcrete groups was determined according to TS EN 12390 -6 (2010) [19] and the splitting tensile strength values are given in Figure 6. When the splitting tensile strength values are examined, it is observed that it shows a similar behavior to the compressive strength. The tensile strength values increased with the increase in cement dosage.

The highest values in all groups were obtained from shotcrete groups where 0.45 water/cement ratio was used, similar to the compressive strength. The relationship between the tensile strength at splitting and the increasing cement dosage ratio for each increasing water/cement ratio is given in Figure 8. When the relationship is analyzed, the highest coefficient of determination (R^2=0, 999) was obtained for the increasing cement dosage of 0.45 water/cement ratio.

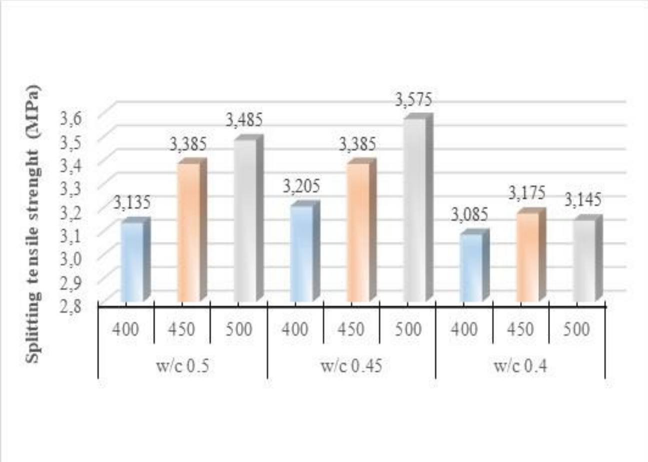

Figure 7. Splitting Tensile Strength Values (MPa)

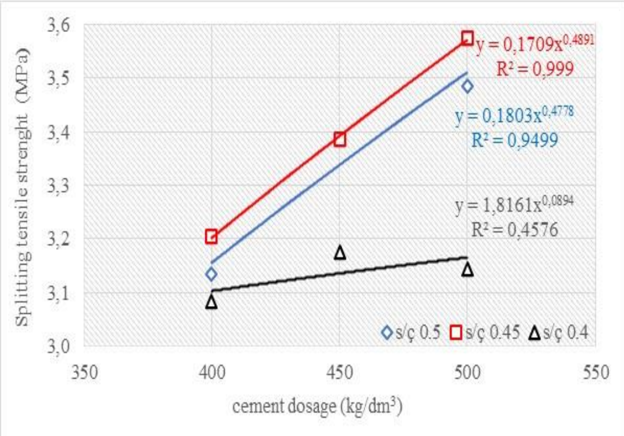

Figure 8. Splitting Tensile Strength Values (MPa)

3.4. Drying shrinkage values

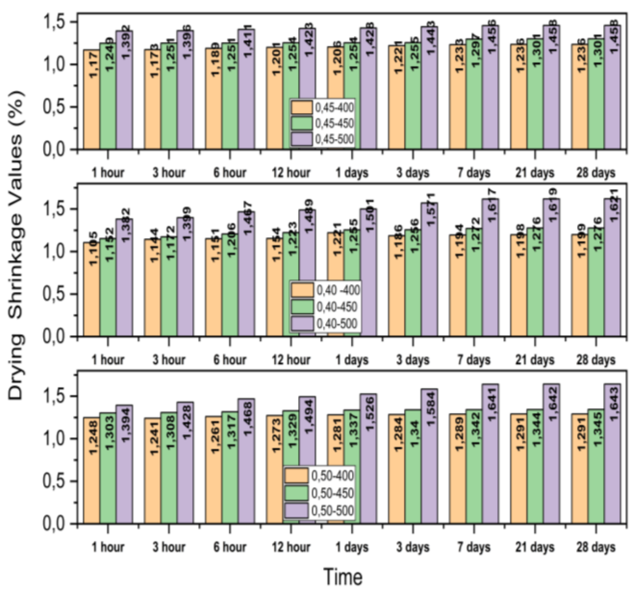

Figure 9. Drying Shrinkage Values

When the drying shrinkage performance values given in Figure 7 are analyzed, it is observed that the drying shrinkage values increased with the increase in curing time during the three-day curing period, while they remained approximately constant for the other curing periods. The shrinkage values increased with increasing water/cement ratio and cement dosage, and the highest shrinkage values were observed in the groups with 0.50 water/cement ratio and 500 dosage. It was observed that 85-95% of the total shrinkage of the shotcrete samples, whose drying shrinkage time-dependent percentage changes are given in Figure 10, was completed in the first 1 hour.

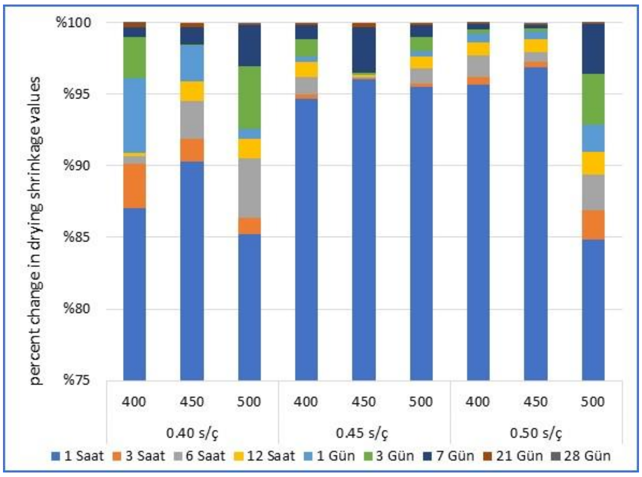

Figure 10. Percent change in drying shrinkage

4. RESULTS

In this study, the effect of cement dosage and water/cement ratio used with shotcrete on compressive strength and drying shrinkage performance was investigated. The results obtained as a result of the above investigations are listed below.

Unit volume weight values increased with increasing cement dosage. The amount of increase varies between approximately 1% and 3%. The UPV values increased by approximately 1% and 5% with increasing cement dosage, while the compressive strength values decreased with increasing water/cement ratio.

Although there was an increase in compressive strength values up to a certain point with the decrease in water/cement ratio, compressive strength values decreased due to the decrease in workability at 0.40 water/cement ratio. When all groups were analyzed, the highest values were obtained from 0.45 water/cement groups.

The values of splitting tensile strength increased with the increase in cement dosage. When all groups were analyzed, the highest values were obtained from the shotcrete groups where 0.45 water/cement ratio was used, similar to the compressive strength.

The shrinkage values increased with increasing water/cement ratio and cement dosage, and the highest shrinkage values were observed in the groups with 0.50 water/cement ratio and 500 dosage. When the drying shrinkage percentage changes were analyzed, it was observed that the shotcrete samples completed 85-95% of the total shrinkage in the first 1 hour.

Furthermore, the data obtained can be used to determine the optimum water/cement ratio and cement dosage for the construction of shotcrete. The results of this study can help to make shotcrete more reliable and durable.

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