Hindawi Publishing Corporation
Advances in Materials Science and Engineering
Volume 2014, Article ID 417514, 6 pages
http://dx.doi.org/10.1155/2014/417514

Research Article

An Experimental Study on Strength and Durability for Utilization of Fly Ash in Concrete Mix

Abdulhalim Karaşin[1] and Murat Doğruyol[2]

[1] *Department of Civil Engineering, Dicle University, Diyarbakır, Turkey*
[2] *Department of Civil Engineering, Siirt University, Siirt, Turkey*

Correspondence should be addressed to Abdulhalim Karaşin; karasin@dicle.edu.tr

Received 22 May 2014; Accepted 10 September 2014; Published 11 November 2014

Academic Editor: Amit Bandyopadhyay

The intention of this study is to discuss the variation of concrete exposed to high sulfate environment of a specific region with respect to strength and durability. Secondly, it is aimed to discuss the possibility of reducing the cement amount in construction of concrete structures. For this purpose, laboratory tests were conducted to investigate compressive strength and sulfate resisting capacity of concrete by using 20% fly ash as mineral additives, waste materials, instead of cement. As a case study the soil samples, received from Siirt Province areas which contain high sulfate rate, have been compared with respect to sulfate standard parameters of TS 12457-4. In such regions contact of underground water seep into hardened concrete substructures poses a risk of concrete deterioration. In order to determine the variation of strength and durability for concrete exposed to such aggressive environment, the samples were rested in a solution of Na_2SO_4 (150 g/lt) in accordance with ASTM C 1012 for the tests. As a result of this experimental study, it is noted that the use of 20% fly ash, replacement material instead of cement, has no significant effect on compressive strength of concrete over time.

1. Introduction

Requirement of energy and raw materials increases gradually in today's developing and growing world. As construction sector grows, these necessities increase as well. When these necessities are met, scale of environmental damage should be less as possible. For this reason, in construction technology mostly two issues have always been research subjects: one is the need of cement as raw material for concrete, which is the most important construction element in the sector, and the other is to improve design criterions for deterioration resistance and lifespan of concrete. Sulfate content causes volume expansion and leads to formation of internal cracks decreasing strength and durability of concrete.

Concrete as the most important material of reinforced concrete structures is being designed to consider strength, durability, workability, and economy concepts. The usage of cement, as the basic material with respect to strength and cost of concrete increases rapidly in developing countries for construction of reinforced concrete structures. For cement producer, minimal cost is desired by using new and economical material source which satisfies necessary quality conditions. For these reasons pozzolanics, well known as chemically active silica and alumina bearing materials, can be used as additive of cement production or admixture for concrete. On the other hand fly ashes, as one of the artificial type of pozzolans obtained from the burning of pulverized coal in power plants, serve also durable function of concrete.

Concrete deteriorates over time because of environmental conditions and loses its strength and durability. The sulfate effect being one of the most aggressive environmental deteriorations decreases durability of concrete structures such as building foundations, piers, infrastructures, bridges etc. sulfate ions in the soil, ground water, sea water, rain water and waste water can be found as solution with other ions [1]. The deterioration mechanism starts with the formation of gypsum and ettringite due to the reaction of sulfate ions with calcium hydroxide and calcium aluminate. The formation of ettringite in hardened concrete causes large volumetric expansions which generate accompanying internal stress leading to cracks. The sulfate attack chemical interaction is a complicated process and depends on many parameters including concentration of sulfate ions, ambient temperature, cement type and composition, water to cement ratio, porosity and permeability of concrete, and presence of supplementary cementitious materials. Moreover the mass transport of sulfate into saturated concrete has a complex mechanism combining diffusion of the sulfate and convection of the solution due to the cracking of the concrete. Furthermore, the sulfate reacts with the hydrated cement phases [2].

The incorporation of supplementary cementitious materials such as blast-furnace slag, fly ash, and silica fume as a partial replacement of ordinary cement has been found to be a beneficial technique of enhancing the resistance of concrete to sulfate attack. Durability which is known as the service life of concrete is the property of being able to not lose its shape and quality for a long time. This concept has emerged as a result of technical and economical design of concrete [3]. Building materials, as well as everything, are not perfect. In addition, natural conditions, errors, and omissions affect the service life of concrete and also increase maintenance and repair costs of concrete. Even developed countries reserve 40% of the investments of construction to maintenance and repair [4].

