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THE EFFECT OF THERMIC POWER PLANT WASTE FLY ASH ON PROPERTIES OF PORTLAND CEMENT

TERMİK SANTRAL ATIĞI UÇUCU KÜLÜN PORTLAND ÇİMENTOSUNA ETKİSİ

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ABSTRACT

Today, increasing environmental awareness, national and international environmental policies are in parallel and getting stricter. The Concrete sector is criticized and under spotlight for consuming a billion tons of natural resources and large amounts of energy and high emissions from cement production - especially CO2. These criticisms are tried to be resolved with alternative ways. Fly ash in concrete and cement production, with the use of industrial wastes with pozzolanic properties such as blast furnace slag and silica fume, more sustainable and more durable end products can be obtained. Fly ash, which is waste of coal-based thermal power plants, is easily accessible and it is one of the most used cement substitute materials due to its suitable fineness and chemical structure. With the appropriate use of fly ash, sufficient or even superior performance can be achieved in concrete. In this thesis study, the fly ash supplied from the thermal power plant will be substituted in CEM I 42.5 R cement at the rates of 0%-10%-20%-30% and will be subjected to various analysis studies determined in accordance with Turkish standards in the cement industry quality control laboratory. In this study, the physical, chemical and mechanical effects of fly ash on Portland cement were investigated by using fly ash from the Thermal Power Plant and CEM I 42.5 R cement together.

Keywords: Cement, fly ash, portland

ÖZET

Günümüzde artan çevresel bilince paralel olarak ulusal ve uluslararası çevresel politikalar giderek katılaşmaktadır. Her yıl milyarca ton tüketilen beton da bu çerçevede mercek altındadır. Sektör gerek büyük miktarda doğal kaynak ve enerji tüketmesi gerekse çimento üretimi kaynaklı - başta CO2 olmak üzere - salınımların yüksek olması sebebi ile eleştirilmektedir. Bu eleştiriler alternatif yollar ile çözümlenmeye çalışılmaktadır. Beton ve çimento üretiminde uçucu kül, yüksek fırın cürufu, silis dumanı gibi puzolanik özellik gösteren endüstriyel atıkların kullanımı ile daha sürdürülebilir ve çevre koşullarına karşı daha dayanıklı nihai ürünler elde edilebilmektedir. Bahsi geçen atıklardan kömüre dayalı termik santrallerin yan ürünü olarak açığa çıkan uçucu küller gerek kolaylıkla ulaşılabilir olmaları, gerekse uygun inceliğe ve kimyasal yapıya sahip olmaları nedeniyle en fazla kullanılan çimento ikame malzemelerindendir. Uçucu küllerin uygun kullanımı ile betonda yeterli hatta daha üstün performans elde edilebilmektedir. Bu tez çalışmasında CEM I 42,5 R çimentosu içerisine Termik santralden tedarik edilen uçucu kül %0-%10-%20-%30 oranlarında ikame edilerek çimento Sanayi kalite kontrol laboratuvarında belirlenen çeşitli analiz çalışmalarına tabi tutulmuştur. Bu çalışmada Termik Santraline ait uçucu kül ve CEM I 42,5 R çimentosu ile birlikte kullanılarak uçucu külün portland çimentosuna fiziksel, kimyasal ve mekaniksel olarak etkisi araştırılmıştır.

Anahtar Kelimeler: Çimento, uçucu kül, portland

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INTRODUCTION

In addition to the main product, waste products arise in the production of electrical energy using ground coal as fuel or in obtaining many materials such as iron, steel and some metals produced for a specific purpose. In thermal power plants where low-calorie lignite coals are burned, as a result of the burning of powdered coal during electricity generation, micron-sized ash particles are formed, which are entrained by flue gases and prevented from being released into the atmosphere by being trapped with the help of electro filters. These ashes, which are volatile and industrial wastes, are called fly ash (UK) (Tokyay and Erdoğdu, 1998).

