UDK 691

STABILITY OF TERNAY IGHTWEIGHT COAL ACHES CONCRETE

G. Sirotin, *Ph.D*, **Y. Ribakov**, *Prof.*

Ariel University, Ariel, 40700, Israel

INTRODUCTION

The increasing strength of normal weight concrete, containing large amounts of fly ash, is reported in many technical publications [1-3]. The following advantageous properties of this concrete should be noted: stability to freezing and thawing resistance, corrosion resistance of reinforcement (penetration of chloride ions), resistance to alkaline gel expansion and other forms of environmental effects. These benefits are the result of improved tightness large volume fly ash concrete.

The following mechanisms of this process are accepted:

- Reduction of the pore volume in the hardening cement paste fly ash is responsible for specifying the classification of specific components (packing effect) and pozzolanic effect using fly ash.

- During the concrete hardening there is non-uniform distribution of water formed due to the influence of the coarse aggregate particles wall effect.

Nevertheless, the durability of lightweight concrete containing fly ash is not adequately elucidated in the technical literature. This paper presents results of an experimental study on durability of lightweight concrete containing bottom ash as a porous aggregate. The economic and environmental advantages of these concretes are as follows:

− Increase of bottom ash volume is used for producing high-performance lightweight concrete (currently bottom ash is mainly used for building and road bedding, structural fills, etc.).

− Increase of fly ash volume is used for concrete production.

Thus, the use of fly ash is promising to improve the durability of lightweight concrete with high porosity aggregate, such as bottom ash. The experiments presented below were conducted to evaluate the effect of using fly ash to increase the durability of the ternary lightweight concrete, which has the potential to produce lightweight concrete on the basis of coal ash.

EXPERIMENTS

Materials

Cement. Portland cement close to ASTM C150 [4], Type 1, was used in all experiments. The physical properties of the cement were as follows: relative specific gravity – 3.15; Blain's fineness – 370 m^2/kg; 28 day compressive strength of standard prisms – 41.5 MPa.

Coal ashes. The fly and bottom ashes were taken from one of Israel's power stations. The fly ash for the experiments was taken in dry conditions from a power station silo. The bottom ash was conveyed to the storehouse at the power station by means of hydraulic transport.

Fly ash. The fly ash met the requirements of ASTM C618 [5], Class F. The sum of SiO_2 + Al_2O_3 + Fe_2O_3 was 81.6% (the standard requirement is min. 70%). The value of SO_3 was 2.98% (the standard requirement is max. 5%). Loss of ignition was about 3% (the standard requirement is max. 6%). The relative specific gravity of the fly ash was 2.25 g/cm^3; Blain's finesse was 385 m^2/kg.

Bottom ash. The grading of samples was close to main requirements to fine and combined fine and course aggregates. The loose bulk density of samples (600 kg/m^3) met to requirements established by ASTM C330 [6] (for lightweight aggregates for structural concrete). Relative particle density (including pores) – 2.3 g/cm^3; water absorption – 25%.

Unprocessed crushed sand (UCS) The sample of UCS was taken from one of the Israel's dolomite quarry. The grading of UCS met to the specifications of ASTM C33 [7] with the exception of lower content of the particles passing sieve 1.18 mm, and higher content of particles passing sieve 0.15 mm. The percentage of the particles passing sieves according to ASTM C33 were as follows: 9.5 mm – 100%; 4.75 mm – 92%; 2.36 mm – 62%; 1.18 mm – 41%; 0.6 mm 31%; 0.3 mm – 20%; 0.15 mm – 17%.

The physical properties of UCS were as follows: relative specific gravity – 2.8 g/sm^3; relative particle density (including pores) – 2.72 g/cm^3; porosity – 3%; water absorption – 1.7%; loose bulk density – 1490 kg/m^3; volume of voids (interspaces between particles) – 45.2%.

