

Araştırma Makalesi - Research Article

Mikro Silika Dolgulu Yüksek Dayanımlı Betonun Mekanik Özelliklerine Ön Isıtmanın Etkisi

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ÖZ

Silis dumanı içeren betonun erken yaş sıcaklığı, silis dumanı yüzeyinin hızlı reaksiyon gösterme ve mukavemeti artırma eğilimi nedeniyle çok önemlidir. Kür metodu geçirimsizliği, dayanımı ve durabiliteyi doğrudan etkiler. Bu çalışmada farklı oranlarda silis dumanı içeren betonların basınç dayanımı, eğilmede çekme dayanımı ve yarmada çekme dayanımı 2 kür metodunda araştırılmıştır. Basınç dayanımı için $15 \times 15 \times 15$ cm küp numuneler, çekme deneyi için 10×20 cm silindir numuneler ve eğilme dayanımı için $7 \times 7 \times 28$ cm kiriş numuneler olmak üzere 3 farklı kalıp kullanılmıştır. Silis dumanı ağırlıkça çimento yerine mineral katkı olarak %8, %10, %12 oranlarında kullanılmıştır. Deney için 2 grup hazırlanmış olup birinci grup 4 hafta su küründe iken ikinci grup ise 1 gün boyunca 75°C 'de ön ısıtma etkisinde ve sonrasında 4 hafta su küründe tutulmuştur. Slump testi kullanılarak taze beton özellikleri araştırıldığında en yüksek slump değerinin ve basınç dayanımı, yarmada çekme dayanımı ve eğilmede çekme dayanımında da en iyi sonuçların %10 silis dumanı içeren numunelerde olduğu görülmüştür.

Anahtar Kelimeler- *Ön Isıtma, Silis Dumanı, Yüksek Dayanımlı Beton, Basınç Dayanımı, Çekme Dayanımı*

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Influence of Preheating on the Mechanical Properties of High Strength Concrete with Micro Silica Filler

ABSTRACT

The early-age temperature of concrete containing silica fume is very important due to the tendency of the silica-fume surface to react quickly and increase strength. The curing method directly affects the permeability, strength, and durability of concrete. In this study, the effects of preheating on the compressive, splitting tensile and flexural tensile strengths of concrete with different ratios of silica fume were investigated. Three different mold type samples were used: $15 \times 15 \times 15$ cm cube samples for the compression test, 10×20 cm cylinder samples for the tensile test, and $7 \times 7 \times 28$ cm beam samples for the bending tensile strength test. As a mineral additive, silica fume was replaced by 8%, 10%, and 12% by weight of cement. Two groups were prepared for the test, group A was left in water for 4 weeks, group B was preheated for 1 day at 75°C , and then left in water for 4 weeks. The results showed that the best addition of silica fume was 10%, which increased workability and reduced the effect of early-age temperature.

Keywords- *Preheating, Silica Fume, High Compressive Concrete, Compressive Strength, Tensile Strength*

I. INTRODUCTION

In the past few decades, structural and economic pressures to speed up construction project delivery have emphasized the need to estimate the early strength gain of concrete. Such a prediction is important for cold and hot weather conditions, and large concrete elements. In large concrete elements, the temperature gradient between the interior and the exterior surfaces is large and varies with age. Therefore, it is practically important to control the temperature at early ages to reduce crack formation caused by thermal shrinkage [1]. Curing temperature affects the early-age [2-5] and late-age strength of concrete [6,7]. Schachinger et al. [8] concluded that concrete subjected to 90°C early-age temperature for 24 to 48 hours caused an increase in the compressive strength. The reason for the increase in strength was mainly due to the pozzolanic reaction of silica fume with $\text{Ca}(\text{OH})_2$. Son and Hosoda [9] examined microcracks in concrete exposed to early-age temperatures of 5°C and 40°C. The results showed that temperatures at an early-age caused higher strength concrete at early-ages, but eventually reached lower strength at late-ages. Kim et al. [10] studied concretes containing different types of cement and fly ash, cured in isothermal conditions up to 50°C, and tested at different ages. They concluded that early-age temperature increased the compressive and tensile strengths at the early-age, but decreased the late-age compressive and splitting tensile strengths. Lin et al. [11] investigated the residual compressive strength of concrete cured in water after exposure to high temperatures. The findings of the study revealed that early-age temperatures significantly affected the residual strength.