The material properties of UK and other wastes indicate that some of them can be used in certain proportions in the construction industry. With the use of wastes, environmental problems are reduced, energy savings and economy are achieved, and the consumption of natural materials is also reduced. In addition, some waste products, due to their unique properties, are used for technical improvements and to obtain higher quality products. Among the wastes from different sources, the UK obtained from thermal power plants and blast furnace slag obtained in iron and steel production take the biggest place in terms of both quantity and usage possibilities (Erdoğan, 1993). Concrete is the most used building material in the world due to its low cost, high resistance to water, being able to be produced in the desired form, having high resistance to environmental factors and being made from easily accessible materials. Considering that approximately 12% of a typical concrete consists of portland cement, 8% of water and 80% of aggregate, the mineral admixture UK is generally used as a secondary binder in the production of mortar and concrete, replacing some of the cement at the rate of weight percent of portland cement. It is used as cement with additives or pre-mixed with cement. Another issue to consider is that the production of portland cement, which is the main binder of concrete, requires a high amount of raw materials and energy. In cement-based systems (such as plaster, mortar, concrete), the use of industrial wastes with pozzolanic properties such as fly ash, blast furnace slag, silica fume can minimize CO2 emissions and reduce the need for natural resources and energy. Thus, cement-based systems can be produced more sustainably. Fly ash, which is released as a by-product of coal-based thermal power plants, is one of the most used cement substitute materials because of its easy accessibility, its ability to be used as a cement replacement material without the need for grinding, and its suitability for its chemical structures. Fly ash, which is a pozzolanic material, can find the required calcium hydroxide from the product released as a result of the hydration of the portland cement in the concrete in order to gain binding properties and can cause the formation of new calcium-silicate hydrate gels. Pozzolan; they are materials that contain siliceous and aluminous compounds, which are not binding on their own but gain binding property when combined with water and lime. Fly ash is an artificial pozzolan. With the appropriate use of fly ash, adequate or even superior technical performance can be achieved in concrete. For example, concretes containing fly ash generally have higher workability and lower hydration heats. Although the compressive strength of these concretes at early ages is lower than those that do not contain fly ash, their strength at later ages can reach almost the same and sometimes even higher levels. It is known that this type of concrete is more resistant to deterioration due to environmental factors (Gürsel and Meral, 2012; Alataş, 1996; Erdoğan and Parla, 1993).

The use of fly ash in the concrete and cement industry provides many economic, ecological and technical benefits by minimizing the environmental damage and storage costs of this product, which would otherwise be considered a waste. For this reason, researches on the role of pozzolans in the evaluation of waste, energy saving and economical improvement in concrete, improvement of concrete properties, and use in the production of high strength concrete are still continuing.

In this thesis, the effect of the use of fly ash, which is an industrial waste, as a binder material in concrete, on the properties was investigated. For this purpose, fly ash obtained from the thermal power plant was substituted into CEM I 42.5 R cement at the rates of 0%-10%-20%-30%. The physical, chemical and mechanical effect of fly ash on Portland cement was investigated by subjecting it to various analysis studies determined in the Cement Industry quality control laboratory.

EXPERIMENTAL STUDY

Material and Method

Cement and Fly Ash: In the study, CEM I 42.5 R Portland Cement (PC) produced in the cement industry was used and the fly ash supplied from the thermal power plant was substituted at the rate of 0-10-20-30%.

Sand and Water: In the study, Thrace CEN Standard sand (1350 ± 5) g prepared in accordance with TS EN 196-1 Standard was used. In the mixture, mains water from Kahramanmaraş province Narlı county was used and rested under laboratory conditions.

Prepared cements TS EN 196-6: Cement test methods Part 6 Determination of 45 µm fineness and blaine in accordance with the fineness determination standard, particle size distribution analysis by granulometry device, TS EN 196-2: Cement test methods - part 2: chemical analysis of cement chemical analyzes according to the methods specified in the standard (reactive SiO2, Insoluble residue, heating loss analyzes and oxide (XRF) analyzes) TS EN 196-3 +A1: Cement test methods - part 3: automatic vicat device in accordance with the standard for setting times and expansion determination, setting time and water/cement ratios were determined with vicat probe and needle (TSE, 2010).

