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Full Length Research Paper

The effect of cure conditions and temperature changes on the compressive strength of normal and fly ash-added concretes

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The aim of this study was to examine compressive strength of fly ash-added concrete and normal concrete cured in water and air and to compare their compressive strength on the 7th, 14th, 21st and 28th days. In addition, the study investigated temperature-induced changes in the compressive strength of concrete samples which completed 28 day cure period. While the compressive strength of concretes cured in air was observed to be higher in early days, it was detected to be higher in concretes cured in water in later days. It was also determined that the compressive strength of fly ash-added concrete was lower than that of normal concrete. In addition, no significant change was observed in the strength of both concrete types at the temperatures up to 400°C, but significant changes were noted over 600°C and the compressive strength of both concrete types decreased by 80% at 800°C

Key words: Fly ash, concrete, cure conditions, compressive strength, elevated temperature.

INTRODUCTION

Energy demand of Turkey, which has increased in parallel with the economic development, has necessitated building of thermal, hydroelectric and natural gas power plants. Thermal power plants, where low-calorie lignite coal is burnt to generate electricity, produce dust particles of micron size (as a result of burning of coal in the form of dust), which are swept together with waste gases and are prevented by electro filters from releasing into atmosphere. Any such flying ash, an industrial waste, is named fly ash (FA) (Tokyay and Erdoğdu, 1998).

Generally, properties of FA change depending on coal properties and coal firing method. In general, FA has pozzolanic property due to its silica and alumina composition and increases workability in fresh concrete thanks to its thin and spherical granular structure. By reacting with the lime formed as a result of cement hydration, FA creates an additional binding gel. FA's produced via firing of lignite coal generally have high lime content and such type of ashes also serves as hydraulic binders (Türker et al., 2007). Some other important effects of FA on concrete are reducing bleeding of fresh concrete, lowering hydration heat of concrete, thus, enabling casting of mass concrete in hot weathers, contributing in long-term compressive strength thanks to pozzolanic reaction, reducing permeability of concrete, and increasing compressive strength against internal and external abrasive effects. Such positive properties have enabled wide use of FA in concrete production and conduct of high number of studies on this issue (Aruntaş, 1996; Malhotra, 1986). However, FA may reduce early-age strength of concrete and, the use of huge amount of FA, particularly the one with high lime content (C Class), in concrete may have negative effects on the stability of concrete volume (Yazıcı et al., 2006; Ramezanianpour and Malhotra, 1995).

Concrete production is one of the sub-sectors of construction, where FA is most frequently used together with cement. FA is used in production of both normal and light-weight concrete as well as reinforced-concrete (the use area of which has gradually enhanced) as either additive or substitute (Aruntaş, 2006). When used at the lowest water/binder rate, FA produces good results in

Table 1. Physical, chemical and mechanical properties of cements and fly ash.

Chemical composition (%)			Physical properties of cement	
	Cement	**FA**	Specific weight	3.15
SiO_2	19.3	42.14	Initial set (min)	119
Al_2O_3	5.57	19.38	Final set (min)	210
Fe_2O_3	3.46	4.64	Volume expansion (mm)	1.00
CaO	63.56	26.96		
			Specific surface of cement and FA (Blaine)	
MgO	0.86	1.78	Cement (m^2/kg)	352
Na_2O	0.13	--	FA (m^2/kg)	290
K_2O	0.80	1.13	**Compressive strength of cement (MPa)**	
SO_3	2.91	2.43	2 days	27.2
Cl^-	0.013	--	7 days	42.4
Loss of ignition	2.78	1.34	28 days	52.7
Dissoluble residue	0.42	--		
			Pozzalanic activity index of FA (%)	
Free CaO (%)	1.22	4.34	7 days	79
			28 days	88

terms of both strength and durability (Topçu and Sarıdemir, 2008).In a study on C-Serial FA, this type of FA was found to negatively affect early-age compressive strength, however, to start showing positive effects after 3 days. Reactions of FA-containing samples and of normal samples to cure conditions were examined and the FA-containing concretes were found to be much more sensitive to cure conditions (Yiğiter et al., 2004). FA-containing concrete gradually gains a more impermeable structure as a result of pozzolanic reactions (Asan and Yalçın, 2003). In another study, when the amount of FA substitute exceeded 5% of the cement amount, FA was found to extend hardening time; not to show full binding characteristic of cement; and to lower compressive strength (Subaşı et al., 2008).