Cement, one of the basic materials of construction engineering, has an important place in view of strength and cost of structure. For cement producer, minimal cost is desired by using new and economical material source. Further in order to decrease the lowest possible cost of a typical concrete mixture using locally available ingredients, the optimum coarse aggregate amount and cement content based on the laboratory trials were determined satisfying the necessary requirements [5]. On the other hand, the controllers and contractors need cheaper, safer, and higher strength materials. It is well known that pozzolanics are chemically active silica and alumina bearing materials [6]. Evaluation of the fly ash as a pozzolan in Turkey and in the world, protecting ecological balance, and preventing environmental pollution seem possible by using the natural raw material. Besides, it improves economy thanks to saving energy, producing cheaper and higher-class materials, and recycling waste materials [7]. On the other hand it is estimated that greenhouse gas emission due to ordinary Portland cement production contributes about 7% of the emission of Earth's atmosphere. Also it has been recognized that the service life of many concrete structures built in corrosive environment unexpectedly expire due to deterioration effects [8]. Therefore, to decrease such problems it is necessary to produce environmentally friendly concrete. The usage of industrial by-product materials may lower the rate of Portland cement consumption.

Cement consumption is increasing parallel to development of building construction sector. The majority of the energy in Turkey and the world is consumed by the industry. Industry damages environment a lot during the production process. Important part of industrial production in Turkey is based on the cement sector. In Turkey energy consumption is heavily depending on primary energies which can be described as an energy form found in nature that has not been subjected to any conversion or transformation process, such as oil, lignite, hard coal, and natural gas. The amount of foreign dependency of this is about 75%, and also electric energy consumption is 60%. In the year of 2008, energy importing expenses have reached over 48.2 billion US dollars [8]. Current energy policies address environmental issues including environmentally friendly technologies to increase energy supplies and encourage cleaner, more efficient energy use, and address air pollution, greenhouse effect, global warming, and climate change [6]. Approximately 2% of the energy produced in the world and approximately 20% industrial consumption in Turkey are demanded by the cement industry alone [9]. World cement production growth continued in 2010, as in previous years, has accessed to 3.3 billion tones production by increasing by 9.2% compared to the previous year. China, India, the European Union member states, the United States, and Turkey are among major producers in cement industry in the world. Turkey is the largest in Europe and the fifth cement producer after the United States in the world. Cement production values in Turkey are given in Table 1 [10].

Table 1: Cement production values, 2010.

Countries	Million tons
China	1868
Indian	210
EU	190.4
USA	65,5
Turkey	62,7
Brazil	58,9
Japan	51,7
Russian	50,4

Cement production of the world reached 3.3 billion tones in 2010. Including 1000 modern cement factories in China as a total 2360 integrated cement factories exist in the world. 140 new cement factories were commissioned in the last 2 years. There are 750 independent grinding plants including 35 in China [11]. Well-known gasses, CO_2, NO_2, and SO_3, causing global warming are being spreaded during the production of cement from chimney of the factories. One of the methods to reduce the consumption of cement in concrete is to use additions. There are a lot of studies interested in replacing a large part of cement with beneficial ash in concrete because of the economy that can be achieved. Additions mostly are waste materials like fly ash, blast furnace stag, and silica fume called pozzolana. They are side products of thermal plants and iron and steel plants and show similarity with cement. Using them in cement as waste and recycled material improves environmental awareness.

A number of research has been carried out to improve the quality of fly and bottom ash in recent years, a remarkable progress in large utilization of coal combustion residues in cement industry [12]. Components of the gases released from the cement factories illustrated in Table 2 [13].

Despite the hazardous gases cement plants exhale, producing cement in Turkey is dramatically increasing. Consequence of such energy consumption and hazardous gases the

Table 2: Components of the gases released from the cement factories.

Name of the component	Rate percent in the total gas emission (%)
Nitrogen oxide	45–66
Carbon monoxide	11–29
Water (vapor)	10–39
Oxygen	3–10

argument arises as one of the aims of this study to improve practices for reducing energy consumption and preventing harmful effects to environment of cement sector. On the other hand, Turkey is rich in natural pozzolans. The use of such material in the production of the cement will reduce the total cost due to ease of grindability and low cost of transportation. Also, many dams have been constructed in eastern part of Turkey and the heat of hydration and sulfate resistance are one of the major problems in mass concrete. The use of such additives in the production of cement may lead to reduction in the heat of hydration and high sulfate resistance [14]. Moreover, this study is aimed to discuss the usage of such additions, which have importance in ecologic balance, for providing both durable (high resistance of sulfate attacks) and economic concrete structures. Also, the negative effects of high rate sulfated grounds on service life and strength of concrete are emphasized.