TS EN 196-1: Cement test methods - Part 1: ambient temperature (20 ± 2) °C and relative humidity min. Weigh (450 ± 2) g of cement sample prepared under laboratory conditions of 50%. weigh Thrace CEN standard sand (1350 ± 5) g and (225 ± 1) g water. The weighed sample is mixed mechanically in an automatic mortar mixing device programmed in accordance with the mixing times given in the standard. After the mortar is prepared, a 3-compartment sample mold with dimensions of 40 mm × 40 mm × 160 mm is placed in the shock device and each compartment is filled with 300 g of mortar. By using a large spreader, it is ensured that the mortar is spread evenly with back and forth movements. Compressing is done by making 60 head drops per minute in the shock machine, which is automatically programmed in accordance with the standard. At the end of this period, the rest of the mortar is added on the first mortar and after it is spread evenly using a small spreader, the compaction process is completed by making 60 head drops per minute again. Immediately after the mortar is removed from the shock machine, the excess mortar is removed by holding the part of the mortar overflowing from the mold with a slight slope in the vertical and stripping direction using a metal gauge. The purpose of this process is to obtain a smoother surface. By covering the mold with a glass plate, the samples were kept at a temperature of (20.0 ± 1.0) °C and a relative minimum humidity. It is kept in the curing cabinet at 90% for 24 hours. The samples were cured in curing pools with a temperature of (20.0 ± 1.0) °C from the time of casting until they reach the 2 and 28 days strength age. After completing the 2 and 28 days curing periods, the prepared samples were subjected to the compressive strength test in an automatic pressure strength device programmed in accordance with the standard. In the study, the effect of substitution of UK to portland cement on its physical, chemical and mechanical properties was examined, and the findings of the study are given below (TSE, 2009).

Chemical Analysis

XRF and chemical analyzes of the PC (Blank-Portland Cement), UK and UK substituted at 10-20-30% ratios in the PC used in the study are given in Table 1.

Table 1. XRF and Chemical Analyzes of PC (Blank-Portland Cement)-Fly Ash and Fly Ash Substituted into PC

Materials Name	PC (Blank)	UK	PC+10 UK	PC + 20 UK	PC + 30 UK
Parameters	**%**	**%**	**%**	**%**	**%**
Insoluble Residue	0.30	73.30	7.20	14.50	22.60
Loss of Ignition	3.30	0.60	3.15	2.70	2.50
SiO_2	19.17	58.58	23.07	26.89	31.04
Al_2O_3	4.80	21.34	6.47	8.08	9.76
Fe_2O_3	2.94	8.15	3.47	4.10	4.45
CaO	64.21	3.06	57.93	52.08	45.65
MgO	0.78	1.54	0.86	0.94	1.00
SO_3	2.79	0.29	2.59	2.44	2.17
Reactive Silica %	-	42.58	-	-	-

Physical Analysis

The particle size distribution of cement affects the properties of concrete such as strength, setting time and water requirement. In this study, fineness determination, Blaine determination and Granulometry determination (particle size distribution) were performed on PC (Blank), UK and PC+UK (10-20-30%) samples in accordance with the TS-EN 196-6 Standard, in Table 2- Table 3 and Figure 1 shows the results.

