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EFFECT OF FLY ASH ADDITION ON MECHANICAL PROPERTIES OF CONCRETE

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ABSTRACT
Although, the use of pulverised fuel ash (PFA) as cement replacement has been widely reported to enhance concrete durability against chemical attack, no enough information is published addressing the effect of high volume fly ash replacement on mechanical properties of concrete. Thus, the current experimental study was carried out to investigate the effect of PFA replacement (10, 25 and 50%) on mechanical properties of concrete. Performance of PFA concrete specimens was compared to specimens made with CEMI (42.5 N). Two different water to binder ratios (0.35 and 0.45) were used. Compressive and flexural strength were evaluated at 7, 28, 60 and 90 days of curing. Workability of fresh concrete mixes was assessed using slump test. The carbonation depths were also tested using 100 mm cube specimens at 90 days of curing. Replacement of cement by fly ash improves the workability of concrete, but causes a reduction in compressive strength and flexural strength of concrete. The reduction increases as the replacement by PFA increases. Replacement of cement by 50% PFA showed decrease in compressive and flexural strength by about 36 and 43 %, respectively compared to CEMI concrete mixes at 90 days.

KEYWORDS: Fly ash, compressive strength; flexural strength, carbonation depth, workability.

INTRODUCTION
The need of high levels of energy by the cement industry causes emission of high levels of carbon dioxide (CO_2) in air. Different supplementary cementitious materials such as fly ash, slag and silica fume are usually used as cement replacement to reduce the quantity of Portland cement in concrete, which assists in reducing the embodied energy and associated CO_2 emission. Fly ash (pulverized fuel ash) is a by-product of an electricity generating plant using coal as fuel. Since, a large amount of fly ash is produced every year, its disposal become a major environmental issue in many countries. Thus, the incorporation of fly ash into concrete has been accepted to be one way for its disposal [1,2].

It is known that the durability of concrete depends on its physical properties, which might be controlled by different factors such as water to cement ratio, cement type and additives [2]. The incorporation of fly ash in concrete causes reduction in water demand of concrete, reducing water/cement ratio for equal consistence and improve workability of concrete [3,4,5]. For a constant workability, the reduction in the water demand of concrete due to fly ash is usually between 5 and 15 per cent by comparison with a Portland-cement-only mix having the same cementitious material content. Furthermore, the reduction is larger at higher water/cement ratios. This is due to increase the paste volume (its spherical shape and fines) that lead to the increase of plasticity and cohesion. A concrete mix containing fly ash is cohesive and has a reduced bleeding capacity. The mix can be suitable for pumping and for slip forming; finishing operations of fly ash concrete are made easier [4,5,6]. Dhir *et al*. [3] states that the addition of fly ash improves the dispersion of the Portland cement particles, improving their reactivity. In addition, the partially replacement of Portland cement by fly ash can also improve the durability of concrete by controlling the high thermal gradients, pore refinement and resistance to chloride and sulfate in the long-term performance [7,8]. As fly ash pozzolanically reacts with lime, this potentially reduces the lime available to maintain the pH within the pore solution. However, fly ash does reduce the permeability of the concrete dramatically when the concrete is properly designed and cured [2,6,9].

Although, PFA concrete tend to have low compressive strength at early ages, its properties may be improved at later ages [5,6,10]. This can be attributed to the slow reaction rate of fly ash, producing concrete with relatively less engineering properties at early ages [6,11]. The refinement of pore structure and the consequence reduction in permeability make the PFA concrete less susceptible to deterioration [4-15].

According to BS EN 197-1, BS 8500 and BS EN 206- 1, there are two categories of fly ash used in concrete: regular fly ash and high-volume fly ash. The regular fly ash concrete utilizes about 25–30% of fly ash by weight of Portland cement and is widely used for massive structures, such as gravity dams [2]. While BS EN 197- 1 permits the use of fly ash of up to 55%, data from the European Ready Mixed Concrete Organization show that the cement addition content was less than 20% of the total cement consumption in ready-mixed concrete. [6].

In this experimental study, the effect of different PFA replacement (10, 25 and 50%) on mechanical properties of concrete were investigated. Performance of PFA concrete specimens was compared to specimens made with CEMI. Two different water to binder ratios (0.35 and 0.45) were used. Compressive and flexural strength were evaluated at different curing ages (7, 28, 60 and 90 days). Slump test was performed on fresh concrete mixes. The carbonation depths were also tested using 100 mm cube specimens at 90 days of curing.

EXPERIMENTAL WORK

Materials used

Cement

CEM I (42.5 N), manufactured by Helwan Company-Egypt, conforming to the requirement of BS EN 197-1:2011 [16] was used. The chemical composition of the cement are given in Table 1.

Pulverized -fuel ash (PFA)

The pulverized –fuel ash (PFA) was obtained from Ash Sika Egypt for construction chemicals, and conformed to BS EN 450-1:2005+A1:2007 [17]. The chemical composition of the cement is presented in Table 1.

Table 1: Chemical composition of CEMI and PFA

Chemical Composition (%)	CEMI	PFA
SiO_2	22.19	51
CaO	62.74	2.6
Al_2O_3	4.08	24.8
Fe_2O_3	3.16	10.7
Na_2O	0.2	1.04
K_2O	0.5	3.4
MgO	1.09	1.6
SO_3	3.1	0.52
LOI	2.52	-

Fine and coarse aggregate

Natural sand with an apparent specific gravity of 2.63 and absorption of 0.5% was used. Crushed siliceous aggregate with maximum size (10 mm), specific gravity of 2.67 and absorption of 1.5%, complying with BS EN 12620:2002+A1:2008 [18] were used.

Water

Potable tap water available at the laboratory used in concrete mixtures in this research

Mixture Proportions and mixing procedures

Mix design proportioning was performed by using weight-batching method and was designed in accordance with the Building Research Establishment (British method)[19]. Proportioning of concrete mixtures is shown in Table 2. All mixtures were mixed in a laboratory pan mixer with a capacity of 56 liters. The mix ingredients placed in the mixer was in the following order; dry aggregates and cement were mixed in the mixer for 30 seconds then water was added gradually in 15 seconds and the mixing continued for 2 minutes. Therefore, the total mixing time was 3 minutes for each concrete mixture. After mixing, A series of 100-mm cubes and prisms (100 x 100 x 500 mm) concrete specimens were cast in pre-oiled moulds and fully compacted using vibration table and the top surface was leveled and finished by trowel.

Table 2: Proportioning of concrete mixes (kg/m^3)

Mix	Mix Proportion (kg/ m^3)					
	CEMI	PFA	w/b	Water	Sand	Coarse Aggregate
CEMI	380	0	0.35	133	1050	815
			0.45	171	1145	850
CEMI-10%PFA	342	38	0.35	133	1050	815
			0.45	171	1145	850
CEMI-25%PFA	285	95	0.35	133	1050	815
			0.45	171	1145	850
CEMI-50%PFA	190	190	0.35	133	1050	815
			0.45	171	1145	850

Curing of test specimens

After casting, the specimens were covered with wet hessian and plastic sheets for the first 24 hours at laboratory temperature 20±2°C. After 24 hours, specimens were removed from the mould and kept in water curing (Fig. 1) at 20°C until the test age.

Figure 1: Concrete specimens in curing water

Experiments on fresh concrete

The workability of freshly mixed concrete was measured by using slump test according to BS EN 12350-2:2009 [20] .

Compressive and flexural strength tests

Compressive strength were performed on standard 100 mm cubes according to BS 1881:Part 116:1983[21]. For flexural strength test, prisms of 100x100x500 mm were used. Each prism was supported on a steel roller bearing near each end is loaded through similar steel bearings placed at the third points on the top surface according to BS EN 12390-5. For each test three specimens were tested at 7, 28, 60 and 90 days of water curing.

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Carbonation depth

Carbonation is generally tested by an indirect method using phenolphthalein. A solution of phenolphthalein indicator is applied onto a fresh cut concrete surface. The indicator changes the colour at pH about 9. The un-carbonated concrete (pH > 9) shows a violet colour, while the carbonated concrete with a lower pH remain grey[22].

The carbonation depth measurements were performed on 100 mm cube specimens. The normal method of determining the depth of carbonation of concrete is to spray concrete surface, or the broken surface itself, with a solution of the indicator phenolphthalein made up as a 1 % solution in alcohol-water. The specimens were tested at 90 days.