2. Materials and Methods

2.1. Sulfate Effect. Sulfate effect reacts to aluminous components and calcic components in hardened concrete and forms ettringite (hydrous calcium aluminum sulfate mineral) and gypsum which cause the increase in volume in the concrete. Reaction products affect adherence of aggregate-cement paste negatively which cause cracks and increase permeability of concrete. On higher reactions, disintegration of concrete totally can be possible [15]. Impermeability of concrete is as important as the control of chemical composition of cement in chemical reactions caused by exterior ion entrance like sulfate attack [16, 17]. The deterioration on the surface of concrete occurred by reason of the decomposition of sulfate ions penetrating into capillary voids on the surface of concrete.

In order to decrease sulfate effect, permeability coefficient of surface of concrete should be low enough to resist. Monteiro and Kurtis [18] stated that there is a critical region which holds the concrete harmless from sulfate effect and if amount of C3A is lower than 8% and water to cement proportion is lower than 0.45, there is no harm in a 40-year exposure. Besides, using fly ash in the rate of 25% and 45% instead of cement decreases expansion. One of the reasons deteriorations constitute the concrete and reinforced concrete structures in the time is the effect of sulfate. Concrete that is exposed to sulfate ions at high density may be harmfully destroyed. Naturally occurring sulfates in soils and groundwater, after a series of chemical processes, may lead to durability problems causing expansion and disintegration of the hardened concrete. As a case study of site investigation

Figure 1: The deterioration of concrete examples from the locations.

Table 3: Comparison of sulfate parameters.

Analysed points	Parameters sulfate (mg/L)	Sulfate TS 12457-4 standards (mg/L) (max. 15 mg/L)
Tillo-1	10,1	Appropriate
Yeni Mah.	9,8	Appropriate
9051 Çakmak Mah.	10,5	Appropriate
8653 Çakmak Mah.	13,8	Critique
Şeyh Zeynep	12,3	Appropriate
9313/1 Çakmak Mah.	**15,1**	**Inappropriate**
STP 3	10,4	Appropriate
STP 15	10,2	Appropriate
STP 30	**15,4**	**Inappropriate**
SBH 2	13,8	Critique

for sulfate content in soil of a specified region [19], the soil samples were tested in Dicle University, Faculty of Science and Art laboratories. The test results discussed with respect to Turkish code requirement TS12457-4 [20] is shown in Table 3. In the table it is stated that some locations nearby Siirt province (in eastern part of Turkey) are appropriate according to the code. The deteriorations of concrete examples from the locations are shown in Figure 1. Therefore for construction process of possible reinforced concrete structures in inappropriate or critical zones it is necessary to take elaboration about deterioration.

In such cases demands of some applications grow to serve concrete against sulfate attacks. Because of contact area of the soil to concrete, using concrete with high density and compression strength with sulfate resisting cement (limited C3A etc.) or improving the site soil are examples of preservation techniques. But such solutions in most cases are difficult in practice or too costly. But such solutions in most cases are difficult in practice or too costly. On the other hand the waste materials such as fly ash and blast furnace called pozzolanic additions used as replacement of fine aggregates and cement

Table 4: The chemical components ratios.

Name of component	Fly ash %	CEM I 42,5 %
SiO_2	54,28	20,0
Al_2O_3	23,58	5,82
Fe_2O_3	8,80	3,62
CaO	5,00	61,61
MgO	1,31	1,42
SO_3	0,53	2,80
K_2O	2,00	0,92
TiO_2	1,48	—
MnO	0,07	—
Ba	0,17	—
$SiO_2 + Al_2O_3 + Fe_2O_3$ (S + A + F)	86,66	
Loss on ignition	1,72	2,8
Blaine (cm^2/gr)	2660	3524

fractionally in concrete mix can resist such soil with high sulfate contents.