Table 2. Physical Analyzes of PC (Blank-Portland Cement)-Fly Ash and Fly Ash Substituted into PC

Parameters / Materials Name	Partıcle Size Distribution 45µm	Specific Gravity cm²/g	Specific Surface g/cm3
PC (Blank)	6.3	3980	3.15
UK	16.9	3700	2.40
PC +10 UK	7.2	4060	3.09
PC + 20 UK	8.5	4230	3.05
PC + 30 UK	9.4	4430	3.01

Table 3. PSD Analyzes of PC (Blank-Portland Cement)-Fly Ash and Fly Ash Substituted into PC

CEM I 42,5 R,% FLY ASH PSD						
Number	Size (µm)	CEM I 42,5 R BLANK	CEM I 42,5 R %10 U.K	CEM I 42,5 R %20 U.K	CEM I 42,5 R %30 U.K	U.K
1	275.423	100.00	100.00	99.69	100.00	100.00
2	239.883	100.00	100.00	99.63	100.00	99.98
3	208.93	100.00	100.00	99.59	100.00	99.75
4	181.97	100.00	100.00	99.59	100.00	99.30
5	158.489	100.00	100.00	99.59	99.92	98.61
6	138.038	100.00	100.00	99.59	99.76	97.63
7	120.226	100.00	100.00	99.55	99.46	96.35
8	104.713	100.00	99.93	99.35	98.97	94.75
9	90.000	99.96	99.56	98.77	98.08	92.60
10	79.433	99.72	98.74	97.90	96.99	90.49
11	69.183	98.60	97.35	96.39	95.29	87.82
12	60.256	96.86	95.31	94.25	93.03	84.79
13	52.481	94.40	92.60	91.45	90.17	81.45
14	45.709	91.26	89.24	88.05	86.77	77.87
15	45.000	90.86	88.82	87.63	86.35	77.45
16	39.811	87.50	85.32	84.15	82.90	74.12
17	32.000	80.60	78.29	77.30	76.13	68.03
18	25.179	72.26	69.98	69.32	68.26	61.37
19	20.000	64.07	61.96	61.35	60.69	55.15
20	15.887	56.06	54.23	54.21	53.39	49.20
21	13.183	49.84	48.29	48.43	47.75	44.60
22	10.024	41.24	40.10	40.38	39.95	38.17
23	8.710	37.08	36.15	36.47	36.18	34.99
24	7.962	34.53	33.72	34.06	33.84	32.99
25	7.586	33.19	32.44	32.79	32.61	31.93
26	6.607	29.51	28.90	29.28	29.19	28.92
27	5.024	22.92	22.53	22.92	22.94	23.15
28	3.802	17.33	17.05	17.41	17.43	17.69
29	3.170	14.33	14.08	14.39	14.38	14.49
30	2.000	8.83	8.57	8.71	8.61	8.13
31	1.096	4.74	4.53	4.51	4.39	3.64