In the present study, compressive strength at different ages of normal and FA-added concretes cured in both water and air conditions was compared on the basis of temperature-induced changes. To this end, 20% of cement was substituted by FA to produce normal concrete. This rate was selected since it was stated in the literature that substitution of 20% of cement by FA produced the highest compressive strength and the values closest to control concrete (Demir et al., 2009; Sümer, 1998).

MATERIALS AND METHODS

In the scope of the present study, CEM I 42.5 Portland cement was obtained from Çimentaş Company and FA from İskenderun-Sugözü thermal power plant. Properties of these materials are given in Table 1. The aggregate used in the study collected from river bed in Palu District of Elazığ Province and the sand of the same area. Maximum granule diameter was selected to be 16 mm. The aggregate was subjected to granulometry test. Granulometry curve of the aggregate is shown in Figure 1.

Concrete mixture calculations were made in compliance with TS 802 Standard. All mixtures were prepared in such a way to produce slump value of 6±1cm and water/binder ratio of 0.40. Concrete mixture ratios are presented in Table 2. Total binder amount was taken as 400 kg/m^3 in all mixtures. Concrete mixtures were casted into cubic samples, each 15*15*15 cm in size, and then compressed via shake table. To produce FA-added concrete, 20% of the cement amount was substituted by FA.

One serial of the samples was left for drying under open air in the laboratory while the other serial was kept in the cure room at 20°C under 98% relative humidity for 24 h and then placed in lime-saturated water for 28 days. Compressive strength of five each samples casted under the same conditions was measured experimentally on the 7th, 14th, 21st and 28th days. These values were averaged to obtain average compressive strength. Normal and FA-added concrete samples, casted at the same size and under the same conditions, were cured in lime-saturated water for 28 days. At the end of the 28-day period, they were kept in drying oven at 80°C till dry weight was achieved. Samples taken from the drying oven were exposed to heat in 900°C-capacity, Protherm-brand, high-temperature oven adjusted at 4°C/min heating speed, till temperatures of 100, 200, 300, 400, 500, 600, 700, 800°C were reached. The samples were held at each specified temperature for 60 min according to BS EN 13501-1 and ISO 834 Standards for housing structures. Samples taken from the oven were placed in the laboratory in such a way to air each surface till their temperature decreased to ambient temperature. Their compressive strength was measured to calculate average compressive strength. Loading speed of concrete pressure testing device was adjusted at 3 kN/s.

RESULTS AND DISCUSSION

The compressive strength values of normal and FA-added concretes at different ages and under different cure conditions are shown in Figures 2 and 3. As shown

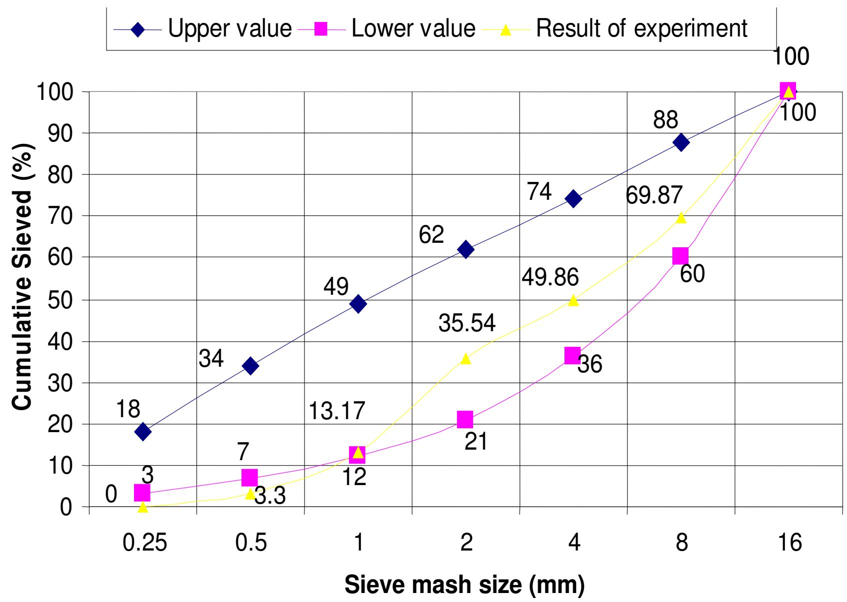

Figure 1. Granulometry curve of the mixture.