Proportioning and preparation of the concrete mixtures

The mixture proportions for the experiments are presented in Table 1. For evaluation of the concrete durability, the volume of pores and capillaries accessible for water is essential. This volume was determined separately for the whole volume of concrete specimens and for the volume of hardened cement-fly ash paste in the specimens. The volume of pores and capillaries in the hardened concrete was assumed equal to that of water dried up by hardening the concrete specimens, i.e. approximately to the mass of water in the fresh concrete less the mass water used for hydration of the cement-fly ash paste. This mass was calculated as the difference between densities (Table 1) of the fresh and hardened concrete (the last was dried up to constant mass).

Table 1. Proportions and properties of concrete mixtures and hardened concrete used in the experiments

Component	No of the concrete mixture								
	1	2	3	4	5	6	7	8	9
Cement, kg/m^3	200	200	200	335	335	335	400	400	400
Fly ash, kg/m^3	-	85	200	-	150	335	-	165	400
Bottom ash, kg/m^3	730	695	640	525	415	295	475	335	210
UCS, kg/m^3	515	515	515	515	515	515	515	515	515
Water, l/m^3	320	300	280	360	345	330	420	410	380
Fresh concrete density, kg/m^3	1765	1795	1835	1735	1760	1810	1810	1825	1905
FA/(C+FA)	-	0.3	0.5	-	0.3	0.5	-	0.3	0.5
Volume of cement or cement-fly ash paste, l/m^3	257	283	328	358	450	546	466	559	663
Density of hardened, kg/m^3	1485	1550	1635	1515	1580	1675	1470	1515	1685
28-days concrete strength, MPa	14	18	22	17	20	24	16	20	25
Volume of pores and capillaries in the concrete, %	59	42	27	50	40	26	55	43	28
Volume of pores and capillaries in cement or cement/fly ash paste, %	28	25	20	29	26	21	34	31	23

The volume of pores and capillaries in the hardened cement or the cement-fly ash paste was calculated as the difference between the volume of pores and capillaries in the concrete and volume of pores and capillaries in the aggregate accessible for filling with water. The last volume was determined from the data of water absorption for bottom ash in the concrete mixture [8]. In our case it was 17.5%. The water absorption of the UCS is essentially lower and can be not taken in account.

The volumes of pores and capillaries are expressed in percent of the concrete specimens volume and of the cement-fly ash paste volume, accordingly.

Capillary water absorption of hardened concrete

Capillary water absorption of concrete is considered as a significant factor affecting its durability. A method [9] for determining capillary absorption of water from the concrete to assess the effect of fly ash on its value has been suggested in earlier studies [10].

Figure 1 shows the effect of fly ash in reducing the concrete capillary absorption index. The test significantly influences the value of the index, however, the relative decrease in the index for both embodiments' time changes slightly. Reducing this parameter was 1.24-1.25 times for FA/(FA + C) = 0,33, and 1.53-1.55 times for FA/(FA + C) = 0,5.

Studying the stability of lightweight concrete with a cyclic wet-dry test

Each wet-dry cycle comprised: submerge the samples in water at 25 ± 5 °C for 4 hours; drying in an oven at 105 ± 5 °C for 16 h; cooled to 25 ± 5 °C for 3-4 hours; and weighing samples. After every 10 cycles, the samples were tested for compressive strength using an ultrasonic method [11]. The total number of cycles was 50. One test cycle is about a representative of one annual cycle of concrete in Mediterranean climate.

The test was performed with 100×100×100 mm specimens prepared from the concrete mixture No. 6 (cement content 335 kg/m^3, FA/(C + FA) = 0.5), in addition to the tested samples, reference samples were prepared and cured in the experiment in constant air temperature of 20 ± 5°C. The dependence of the test samples strength and the corresponding reference to the number of wet-dry cycles is shown in Figure 2.