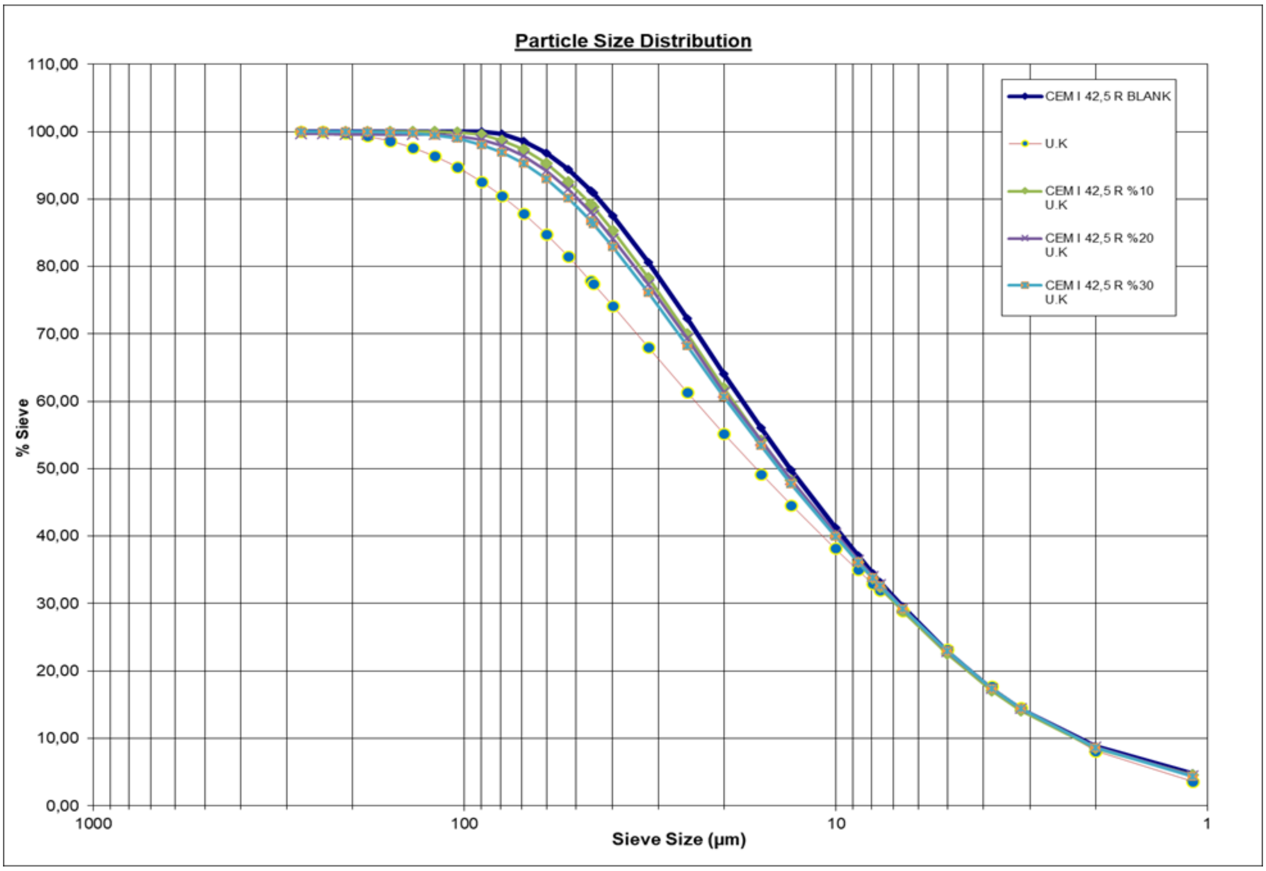

Figure 1. PC (Blank-Portland Cement) and Particle Size Distribution Graph of UK Substituted into PC

Mechanical Analysis

In the cement industry quality control laboratory, setting time, standard consistency determination, volume expansion analysis according to TS EN 196-3 Standard and compressive strength analyzes in accordance with TS EN 196-1 standard were carried out on cement samples with PC and UK substitutes (10-20-30%). Analysis results are given in Table 4 and Table 5.

Table 4. Setting Time, Water Requirement and Volume Expansion of PC (Blank-Portland Cement) and UK Substituted into PC

Viewed Property / Sample Type	Initial Setting Time (min.)	Final Setting Time (min.)	Water Requirement %	Volume Expansion mm
PC (Blank)	02:20	03:00	28.1	1
PC+ 10 UK	02:35	03:15	27.5	2
PC+ 20 UK	02:50	03:40	27.2	2
PC+ 30 UK	03:10	04:10	26.6	2

Table 5. The Effect of PC (Blank-Portland Cement) and UK Substituted in PC on the Compressive Strength

Parameters / Sample Type	Day 1 (Mpa)	Day 2 (Mpa)	Day 7 (Mpa)	Day 28 (Mpa)	1 Day %Amount of Increase	2 Day %Amount of Increase	7 Day %Amount of Increase	28 Day %Amount of Increase
PC(Blank)	19.3	30.0	40.6	50.4	-	-	-	-
PC+ 10 UK	17.0	26.5	37.1	46.4	11.9	11.7	8.6	7.9
PC+ 20 UK	14.3	22.5	32.5	41.8	25.9	25.0	20.0	17.1
PC+ 30 UK	11.3	19.0	27.7	39.4	41.5	36.7	31.8	21.8