The use of wastes, such as fly ash, silica fume, marble dust, and red mud from various industrial plants is widely used in concrete and cement technology. These wastes prevent environmental pollution and contribute positively to the economy and durability of concrete. [12-17]. Adding silica fume to cement concrete increases the compressive strength and other mechanical properties of the concrete. These improvements are due to the closed packing achieved in the cement paste system, which reduces the total porosity and improves the interfacial transition zone [18]. Furthermore, the pozzolanic reaction with the calcium hydroxide crystals producing additional calcium-silicate-hydrate (C-S-H) and eliminating areas of stress concentrations and prone to failure initiation $\text{Ca}(\text{OH})_2$ crystals [11]. Based on the aforementioned advantages of adding silica fume to concrete, many studies have been conducted to evaluate the optimum ratio of silica fume in concrete. To produce a high strength concrete, silica fume was replaced by 5-20% of cement weight [19]. Tohumcu and Bingöl [20] produced a self-compacted concrete (SCC) using 5%, 10% and 15% of silica fume, and 25%, 40% and 55% of fly ash. The results showed that the highest compressive strength was observed in concrete samples containing 15% silica fume. Demir [21] replaced silica fume and fly ash in concrete by 5, 10, 15, 20 and 25%. The results showed that when 20% silica fume was added to concrete, the best compressive and tensile strength were obtained.

Successful addition of silica fume into cement composites will enhance the performance under preheating at early-ages. In this evaluation, silica fume particles were used as additives for a high strength cement concrete at different proportions. Two curing methods were applied. In the first group, the concrete was left in water for 4 weeks, while in the second group, concrete was subjected to a preheating temperature of 75°C for 1 day after that left in water for 4 weeks. The mechanical properties of the preheated cement concrete samples were thoroughly evaluated and compared to the first group. The mixing design, testing procedures, and test results are discussed in detail in the following sections.

II. MATERIALS AND METHODS

A. Materials

In this study, CEM II/A-M 42.5R ordinary Portland cement compliance with the Turkish standard TS EN 197-1 [22] and TS EN 196-1 [23] was used. These standards are compatible with European standards. The chemical and index properties cement and silica fume used are summarized in Table 1. To increase the workability of concrete a modified polycarboxylate superplasticizer was added to the mixture by 2% of the cement weight. The specific gravity of the aggregates was carried out in accordance with Turkish standard TS EN 1097-6 [24] and the results are summarized in Table 2. Figure 1 shows the granulometry of the aggregate used in this study.

Table 1. Index and chemical properties of cement

Chemical composition (%)	CEM II/A-M 42.5R	Silica fume (SF)
SiO ₂	17.60	88.8
Al ₂ O ₃	4.45	0.17
Fe ₂ O ₃	3.08	0.11
CaO	60.02	1.01
MgO	2.29	0.88
SO ₃	2.67	0.42
Loss on ignition	8.49	2.40
Na ₂ O	0.22	0.19
K ₂ O	0.63	5.08
Na ₂ O+0,658K ₂ O	0.63	-
Cl	0.01	-
Unmeasured	0.54	1.48
Free CaO	0.69	-
Total additives	19.90	-
Index properties		
Specific gravity	3.01	2.36
Specific surface (cm ² /g)	4403	302
Compressive strength (MPa)	51.03	-