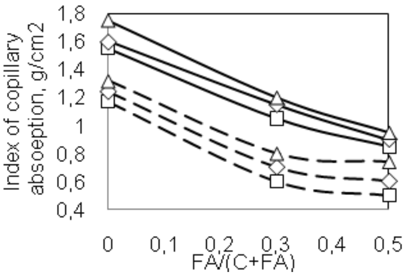


Fig. 1. The effect of fly ash content on lowering the capillary absorption index of lightweight concrete

□ ◇ △ - *cement content 400, 335 and 200 kg/m^3, accordingly*

——— - *the time of test 4 h*

– – – – - *the time of test 2 h*

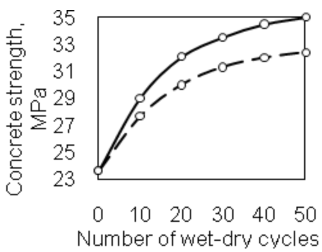


Fig. 2. The effect of number of wet-dry cycles on concrete compressive strength

——— - *tested specimens*

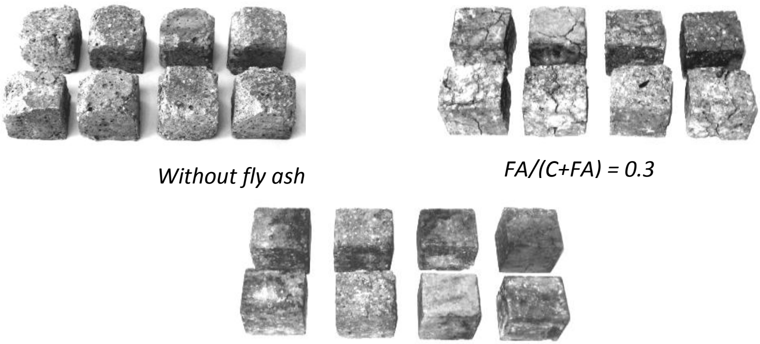
– – – - *reference specimens*

Increasing the compressive strength of the reference, which was found in experiments connected with the fly-ash pozzolanic effect. The test specimens, which were subjected to the influence of wet dry cycles showed no mass loss or cracks formation. Furthermore, an increase in strength of the samples by wet processing during the dry test was identified.

Lightweight concrete soundness

The crystallization test procedure, used in this study, corresponds to requirements of ASTM C88 [12], except samples with regular cubic shape. The dimensions of all tested specimens were 50 × 50 × 50 mm, which corresponds to the maximum size of aggregates used to standard test. Concrete quality assessment and analysis of visible cracking was performed after each test cycle. Na_2SO_4 solution was prepared in accordance with the requirements of ASTM C88.

The photographs in Fig. 3 show the damage caused to the specimens after 5 cycles of the test.



FA/C + FA) = 0.5

Fig. 3. Destruction of lightweight concrete specimens caused by 5 crystallization test cycle

DISCUSSION

The use of fly ash in lightweight concrete with bottom ash as an aggregate causes the following change in the proportion and the concrete structure:

- Increasing the volume of cement/fly ash paste compared to concrete without fly ash. This growth was 20% for FA/(C + FA) = 0.3, and 40% for FA/C + FA) = 0.5. Accordingly, the amount of bottom ash was lower.

- Reducing the volume of pores and capillaries in the fly ash cement paste compared to the cement paste (20% when FA/(C + FA) = 0.3, and 45% if FA/C + FA) = 0.5).

- Reducing the volume of pores and capillaries in the concrete (10% when FA/(C + FA) = 0.3 and 30% when FA/C + FA) = 0.5.

- Some reduction in the volume of water in a concrete mixture (about 5% if FA/(C + FA) = 0.3, and 10% when the FA/C + FA) = 0.5).

The following improvements of concrete properties were observed:

- Increase of 4.5% and 11.5% in the density and an increase of 35% and 90% in strength for FA/(C + FA) = 0.3 and 0.5, respectively.