RESULTS AND DISCUSSION

Fresh Properties

The results of slump test are presented in Figure 2. It can be seen from the figure that concrete workability increased as the replacement by PFA and the w/b ratio increased in all concrete mixes. Concrete mix made with CEMI and w/b ratio of 0.35 showed the lowest value of slump (35 mm), while the slump increased up to 160 mm for mix made with 50% PFA. Replacement of cement by 50% PFA caused an increase in slump by about four and three times compared to CEMI mix when w/b ratio of 0.35 and 0.45 used, respectively. Previous studies [1,23,24] showed that for a constant workability, the reduction in water demand of concrete due to the addition of fly ash usually lay between 5 and 15 per cent and the reduction is larger at higher water/cement ratios.

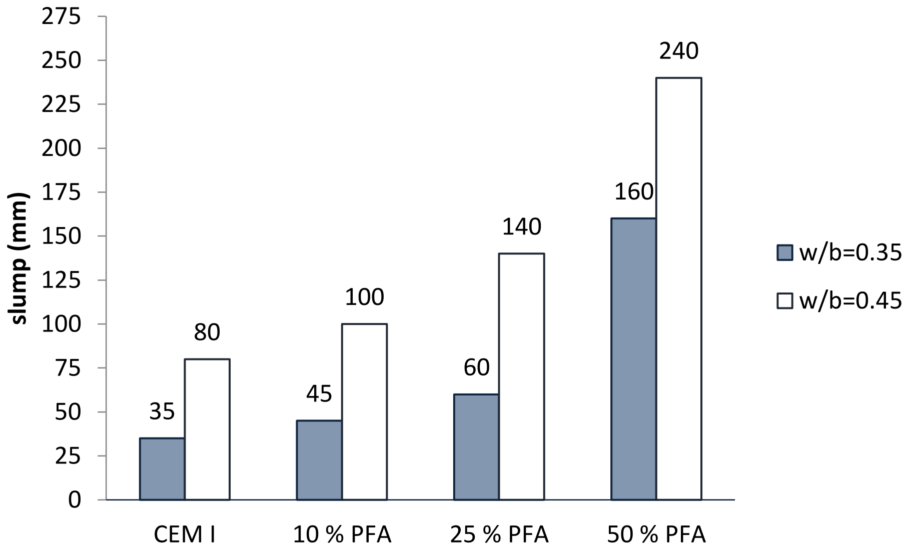


Figure 2: Slump values for all concrete mixes

Compressive Strength

The compressive strength results for concrete made with 0.35 and 0.45 water to binder ratios are shown in Figures 3 and 4, respectively. Generally, increasing the fly ash content in concrete lead to reduction in the strength of concrete. This is expected as the secondary hydration reaction due to pozzolanic action is slow at initial stage. All specimens showed increase in compressive strength values with age. The highest value of compressive strength (48 MPa) was recorded for CEMI concrete specimens at 90 days. The replacement of cement by PFA caused an obvious reduction in compressive strength values. A value of 28 Mpa was gained for concrete specimens made with 50 %PFA replacement and 0.45 w/b ratio at 90 days of curing. The results also showed that the compressive strength of concrete specimens decreased as the water to binder ratio increased. When water to binder ratio was increased from 0.35 to 0.45, slight differences in compressive strength values for concrete made with CEMI and 10% PFA were shown, while reduction by about 23% and 31% in compressive strength were observed when 25% and 50% PFA replacement were used.

Dias et al, [6] stated that a mix containing PFA may develop lower strengths at early ages. At later age, the additional formation of calcium silicate hydrates due to the use of PFA would increase density, refine the pore structure of concrete [25,26,27]. Therefore, fly ash concrete with equivalent or lower strength at early age may have equivalent or higher strength at later age [11,14].