Table 2. Properties of aggregate

Aggregate size (mm)	Specific Gravity
0-2	2.610
2-4	2.650
4-8	2.661
8-16	2.685

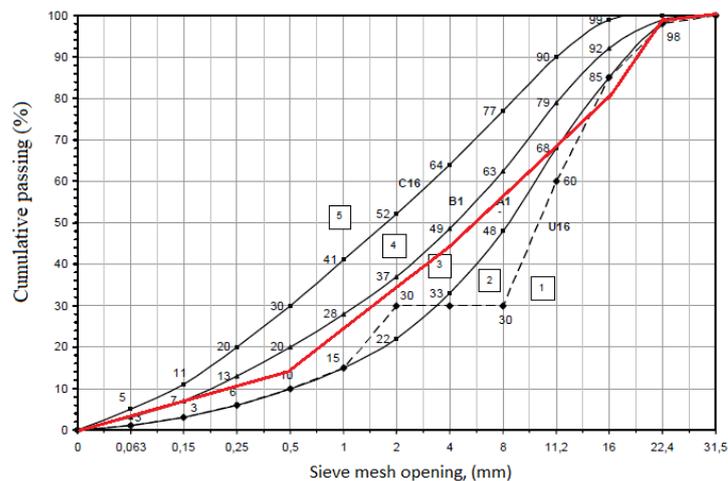


Figure 1. Aggregate granulometry

B. Concrete Mix Design

In this study, the concrete was designed according to the Turkish Standard TS EN 206 [25]. The samples were cast by replacing the cement weight with 8%, 10%, and 12% silica fume. According to preliminary experimental works to produce a high strength concrete, the water/binder ratio was 0.276 and the water reducing additives superplasticizers was 2% by weight of cement. These ratios provided proper workability with minimum consistency. Three different mixing ratio groups were cast to produce 15 × 15 × 15 cm cube samples for compressive test, 10 × 20 cm cylinder samples for splitting tensile test and 7 × 7 × 28 cm beam samples for flexural

strength test. The mix ratios are summarized in Table 3. The amount of aggregate, W/C and superplasticizer ratios were kept constant because the quantity of silica fume added was slightly different.

Table 3. Concrete mix proportions

Group	C	SF	Aggregate				W	SP's
			0-2 (mm)	2-4 (mm)	4-8 (mm)	8-16 (mm)		
	kg/m ³	kg/m ³	kg/m ³	kg/m ³	kg/m ³	kg/m ³	(%) by weight of cement	
SF (8%)	460	40	616	179	628	363	138	2
SF (10%)	450	50	616	179	627	362	138	2
SF (12%)	440	60	616	179	627	362	138	2

C. Experiments

1. Concrete Slump Test: The concrete slump test is performed to determine the workability of fresh concrete, which is an important factor to find the consistency amount of water. In this study, the fresh concrete properties were made according to TS EN 12350-2 [26]. The slump values were measured using a standard slump cone apparatus.

2. Compressive, Splitting, And Flexural Tensile Tests: Compressive strength, splitting tensile and flexural tensile strength of samples were determined using ELE brand AUTOTEST with 300 tons capacity. The loading rates were 0.4 MPa/s, 0.02 MPa, and 0.04 MPa for compressive strength, splitting tensile and flexural tensile strengths, respectively. This loading rate is within the range specified in TS 12390-3, TS EN 12390-6, and TS EN 12390-5 [27-29].

III. RESULTS AND DISCUSSION

A. Concrete Slump Test

Chemical and mineral additives directly affect the properties of fresh concrete. In this study, superplasticizer as a chemical additive and silica fume as a mineral additive was used. Base on the preliminary experimental works to produce a high strength concrete, the water/binder ratio was 0.276 and the water reducing additives superplasticizers was 2% by weight of cement. These ratios provided proper workability with minimum consistency. The results of the slump test are listed in Table 4. All slump test values are in the range of 1-4 cm and indicate S1 class according to TS EN 12350-2 [26]. The slump of all groups was approximately the same with a small increase in groups containing 10% silica fume.