Table 6. Compressive Strength Results of PC (Blank-Portland Cement) and UK Substituted in PC according to Molds

Sample Name	Cement No	Day	PRESSURE STRENGTH (Mpa)				
			PRESSURE RESISTANCE ACCORDING TO MOLDS (Mpa)				
			1.Prism	2.Prism	3.Prism	4.Prism	Average
PC (Blank)	263	1	19.2	19.3			19.3
		2	29.8	30.1	29.6	30.5	30.0
		7	40.8	40.3			40.6
		28	50.6	50.0	50.4	50.5	50.4
PC+ 10 UK	264	1	16.9	17.0			17.0
		2	26.4	26.4	26.4	26.7	26.5
		7	37.3	36.8			37.1
		28	46.6	46.7	46.0	46.1	46.4
PC+ 20 UK	265	1	14.4	14.2			14.3
		2	22.2	22.7	22.2	22.8	22.5
		7	32.7	32.3			32.5
		28	41.6	42.5	41.8	41.4	41.8
PC+ 30 UK	266	1	11.4	11.1			11.3
		2	19.3	18.7	19.1	18.9	19.0
		7	27.8	27.5			27.7
		28	39.5	39.1	39.3	39.8	39.4
Room Temp (°C) / RH (%)	20 °C / 56.1						
Humidity Cabinet Temperature (°C) / RH (%)	20,1 °C / 97.1						
Tank Water Temp (°C)	20 °C						

CONCLUSION AND EVALUATION

When the chemical composition of UK and PC given in Table 1 was examined in the study, it was observed that UK contained 58.58% SiO2 and PC had a CaO content of 64.21%. When the chemical composition of the UK used is evaluated according to the TS EN 197-1 standard, it meets the minimum 25% reactive silica requirement and is classified as siliceous fly ash (V). When evaluated according to ASTM C 618 standard, S+A+F total is 88.07% (min. 70%), MgO content is 1.54% (max. 5%), SO_3 content is 0.29% (max. 5%), It has been determined that the Ignition Loss of 0.60% (Max. 12%) meets the requirements and it has been observed that the UK is class F fly ash. It was observed that the chemical structure of PC changed in this direction as the ratio of UK substituted into PC increased (TSE, 2013; ASTM C618, 2012).

When the physical analysis results of UK substituted into PC in the study, given in Table 2, were examined, it was observed that the grain size of PC was smaller than UK, and the specific surface area and specific gravity values were higher than UK. It was observed that the particle size and the specific surface area of the PC increased and the specific gravity value decreased as the UK added ratio increased by substituting 10-20-30% of UK into the PC, respectively. The specific surface is an average value. Although it is expected that the fineness will decrease as the specific surface increases, sometimes they have approximately the same specific gravity and the particle distribution may be different. UK specific gravity value is lower than PC. For this reason, it was observed that the specific gravity value decreased as the UK substitution ratio increased. In this study, when PC (Blank) was compared with PC+ 30% UK, the grain size value increased with 30% UK substitution, but also an increase in specific surface value was observed. Due to the low specific gravity of UK at 3.01 g/cm3, it was observed that the specific gravity value decreased with the addition of 30% UK.

In the study, the samples were prepared homogeneously with the Malvern Mastersizer 2000 model granulometry determination (particle size distribution) device and the size distribution of the particles in the range of 275-1 µm was measured according to the laser diffraction method. According to the results given in Table 3, especially these ranges were examined since they have a greater effect on the strength in the 3.17-32 µm range in the cement particle size distribution. According to these results, a comparison of the values of 3.17 µm and 32 µm with the specific surface and 45 µm grain size values was made. Theoretically, as the specific surface (Blaine) increases, a decrease in the value of 3.17 µm is expected, and in case of an increase in the grain size of 45 µm, a decrease in the value of 32 µm is expected. When the results given in Table 3 are examined, it has been observed that the 45 µm grain size value and 32 µm values confirm each other. When the particle size distribution graph (Figure 1) was examined, a homogeneous distribution was observed compared to the PC (Blank). In order to evaluate the cement quality and grinding performance in the cement industry quality control, the interpretation of the values obtained with the particle size distribution device, as well as the specific surface and particle size distribution methods, by comparing the results obtained with the existing methods, is of great importance in quality control studies.