2.2. Laboratory Studies. In this part effect of fly ashes (FA) and blast furnace slag (BFS) on properties of super plasticizer (SP) added concrete was investigated experimentally against sulfate effect. FA and BFS were added to Portland cement (C42.5) 20% by weight of the cement. The cement properties are summarized in Table 4. FA and BFS replacement concretes were compared with each other as well as with Portland cement concrete. Firstly 15 cm cube specimens were prepared with produced concrete mix and cured at 7, 28, 90, and 150 days. For this purpose, high density sulfate of soils was examined by comparing the ratio of TS 12457-4 Standards. In the laboratory, fly ash was added to the mix as replacement of 20% by weight of the Portland cement. The 0.56 water/cement ratio and 300 kg/m^3 cement dozage are selected for the reference mix. A control concrete sample is also produced having the same dozage. The performance of mineral additives concrete was obtained in both the sulfate and water cures. In this context, three series of concrete samples were produced; in two concrete samples a series with constant ratio of fly ash was used as additives, and one series of sample was used without additives. In order to see the effect of strength and durability of concrete at high-rate sulfate, concrete samples were rested in a solution of Na_2SO_4 (150 g/L) in accordance with ASTM C 1012. To examine the destructive effect of sulfate on concrete one group of specimens was kept continuously in sodium sulfate solution with concentration of 150 g/L (in 15% sulfate solution) for 5 months. During this period the other group samples were rested in water. At the end of each curing period, a total of 3 specimens were tested for each concrete property. Surface hardness and compressive strength of concrete samples exposed to sulfate effect were measured regularly. At the same time, the surface distortions and changes of weight of the samples were observed periodically [21]. The mixing processes of fresh concrete and the curing process of concrete specimens are shown in Figure 2.

Figure 2: The mixing of fresh concrete and curing processes.

Table 5: Mix ratio of 1 m^3 concrete and slump values.

1 m^3	Plain concrete sample (S3)	Fly ash added sample (S4)
Water	170 kg	170 kg
Portland cement	**300 kg**	**240 kg**
Fly ash (20%)	—	**60 kg**
Coarse aggregate 15–30	348 kg	348 kg
Coarse aggregate 7–15	544 kg	544 kg
Fine aggregate 0–5	1013 kg	1013 kg
Admixture	1,8 kg	1,8 kg
Slump (cm)	**18**	**13**

In this study, the ordinary Portland cement obtained from Limak Ergani Cement Plant and fly ash of Kahramanmaraş Afşin Elbistan Thermal Reactor were used for the mix designs. The chemical analysis was made by laboratories of Limak Ergani Cement Plant [22]. The chemical component of the fly ash and cement is shown in Table 4.

The effect of particle size distribution is one of the dominant parameters on the compressive strength and sulfate resistance of blended cement mortars incorporating Portland cement and natural pozzolan [14]. As it is seen in chemical analysis, cement and fly ash show similarity in case of fineness. Blaine value as a specific surface weight of fly ash as a mineral additive material is close to that of the Portland cement value. In the table the content of $SiO_2 + Al_2O_3 + Fe_2O_3$ satisfies class F fly ash requirements of both Turkish Standards for fly ashes (TS 639) and ASTM C 618 specifications. Mix design for 1 m^3 fresh concrete for reference sample S3 category and %20 fly ash used as replacement of cement S4 category are shown in Table 5.

3. Results and Discussions

According to classification in TS EN 206-1 and TS 12390-3 [23, 24], the samples derived from fly ash mix belonging to S3 category and the sample including no addition belonging to S4 category were investigated with laboratory tests. The slump values of the fresh concrete results were shown in Table 5.

Figure 3: Generation of cavities on surfaces of the plain concrete specimen due to sulfate reactions.

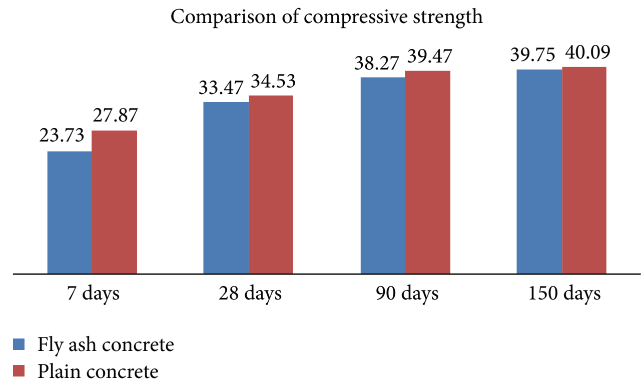

Figure 4: The comparison of compressive strength of specimens cured in sodium sulfate solution with respect to time (Mpa).

Table 6: Compressive strength values of 28-day-old cubic samples (Mpa).

	In hydropathy (Mpa)	In 15% sodium sulfate (Mpa)	Change %
Fly ash concrete	33,73	33,47	−0,86
Plain concrete	36,04	34,53	−4.37
Change %	−6,7	−3,2	

From the table it is obvious that the fly ash concrete has low permeability. On the other hand the low slump value of FAC may not mean low workability. Since the ball-bearing effect of fly ash creates lubricating action that increases workability without slump losses.

To examine the destructive effect of sulfate on concrete, a group of samples was prepared and was kept in 15% sulfate solution and its 28-day-old compressive strength was compared to samples kept waiting in a hydropath. Sulfate content causes volume expansion, as illustrated in Figure 3, leading to the formation of surface voids and internal cracks which decrease strength and durability of plain concrete.

For compressive strength values, a pressing machine of ELLE trademark was used with a pressure ratio of 4.5 kN/mm^2/sn. Before the compression test, the samples were taken out from curing pool 48 hours earlier. The monotonic axial compression of the 28-day-old specimens (appropriate to TS 3114 and ISO 4012) values of the samples exposed to hydropath and sulfate cure was shown in Table 6.

The test results of the table indicate that strength of both sample types decreases in sulfate cure. However the reference sample loses about 5% its strength as the other loses less than 1%. Then the initial strength difference decrease from 2.28 kN (6.7%) to 1.06 kN (3.2%) means the that fly ash causes slight difference.

Compressive strength of the reference mix and the mix containing fly ash of 7-day-, 28-day-, 90-day-, and 150-day-old specimens were determined and shown in Figure 4. The compressive strength values of each group in both Table 6 and Figure 4 are the average values of 3 specimens.

The results of Figure 4 show that the strength of FA concrete is about 18 percent less than that of concrete at early stage. The difference means that longer mold time is necessary for concrete with fly ash. As indicated in the figure, the difference tends to decrease at later stages as discussed elsewhere [25]. Namely, it decreased to less than 1 percent at 5 months later. Using fly ash as replacement of ordinary Portland cement causes a considerable reduction in early strength. In case of sulfate attacks, FA concrete specimens gain more strength than plain concrete specimens over time. Consequently, a slight difference in strength is noted at the final stage.

It is possible to conclude that the mineral additives can fill concrete cavities better because of their fine graininess. They can also increase resistance of concrete against negative influences caused by sulfate by creating a less permeability on the surface of concrete with a slight compression strength loss (about 1%) after 5 months. Using fly ash instead of cement in concrete mix design also returns profit economically. However, using fly ash instead of cement in the concrete mix also provides significant economic benefits.

4. Conclusions

A large amount of greenhouse gases is diffused around during the production of cement. Cement industry constitutes 20 percent of Turkey's energy consumption and 2 percent worldwide. In this sense, it is certain that usage of mineral additives, which is a leading alternative to reduce usage of cement, will reduce environmental damage. As a result, it is found that using certain amount of mineral additives instead of cement will provide enduring and economic concretes. While environmental and health factors are taken into consideration, using such waste materials as mineral additives has great importance in production of concrete.

The sulfate content is determined to decrease upon the strength and durability of concrete structures. In this study the variation of strength and durability for concrete exposed to aggressive environment, sulfate attacks have been examined. It has been noted that, in case of sulfate attacks, at early stages fly ash concrete as composite materials shows weak strength properties with respect to those of plain concrete. However, it was observed that over time the FA concrete gains strength more rapidly. Namely, the strength difference reduced to a ratio of about 1% at the end of 5-month period.

Since fly ash ties up free lime which leads to less bleed voids, it leads a considerable reduction of permeability to water and sulfate as aggressive chemical. Moreover, in case of sulfate attacks the experimental results show that uses of %20 FA (fly ash) as replacement of Portland cement cause a slight difference in strength properties of concrete samples. Economic benefit can be achieved by using fly ash as a pozzolanic addition in the concrete mixture. As a conclusion, use of such additions, waste materials, provides both durable and economic concrete structures and ecologic balance.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

References

[1] N. M. Al-Akhras, "Durability of metakaolin concrete to sulfate attack," *Cement and Concrete Research*, vol. 36, no. 9, pp. 1727–1734, 2006.