B. Compressive Strength Test

The compressive strength values of concrete are shown in Figure 2 and Table 4. In cure A, it was observed that the strength was inversely proportional to the amount of silica fume. This decrease in strength with the increase in the amount of silica fume may be explained due to the decrease in the amount of cement, which means that the CH formation in the concrete was reduced and produced less C-S-H gel despite pumice pozzolanic properties. On the other hand, curing B showed an increase in compressive strength as the amount of silica fume increased. The reason is that preheating at early ages accelerated the pozzolanic reaction of silica fume with Ca(OH)₂ [30,31]. Samples containing 12% silica fume preheated at an early age showed a 13% increase in compressive strength in comparison to normal curing. This indicates that the compressive strength of concrete can be increased by preheating at an early-age [32,33].

Table 4. Test results

Group	Slump (cm)	Compressive strength (MPa)		Splitting tensile strength (MPa)		Flexural tensile strength (MPa)	
		Cure A	Cure B	Cure A	Cure B	Cure A	Cure B
8% SF	2.0	59.9	45.6	3.7	1.8	8.6	7.6
10% SF	3.0	53.7	47.5	3.9	3.1	8.2	8.9
12% SF	2.0	45.1	50.8	3.7	2.5	7.0	6.0

Cure A: Placed in water for 4 weeks.

Cure B: Placed in the oven at 75 C° for 1 day then in water for 4 weeks

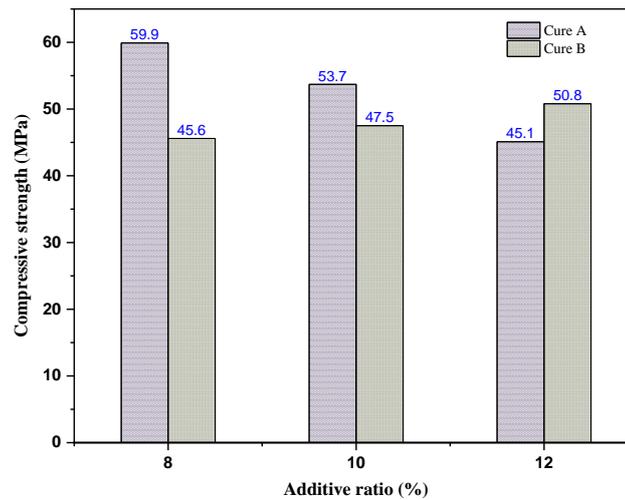


Figure 2. Compressive strength results

C. Splitting Tensile Test

According to the splitting tensile test results shown in Figure 3 and Table 4, the highest splitting tensile strength was obtained at 10% silica fume for both curing conditions. The increase in the splitting tensile in this ratio was because of the increase in the slump value. Concrete with high slump value indicates a more compact matrix with fewer amounts of voids. Adding more than 10% silica fume reduced the amount of cement that caused the reduction of CH formation in concrete and thus produced less C-S-H gels, despite having pozzolanic properties.

The results showed that the cure A samples were higher than cure B. This demonstrated that the curing condition clearly affected the strength of concrete. In comparison to the cure A samples, the cure B samples containing 8%, 10% and 12% silica fume showed a reduction in splitting tensile strength of 51.4%, 20.5%, and 32.4%, respectively. The splitting tensile strength results showed that under both curing conditions, the best proportion was 10% silica fume. These results were the same as the compressive strength results. The increase in splitting tensile at this ratio may be explained by the fact that pumice exhibits more pozzolanic activity in late curing ages and reacts with CH formed as a result of hydration of cement to form new C-S-H gels.