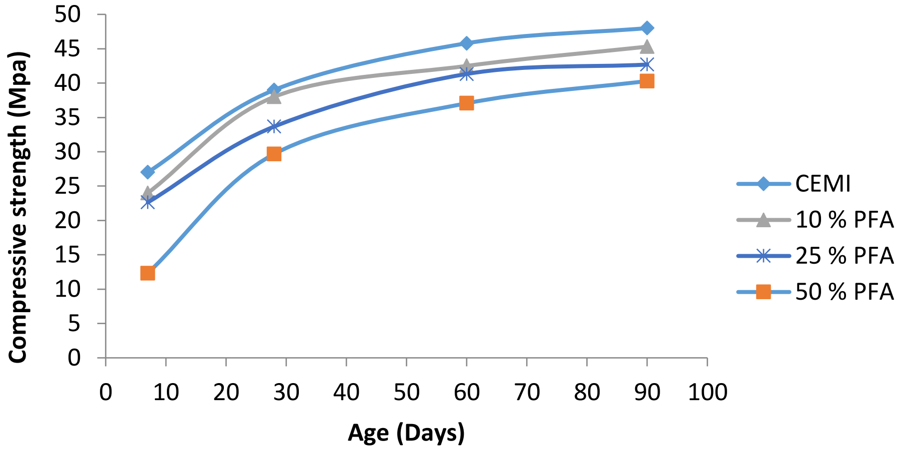


Figure 3: Compressive strength of concrete with w/b of 0.35

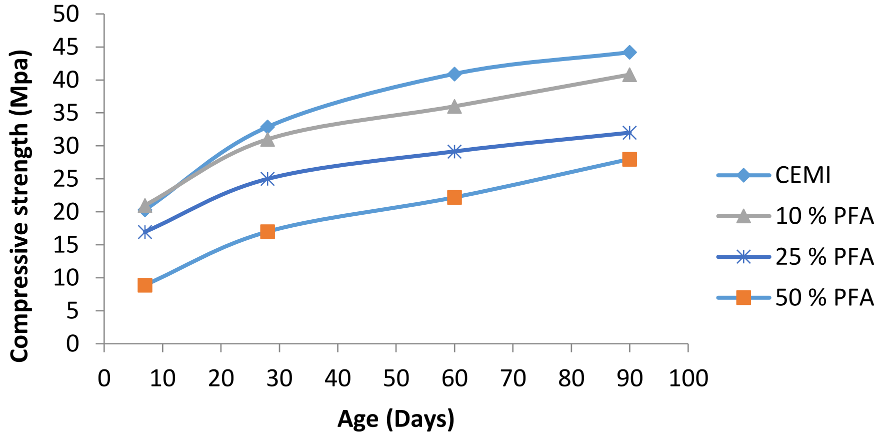


Figure 4: Compressive strength of concrete with w/b of 0.45

Flexural Strength

The results of flexure strength are illustrated in Figures 5 and 6. Generally, the flexural strength values showed slight decrease as the water to binder ration increased from 0.35 to 0.45 at 90 days. On the other hand, obvious decrease in flexural strength values were noted when the PFA replacement increased. Value of about 6 Mpa was recorded at 90 days for CEMI concrete compared with 3.8 Mpa for concrete made with 50% PFA.

It can be seen that the flexural strength values increased gradually over the age. In addition, the flexural strength of concrete made with CEMI showed the highest flexure strength value at 7 days, while replacement by 50% PFA resulted in biggest reduction in the flexural strength value.