[2] P. J. Tumidajski, G. W. Chan, and K. E. Philipose, "An effective diffusivity for sulfate transport into concrete," *Cement and Concrete Research*, vol. 25, no. 6, pp. 1159–1163, 1995.

[3] M. S. Akman, "Importance and property of concrete durability," in *Proceedings of the 1st National Concrete Congress*, İstanbul, Turkey, May 1989.

[4] P. K. Mehta, *Concrete-Structure, Properties, and Materials*, Prentice Hall, Englewood Cliffs, NJ, USA, 1986.

[5] S. Ahmad, "Optimum concrete mixture design using locally available ingredients," *The Arabian Journal for Science and Engineering*, vol. 32, no. 1, pp. 27–33, 2007.

[6] A. Aslan and A. Demirbas, "Utilization of volcanic slag in cement industry from Manisa in Turkey," *Energy Education Science and Technology Part A: Energy Science and Research*, vol. 30, no. 1, pp. 715–718, 2012.

[7] H. Y. Aruntaş, "Usage potential of fly ash in construction," *Journal of Gazi University Engineering Faculty*, vol. 21, no. 1, pp. 193–203, 2006.

[8] The Energy Outlook of Turkey, "UCTEA, Union of Turkish chambers of mechanical engineers and architects report 2010," Tech. Rep. MMO/2010/528, 2010.

[9] The Republic of Turkey Ministry of Science Industry and Technology, "Soil products industry," Cement Industry Report 2012/2, 2012.

[10] Cembureu, Activity Report 2010.

[11] Republic of Turkey Ministry of Economy, *Cement Sector*, Republic of Turkey Ministry of Economy, 2012.

[12] A. Demirbaş and A. Aslan, "Evaluation of lignite combustion residues as cement additives," *Cement and Concrete Research*, vol. 29, no. 7, pp. 983–987, 1999.

[13] J. Wulf-Schnabe and J. Lohse, "Economic evaluation of dust abatement techniques in the European Cement Industry, a report produced for the European Commission," DG XI Contract B4-3040/98/000725/MAR/E1, 1999.

[14] H. Binici, O. Aksogan, I. H. Cagatay, M. Tokyay, and E. Emsen, "The effect of particle size distribution on the properties of blended cements incorporating GGBFS and natural pozzolan (NP)," *Powder Technology*, vol. 177, no. 3, pp. 140–147, 2007.

[15] H. Yazıcı, "Investigation on sulfate resistance of blast furnace slag mortars," *Journal of Dokuz Eylül University Science and Engineering*, vol. 8, pp. 51–58, 2006.

[16] ASTM C 1012, "Standard Test Method for Length Change of Hydroulic-Cement Mortars Exposed to a Sulfate Solution," 1995.

[17] B. Baradan, H. Yazici, and H. Ün, "Durabilit of reinforced concrete," *Journal of Dokuz Eylul University Engineering Faculty*, pp. 89–185, 2002.

[18] P. J. M. Monteiro and K. E. Kurtis, "Time to failure for concrete exposed to severe sulfate attack," *Cement and Concrete Research*, vol. 33, no. 7, pp. 987–993, 2003.

[19] Republic of Turkey of 9thRegional Directorate of Highways Diyarbakir 2007.

[20] TS EN 12457-4, Characterisation of waste-Leaching-Compliance test for leaching of granular waste materials and sludges—Part 4, 2004.

[21] A. Karaşin and M. Doğruyol, "Use of pozzolanic additions for concrete to resist sulfate effects," *Journal of New World Sciences Academy Engineering Sciences*, vol. 1A0157, no. 6, pp. 348–357, 2011.

[22] Limak Ergani Cement Plant, Diyarbakir, Turkey 2011.

[23] TS EN 206-1, *Concrete Part 1: Specification, Performance, Production and Conformity*, Turkish Standards Institution-TSE, Ankara, Turkey, 2002.

[24] "Testing hardened concrete—part 3: compressive strength of test specimens," TS 12390-3, Turkish Standards Institution, Ankara, Turkey, 2003.

[25] H.-S. Shang and T.-H. Yi, "Behavior of HPC with fly ash after elevated temperature," *Advances in Materials Science and Engineering*, vol. 2013, Article ID 478421, 7 pages, 2013.