Although there are factors such as temperature, grain size, amount of water and additives affecting the setting time of cement, it is said that the use of fly ash increases the setting time. The main reason for this is that fly ash does not have binding properties on its own, and it also reacts with calcium hydroxide released as a result of the hydration of the cement in order to gain binding properties. It was observed that the setting start and end times increased as the setting increased. In the PC (Blank) study, it has been determined that the setting start time is 140 minutes and the set end time is 180 minutes. Compared to this, with 10% UK substitution, the initial setting time of cement increased to 155 minutes and the set end time to 195 minutes. When the substitution rate is 20%, the setting start time for cement increased from 170 minutes to 220 minutes. When the substitution rate was 30% UK, it was observed that the set start time in cement increased from 190 minutes to 250 minutes. When the values obtained are evaluated according to the TS EN 197-1 standard, they are within the accepted limits. When the effect of UK on volume expansion and water requirement is examined, it has been observed that it increases the volume expansion compared to PÇ, and it is seen that it meets the maximum 10 mm requirement for all cement types in the TS EN 197-1 standard. It was observed that the water requirement decreased as the UK replacement rate increased. Due to the poor water absorption of the UK, the decrease in the water requirement as the UK substitution rate increases has met the expectation.

When the results of the compressive strength determination made are examined in Table 5, it has been determined that the compressive strength of PC 2 days is 30 MPa and the 28-day strength is 50.4 MPa. early strength min. 20 MPa, 28-day standard strength min. 42.5 MPa. It should be in the range of 62.5 MPa. It has been observed that the results obtained comply with the TS EN 197-1 Standard. (TSE, 2012) In this direction, the effect of UK on the strength was examined by substituting 10-20-30% of UK into the PC. According to the results of the study, it was observed that there was a loss of strength at the rate of 11.7% in the 2-day early strength compared to the Blank study when 10% UK was added, and this loss occurred at the rate of 8.6% and 7.9% at the 7 and 28 days. When the UK was replaced by 20%, a 25% loss of strength occurred in 2 days compared to the Blank study, while a 20%-17% loss of strength occurred at 7 and 28 days, respectively. When the UK was replaced by 30%, 36.7% strength loss was observed in 2 days compared to the Blank study, and 31.8%-21.8% strength loss was observed at 7 and 28 days, respectively. According to these results, it was observed that as the UK ratio increased, the early strengths decreased compared to the final strengths. This can be explained by the fact that the hydration reaction is slower than the PC.

When the results obtained are evaluated in general, requirements are given according to different strength classes (32.5, 42.5 and 52.5 MPa) and additive ratios within the scope of TS EN 197-1 Standard. It has been observed that when 10% UK is substituted in accordance with this standard, the 2-day early strength is 26.5 MPa and the 28-day strength is 46.4 MPa, and cement in the 42.5 strength class can be produced. When the strength results of cement samples with 20% and 30% replacement ratios are evaluated, it is seen that they can be produced in accordance with the lowest 32.5 MPa strength class.

As a result, the use of waste materials in cement is also beneficial to reduce environmental damage. While it is useful for the environment with reduced greenhouse gas emissions, especially with the reduction of clinical use, the reduction of the production and use of the linkages produced with high energy costs in the cement industry will also benefit from reducing water consumption for a more sustainable world.

Expanding the study of cement produced with fly ash, especially in order to observe its performance at later strength ages, analysis with SEM and X-Ray Diffractometer (XRD) method will be beneficial in terms of monitoring the effects on concrete in the long term.

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