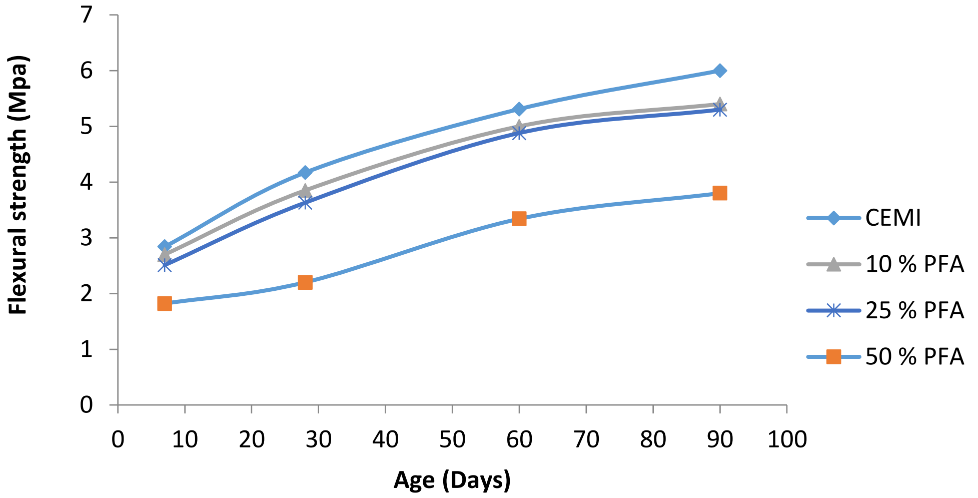


Figure 5: Flexural strength of concrete with w/b of 0.35

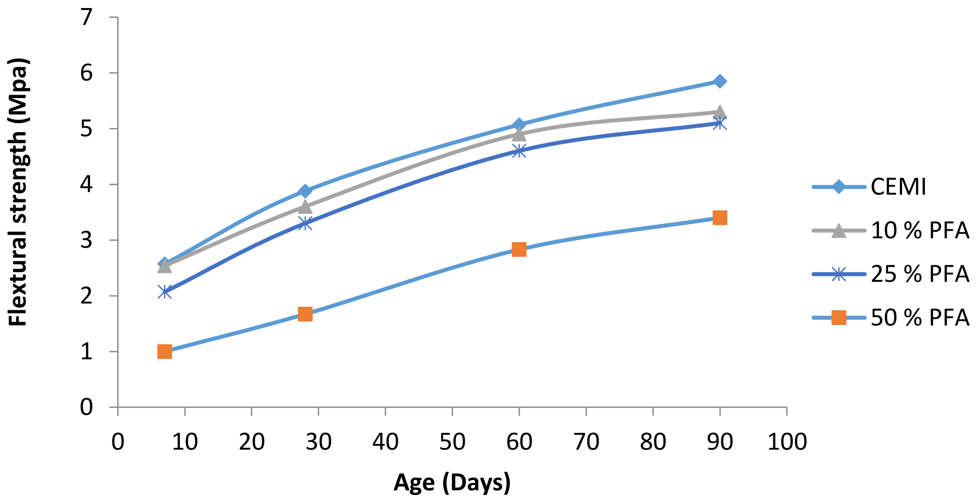


Figure 6: Flexural strength of concrete with w/b of 0.45

Carbonation Depth

The results of carbonation depth of concrete curried for 90 days are shown in Figures 7 and 8. The results revealed that the carbonation depth increased as the water to binder ratio increased and as the PFA replacement increased. CEM I concrete showed the lowest carbonation depth (less than 1mm) and no noticeable change in the carbonation depth values were recorded when the w/b ratio changed from 0.35 to 0.45. Concrete made with 50% PFA showed the highest carbonation depths. These were 7 and 4 mm for PFA concrete made with 0.45 and 0.35 water to binder ratio, respectively. While, values of 3 and 2.5 mm were recorded for concrete made with 25% PFA and prepared with 0.45 and 0.35 water to binder ratios, respectively.

The pH of the pore water in hardened Portland cement paste decreases from 13.5 to a value of about 9 due to the carbonation and this may increase the corrosion risk of steel reinforcement [2, 28, 29].

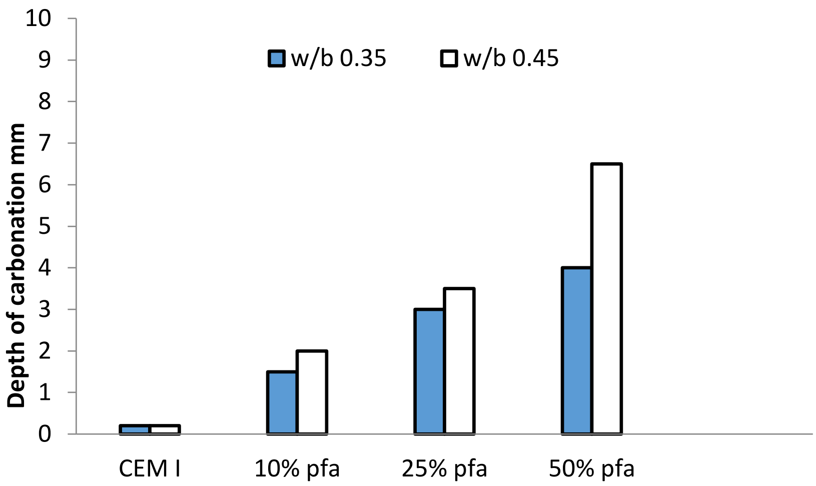


Figure 7: Carbonation depth of concrete

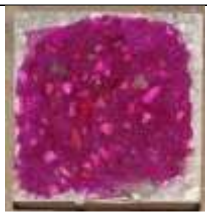
W/B ratio	**0.45**	**0.35**
CEMI		
10% PFA		
25% PFA		
50% PFA		

Figure 8: Carbonation depth of concrete

CONCLUSIONS

The following findings can be drawn from the obtained experimental results:

1. High volume replacement by fly ash results in increase the workability of concrete.
2. The replacement of cement by fly ash causes a reduction in compressive strength of concrete.
3. The flexural strength of concrete decreases significantly with the replacement by fly ash.

4. The compressive and flexural strength of fly ash concrete are improved with curing age.
5. Fly ash concrete shows high susceptibility to carbonation, which may affect concrete durability in long-term performance.

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