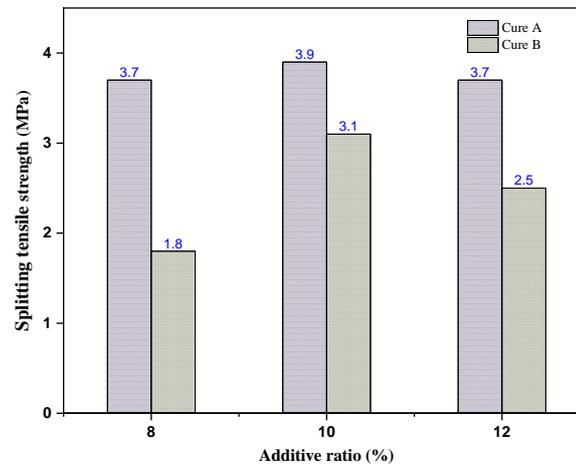


Figure 3. Splitting tensile results

D. Flexural Tensile Test

Figure 4 and Table 4 show the flexural tensile test results for both cure A and cure B. The results showed that the flexural tensile strength was inversely proportional to the additive ratios in the cure A samples. On the other hand, in cure B samples, the highest strength was seen in concrete containing 10% silica fume. The strength of 10% silica fume was maximum for both cure A and cure B. Also, at this rate cure B showed a clear increase in strength, even more than cure A. This result shows that the flexural strength of concrete containing silica fume can be increased by preheating the concrete at an early age.

The increase in the performance of concrete containing 10% silica fume was convenient with the results obtained in compressive and splitting tensile strength tests. Moreover, as mentioned before, the increase in the flexural tensile for samples containing 10% silica fume can be explained by the high slump value, which means fewer voids, and the pozzolanic activity in advanced curing ages which reacts with CH formed as a result of hydration of cement to form new C-S-H gels. Nevertheless, in the high additive ratios a decrease was observed because of the decrease in cement amount, CH formation in concrete decreased and thus pumice produced less C-S-H gel despite having pozzolanic property.

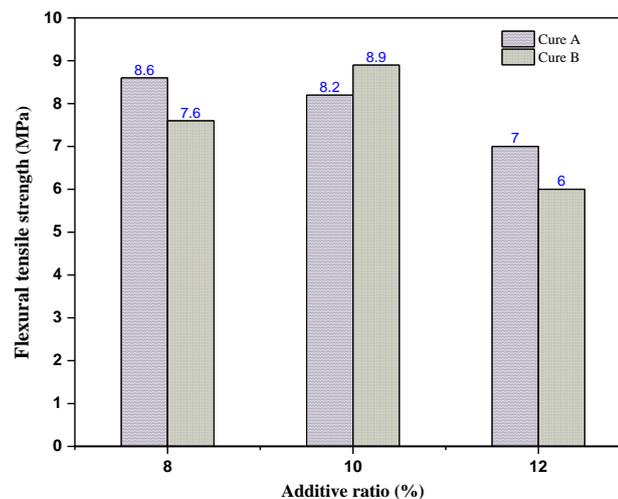


Figure 4. Flexural tensile results

IV. CONCLUSION

This present study compared the effect of the curing method for concrete containing silica fume on the basis of compressive, splitting tensile, and flexural tensile tests. Based on the results of this study, the following conclusions were reached:

- The slump of all groups was approximately the same with a little increase in groups containing 10% silica fume.
- Addition of silica fume to concrete decreased the compressive strength of concrete in curing A samples, while in samples subjected to preheating temperature (curing B) at an early age, the compressive strength increased as the amount of silica fume increased.
- Samples containing 12% silica fume, when subjected to preheating temperature (cure B) at an early age, showed much higher compressive strength values than water cured (cure A).
- The highest tensile and flexural strength was obtained at 10% silica fume for both curing conditions.

Further recommended studies include:

- The durability properties such as freeze-thaw, chemical attack, and abrasion of the concrete containing silica fume exposed to early-age temperature,
- Detailed microstructural and pore structure studies are recommended on the subject (e.g. SEM, XRD and TGA) in order to determine the mechanism by which silica fume acts, as a partial replacement when exposed to preheating temperatures,
- Different curing methods with different temperatures besides different pozzolanic materials,
- The effect of silica fume on concrete exposed to high temperatures at late-ages.

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