Table 2. Mixture calculation for 1 m^3 concrete.

Composition	Mixture ratio of normal concrete		Mixture ratio of FA concrete	
	Volume (dm^3)	Weight (kg)	Volume (dm^3)	Weight (kg)
Cement	**129**	400	103.2	320
FA	**--**	--	25.8	80
Water	160	160	160	160
Air	20	--	20	--
0-4 mm aggregate 50%	345.5	932.85	345.5	932.85
4-16 mm aggregate 50%	345.5	932.85	345.5	932.85
Total	1000	2425.7	1000	2425.7

in Figure 2, early-days strength of the concrete cured in water is relatively lower than that of the concrete cured in air. When compared to the concrete cured in air, the strength of the concrete cured in water started to improve after the 19th to 20th day and peaked on the 28th day. The reason behind higher early-days strength of the concrete cured in air may be earlier initial set (Subaşı et al., 2008; Demir et al., 2009). In addition, when the strength on the 28th day is assumed to be final compressive strength; 54% of the final strength was achieved on the7th day, 69% on the 14th day, and 94% on the 21st day for the water-cured concrete samples while 79% of the final strength was achieved on the 7th day, 89% on the 14th day and 96% on the 21st day for the air-cured concrete samples.

Figure 3 shows a parallelism between the compressive strength values of the samples with FA air-cured and water-cured. However, when compared to the compressive strength of the air-cured samples, that of the water-cured samples was observed to be higher at the end of the 28-day period. When the strength on the 28-day is assumed to be the final strength of the FA concrete; 72% of the final strength was achieved on the 7th day, 81% on the 14th day and 86% on the 21st day for the water-cured samples while 79% of the final strength was achieved on the 7th day; 90% on the 14th day and 93% on the 21st day for the air-cured samples.

Figure 4 shows the relationship between compressive strength values of air-cured normal concrete and FA-added concrete samples. Figure 5 explains the relationships between compressive strength values of water-cured normal concrete and FA-added concrete samples. Compressive strength of FA concrete was recorded to be low at the end of 28-day period in both cases. Analysis of the graphics in Figures 4 and 5 shows that curves of normal concrete samples tended to take a nearly-horizontal position while those of FA concrete samples tended to increase. This tendency means that FA

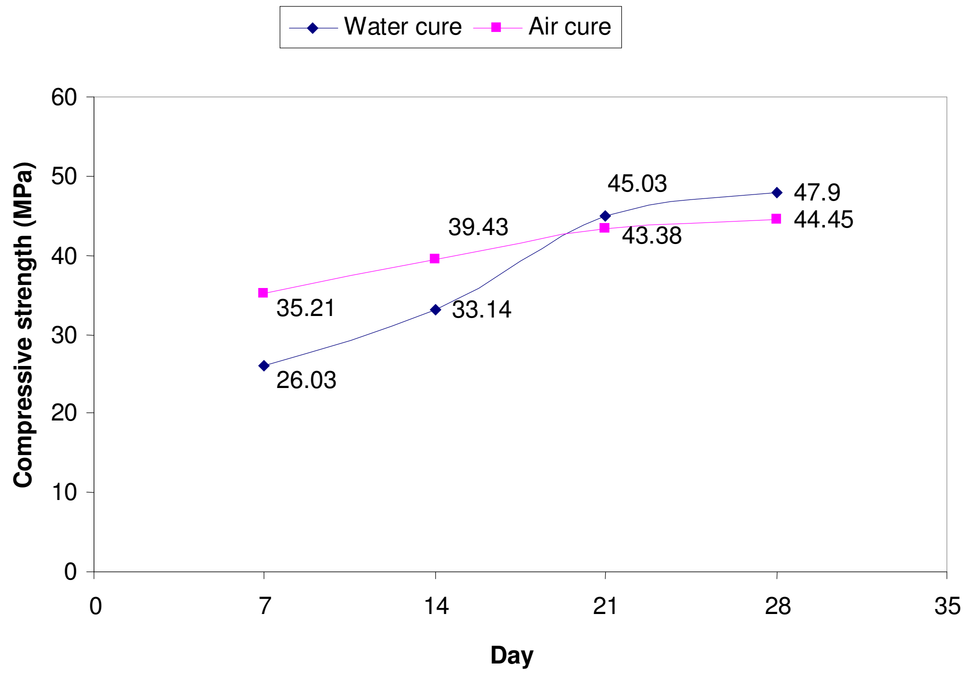

Figure 2. The relationship between cure influence and compression strength in normal concrete.

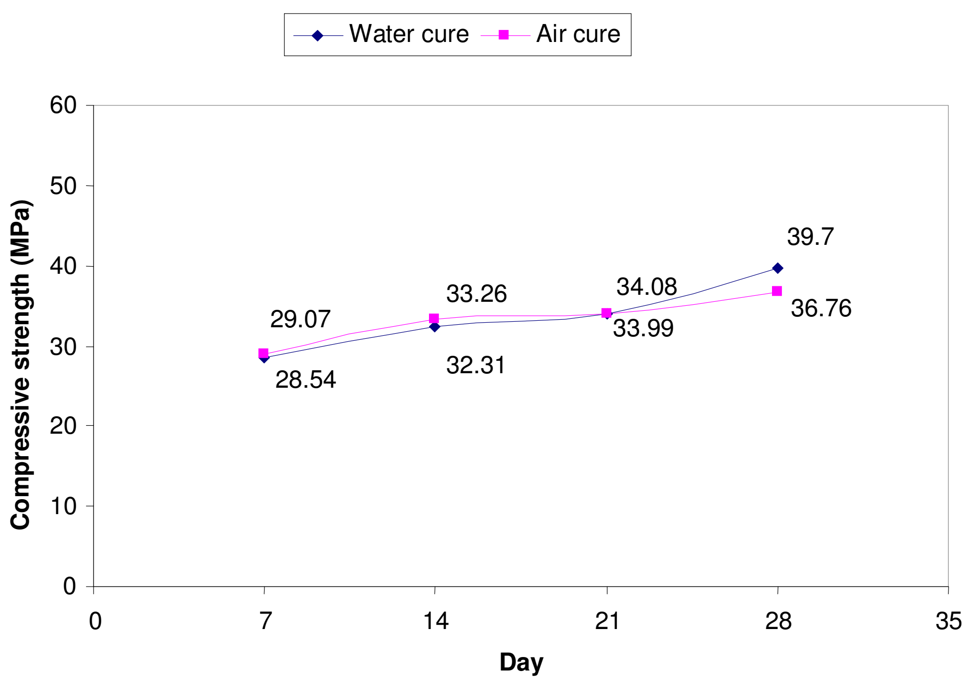

Figure 3. The relationship between cure influence and compression strength in fly ash added concrete.

concrete did not achieve its final compressive strength value at the end of the specified period. Low strength values recorded in the early days and the increase record in the strength values (due to interaction with the free lime released) in the following days result from the chemical and mineralogical structure of FA. Compressive

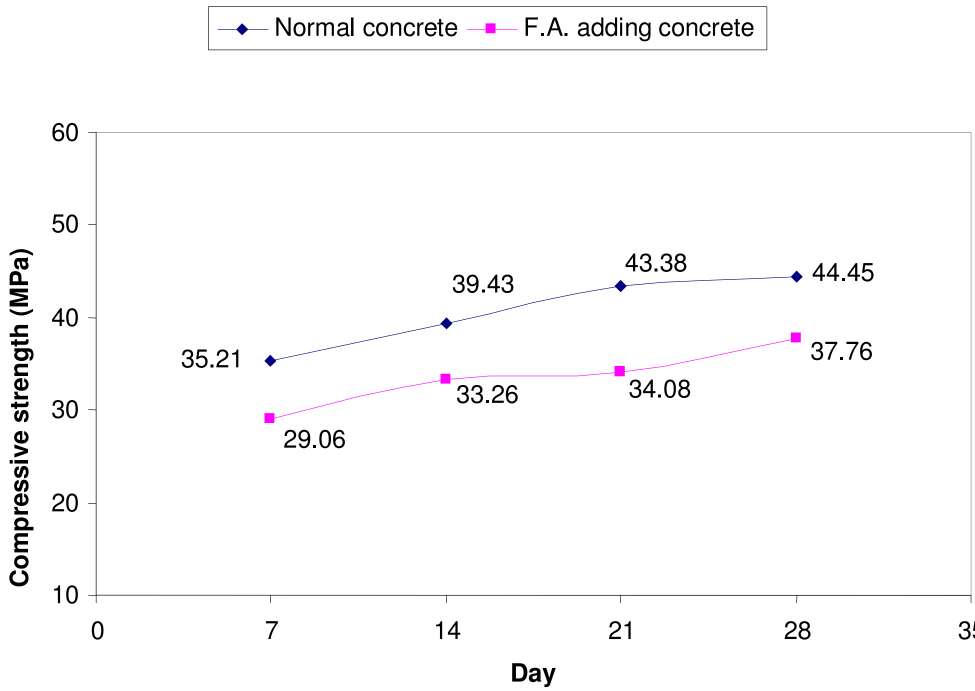

Figure 4. The relationship between the compression strengths of fly ash added and normal concretes cured in air.

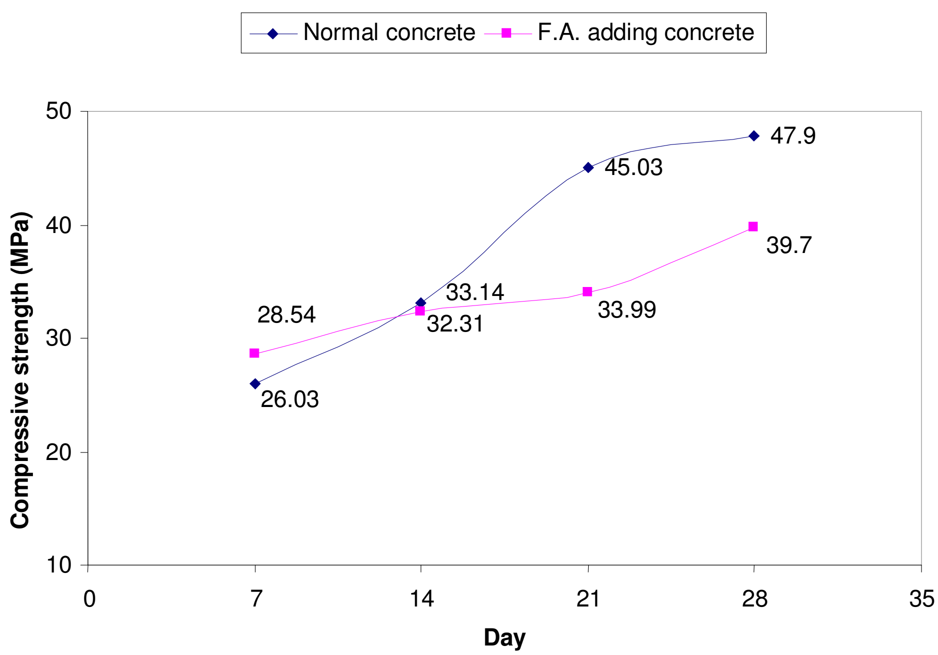

Figure 5. The relationship between the compression strengths of fly ash added and normal concretes cured in water.

strength tendency should be monitored for a longer period so as to fully and clearly understand the exact effects of FA on compressive strength.

Figure 6 shows the temperature-induced changes recorded in compressive strength values of normal and FA concrete samples. As can be seen in the Figure 6, no

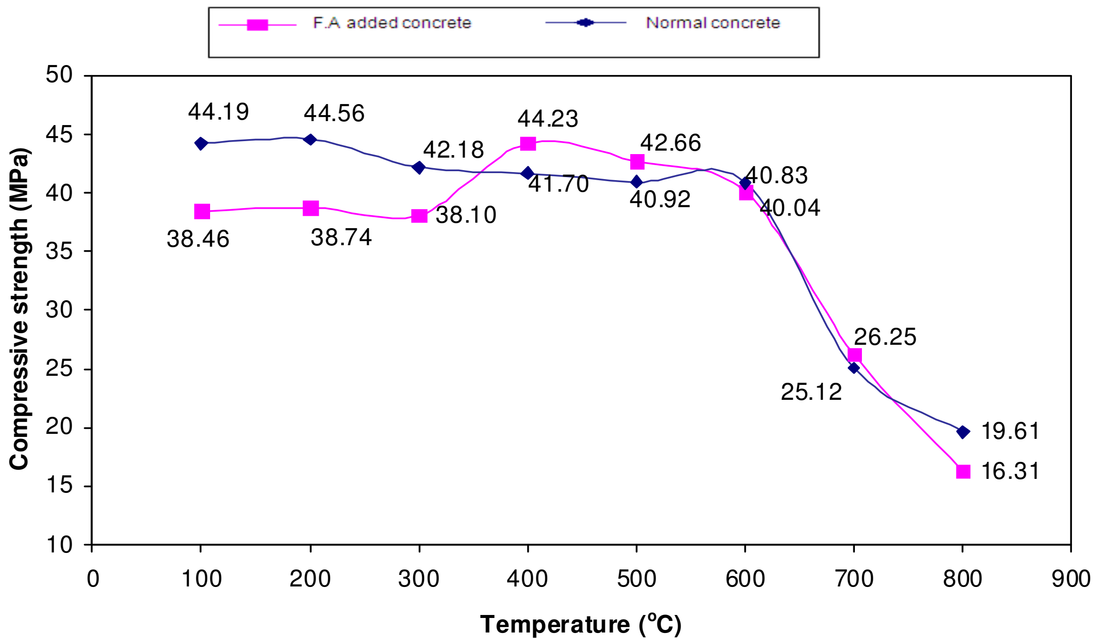

Figure 6. The relationship between temperature changes and compression strengths of fly ash added and normal concretes.

significant decline was recorded in the compressive strength of normal concrete samples up to 500 to 600℃ however, compressive strength started to decline sharply after 600℃. While no significant difference was observed in the compressive strength of FA concrete samples up to 300℃ compressive strength started to improve after 400 - 500℃ thanks to FA's structure. Such behaviour of FA should be analyzed in a future structural study. After 600℃, the strength of FA-added samples started to decline again. It was also observed that compressive strength of both serials of concrete samples declined by nearly 80% at 800℃ and obvious cracks (even fractures) developed on sample surfaces.

Conclusions

Analysis of the changes in compressive strength of air-cured and water-cured concrete samples showed that air-cured samples had higher compressive strength than the water-cured ones in the early days and that strength of water-cured samples started to increase more than that of air-cured ones as of the 19th to 20th day.

At the end of 28-day period, compressive strength of normal concrete samples was found to be higher than that of FA concrete samples; however, the difference between them decreased to 16% on the 28th day from 23% on the 21st day. Increase record in the compressive strength of FA samples in the last days suggests that the difference between strength values of normal and FA-added samples can be made up.

In the tests analyzing temperature-induced changes in compressive strength of the study samples, no significant decline was recorded in either serial up to 400℃. Strength of FA-added samples was recorded to improve by 16% at 400, 500 and 600℃. Obvious cracks started to develop on sample surfaces after 600℃ and compressive strength declined by 80% in both serials.

Fly ash obtained from Sugözü-İskenderun thermal power plant was recorded to positively affect the work-ability of concrete. Use of FA (20%) in concrete mixtures will not have negative effects on strength and, will make significant economic contribution.

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