- Reduction of capillary absorption, 16-17% and 33-36% for FA/(C + FA) = 0.3 and 0.5, respectively (test duration was 4 and 2 h).

The results of determining the soundness of the specimens with cement/fly ash content FA/(C+FA) = 0.5 by using wet-dry test, revealed that lightweight concrete containing bottom ash and fly ash passed 50 wet-dry cycles without lowering the strength and changing the space. Such test corresponds approximately to 50 annual environment cycles of the Mediterranean climate.

The cyclic crystallization test demonstrates that using an appropriate fly ash volume provides the possibility to control the damage, caused by the exposure of concrete to the surrounding environment. It should be noted that concrete specimens, prepared using mixtures No 2, 3, 5, 6, 8 and 9, passed 5 crystallization test cycles. Under these conditions the specimens without fly ash have completely destructed.

CONCLUSIONS

Durability of lightweight concrete containing porous bottom ash can is essentially improved by using high volume of fly ash as an additive to cement. In this case are:

– An increase in the cement-fly ash paste matrix volume (as compared to concrete without fly ash).

– A decrease in the volume of pores and capillaries in the cement/fly ash paste (as compared to the cement paste matrix).

– Essential decrease in the lightweight concrete capillary water absorption.

Accordingly, the following effect of high fly ash volume addition on the lightweight concrete durability under cyclic tests is established:

- An essential increase of the lightweight concrete soundness under the strict crystallization test.

- A high resistance of lightweight concrete to the prolonged wet-dry cycles test.

Summary

A study of different proportions of ternary lightweight concretes based on fly ash as an additive to cement and bottom ash as an aggregate under laboratory and field conditions confirmed an expediency of

use in thermal-insulating/structures and structural elements. The current paper presents results of a study on durability of ternary lightweight concrete performed considering the influence of Mediterranean climate, characterized by a very hot summer with temperature extremes (especially in the desert regions) and very wet winters with prolonged rains.

References

1. Mehta, P.K. "High-Performance, High-Volume Fly Ash Concrete for Sustainable Development"; Proceedings of International Workshop on Sustainable Development and Concrete Technology, Editor Wong, K., Beijing, China, 2004, pp. 3-14.
2. Camões, A., Agular, B., Jalali, S. "Durability of Low Cost High Performance Fly Ash Concrete"; International Ash Utilization Symposium, Center for Applied Energy Research, University of Kentucky, Paper 43, 2003.
3. Butalia, T.S. "Corrosion in Concrete and the Role of Fly Ash in its Migration"; CAER-University of Kentucky, Center for Applied Energy Research, Lexington, KY, USA, v. 15, No 4, 2004, pp. 1-4.
4. ASTM C150/C150M-12. Standard Specification for Portland Cement.
5. ASTM C618-12a. Standard Specification for Coal Fly Ash and Raw or Calcined natural Pozzolan for Use in Concrete.
6. ASTM C330/C330M-13. Standard Specification for Lightweight Aggregates for Structural Concrete.
7. ASTM C33/C33M-13. Standard Specification for Concrete Aggregates.
8. Nisnevich, M., Sirotin, G., Eshel, Y. and Schlesinger, T. "Environmental Aspects of Utilizing Coal Combustion By-Products for Production of Lightweight Concrete"; Proceedings of the 20th Annual International Pittsburgh Coal Conference "Coal-Energy and Environment", Pittsburgh, USA, 2003, pp. 1-3.
9. ASTM C158513. Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic Cement Concretes.
10. Nisnevich, M., Sirotin, G., Dvoskin, L. and Eshel, Y. "Using High-Volume Fly Ash in Lightweight Concrete with Bottom Ash as Aggregate"; Proceedings of 7th International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Editor Malhotra, V.M., SP-199, v.1, Madras, India, 2001, pp. 99-114.
11. ASTM C597-09. Standard Test Method for Pulse Velocity through Concrete.
12. ASTM C88-13. Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate.