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Durability of Lightweight Expanded Clay Aggregate Concrete

Michala Hubertová[a,]*, Rudolf Hela[b]

[a]*Lias Vintířov, lightweight building material k.s., 357 44 Vintířov, Czech Republic*
[b]*Brno University of Technology, Institute of Technology of building Materials and Components, Veveri 331/95, 612 00 Brno, Czech Repubic*

Abstract

The paper describes a development and use of lightweight concrete and lightweight self-compacting concrete using artificial lightweight aggregate based on expanded clay for ready mix concrete and precast elements. The objective of this research was to evaluate the lightweight concrete on durability of concretes placed in chemically aggressive liquid and gaseous environments (high concentrations of sulphate, chloride ions, automotive gas, oil and gaseous CO_2 and SO_2 environments).

Keywords: expanded clay aggregate, lightweight concrete, durability;

1. Introduction

Lightweight high performance concretes, i.e. self-compacting concrete and lightweight fibre reinforced concrete are the types of concrete that are not incorporated in any standard or guideline. High water absorbing capacity, low volume weight and low strength of lightweight aggregate are the main problems of design, production and placing of lightweight concrete. Hence, in particular the type and properties of lightweight

* Tel.: +420777740014
E-mail address: michala.hubertova@gmail.com.

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aggregate those have the major effect on behaviour of these types of concrete. Lightweight aggregate Liapor produced in the Czech republic was the only porous aggregate used for the experiments.

As a part of the research concerning lightweight concrete, the influence of admixture of metakaolin on rheological properties of fresh concrete and physico-mechanical properties of hardened concrete was tested in the first stage [2]. After evaluation of the test results of 40 mix-designs that as far as the above mentioned properties and the economy are regarded, the batch containing 5% by volume of metakaolin can be considered very effective. Currently we test concerning the resistance of lightweight concrete and lightweight self compacting concrete to corrosive environment are running as a part of research work. In this paper the evaluation of a part of developed mix designs after 1 year of exposition to corrosive environments are described, and influence of selected additives on the resistance of lightweight concrete.

2. Eperimental

It were developed set of 5 mix-designs with difference only in the used type of admixtures used. The amount of Portland cement (370 kg/m^3), additives (40% by volume of cement) and admixtures (polycarboxylates based super plasticizers) was the same for all mix-designs. The composition of aggregates was for all mix-designs also the same Used was a combination of lightweight expanded clay based aggregates and natural dense stone. The amount of effective water to keep constant consistence was between 160 and 170 kg/m^3 depending on the additive used.

Basic reference mix (MIX I-A) was mixed with black coal fly ash in the proportion of 40% by volume of cement. This mix was modified with metakaolin in the proportion of 5% by volume of cement (MIX I-B) and microsilica powder in the proportion of 5% by volume of cement (MIX I-C). The mix-design (MIX I-D) contained micronized lime stone in the proportion of 40% by volume of cement. Chemical analysis of used metakaolin and microsilica is given in Table 1. After 28 days, basic physico mechanical properties were tested with reference specimens. Test samples made from above mentioned mixes were subjected to action of different corrosive environments. Other samples were placed in corrosive environments for the period of 12 months.

Table 1. Chemical characteristics of metakaolin and microsilica

	TiO_2	P_2O_5	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	K_2O	Na_2O	SO_4^{2-}	SO_3	MgO
meta-kaolin	0.49	0.15	49.2	1.01	42.2	0.9	1.83	0.79	0.11	0.48	---	---
micro silica	0.02	0.09	89.25	0.67	0.21	1.55	1.83	1.45	0.49	---	0.33	2.85

Table 2. Specification of environments

Substance	Concentration	Relative Humidity
Gaseous environment – CO_2	98%	75%
Gaseous environment – SO_2	98%	75%
Liquid environment - NaCl	1000 mg Cl^- per 1 liter of solution	---
Liquid environment – Diesel oil	100%	---
Reference placing	---	100%

3. Evaluation of Mix-Designs. Observation And Comments

The following Tables 3 to 8 indicates the evaluation of mix-designs according to the methodology [1].

Table 3. Change of physico mechanical properties of samples in gaseous environments

MIX	Compressive strength after 180 days [MPa]		Difference of compressive strength compared to ref. sample [%]		Difference of volume weight comp. to values befor exposing [%]	
	CO_2	SO_2	CO_2	SO_2	CO_2	SO_2
I – A	49.8	51.6	2.47	6.07	1.37	1.21
I – B	49.8	49.8	6.98	6.87	1.25	1.37
I – C	49.0	49.6	0.62	1.95	0.67	1.40
I – D	47.2	48.8	0.21	3.61	1.22	0.91

Table 4. Change of physic mechanical properties of samples in liquid environments – constant conditions

MIX	Compressive strength after 180 days [MPa]		Difference of compressive strength compared to ref. sample [%]		Difference of volume weight comp. to values before exposing [%]	
	chlorides	Diesel oil	chlorides	Diesel oil	chlorides	Diesel oil
I – A	49.7	48.2	2.16	-0.93	0.85	0.68
I – B	50.0	45.3	7.3	-2.69	0.62	1.3
I – C	49.5	48.1	1.64	-1.23	1.26	0.96
I – D	47.5	47.2	0.85	0.32	1.19	1.01

Table 5. Change of physic mechanical properties of samples in liquid environments – cyclical conditions

MIX	Compressive strength after 180 days [MPa]		Difference of compressive strength compared to ref. sample [%]		Difference of volume weight comp. to values before exposing [%]	
	chlorides	Diesel oil	chlorides	Diesel oil	chlorides	Diesel oil
I – A	48.7	48.8	0.21	0.31	0.8	0.86
I – B	46.8	46.4	0.43	-0.32	0.75	1.63
I – C	48.9	40.2	0.41	-1.03	0.92	0.5
I – D	48.7	47.0	3.4	-0.21	0.56	0.95

Table 6. Classification of samples exposed to CO_2 in the stage of carbonation

MIX	Carbonation degree ^oK [%]	Modification change degree^oMP [-]	pH [-]	Carbonation stage
I - A (P)	52.1	0.85	11.51	I.
I - B (P)	34.1	0.95	11.84	I.
I - C (P)	64.2	0.45	10.51	II.
I - D (P)	65.3	0.41	10.78	II.

Table 7.Classification of samples exposed to SO_2 in the stage of sulphation

MIX	Sulphation degree ^oS [%]	pH [-]	Sulphation degree
I - A (P)	7.778	11.51	I.
I - B (P)	8.660	11.84	I.
I - C (P)	13.695	10.51	I.
I - D (P)	12.935	10.78	I.
I - B (H)	12.802	11.13	I.

Note: (P) – sampling from the surface of test specimen
(H) – sampling from the depth of 20 – 30 mm under the surface of test specimen

Table 8. Chemical analysis of samples placed in chlorides

	Chlorides – constant [%]	Chlorides – Cyclical [%]
1 – A (P)	< 0.010	< 0.010
1 - B (P)	< 0.010	< 0.010
1 - C (P)	0.040	0.040
1 - D (P)	0.070	0.050
1 - B (H)	< 0.010	< 0.010

3.1. Effect of CO2

Samples exposed to CO_2 in particular surface layers (0–20 mm deep from the surface) are in the second stage of carbonation with the exception of MIX I-A with fly ash and MIX I-B with metakaolin. The degree of carbonation is also confirmed by occurrence of carbonation products (calcite. aragonite. vaterite) in the micro structure of concrete matrix of these mix-designs. In the second stage of carbonation other hydration products of cement are altered. for example newly formed modification of $CaCO_3$ together with amorphous gel of silicic acid form a crystalline neoformations of $CaCO_3$ with very fine grain. Properties of concrete do not change much. which explains only little differences in compressive strengths and volume weights of mixes. MIX I-A (with fly ash) and I-B(with metakaolin) are in the first stage of carbonation after 360 days of exposition to 98% CO_2 and 75 % relative humidity of air. which is the same condition as that of samples placed in exterior environment as regards the level of carbonation. In the first stage of carbonation. calcium hydroxide in the microstructure of the cement matrix (both crystalline – Portlandit and from the space between grains) is attacked by carbon dioxide. The product of these chemical reactions is calcium carbonate crystallizing in the form of calcite. In the second stage of carbonation. carbon dioxide reacts with calcium-hydro-silicates forming fine-grain calcium carbonate in the microstructure of concrete in particular in the form of aragonite and vaterite.

3.2. Effect of SO_2

All mix designs were classified in the stage 1 of sulphation after 360 days of exposition to 98% SO_2 with relative humidity of air 75%. After comparison of SO_2 content in samples located in corrosive gas and external environment we have to state considerable increase of the content of SO_2. Increased degradation of surface layers was also confirmed by marked coloring of samples. However. results of X-ray diffraction analysis did not confirm occurrence of products of sulphation (gypsum. monosulphate. trisulphate) indicating increased degradation of cement matrix. In the first stage. $Ca(OH)_2$ (or its solution) in the spaces between grains is altered to hemi-hydrate of calcium sulphate. which partly fills pores. Strength of concrete rises. but the value of pH decreases.

3.3. Effect of Cl^-

Comparison of results of mineralogical composition of mix-design placed in chlorides and in external environment showed that action of chlorides on mix-designs modified with fly ash in the time period of 360 days did not cause formation of new phases in their microstructure. which would mean degradation of concrete matrix due to chlorides. We have to highlight that none of tested mix-designs showed after 360 days in chlorides occurrence of Friedel´s salt or other minerals. which could cause expansion pressures in microstructure of the material and degrade matrix to the extent of decreasing strengths of the tested concrete. Modified MIX I-B showed increase of strength. which indicates positive effect of metakaolin. Even though we

expected higher level of degradation through cyclical action of chlorides. we did not find any major changes compared to constant exposition of test samples.

3.4. Effect of diesel oil

Samples exposed to Diesel oil for 360 days did not show any major changes of microstructure of cement matrix. The most evident proof contamination by oil products (Diesel oil) is the loss of ignition. Results of this analysis show slight contamination of surface layers of tested mix-designs. Comparison of samples from 200 mm depth of specimen placed in Diesel oil and in external environment show. that only the surface of tested concrete was contaminated. Contamination of surface of samples with cyclical exposition to Diesel oil is lower than that of samples in constant exposition. Difference in strength compared to reference values are negligible. only within 3%. Comparison of contamination of different mix-designs shows that mix-design I-A (with fly ash) and I-B (with metakaolin) unambiguously resist to penetration with oil products (Diesel oil).

4. Conclusion

Mixes are designed in strength classes LC 30/33 to LC 35/38 and volume classes D 1.6 to D 2.0 according to European standard EN 206-1. Based on the results found it can be state that using coal fly ash is unambiguously positive as far as resistance and durability of lightweight concrete in corrosive environment. in particular CO_2 and SO_2 is regarded. The analyses imply that mix I-A (with fly ash) and in particular mix with fly ash modified with metakaolin (I-B) are much more resistant to corrosive agents than other mixes. Using porous aggregates for high strength concretes might be surprising considering importance of strength of aggregate for strength of high strength concrete. Lightweight aggregate is porous and has rather low strenght. Nevertheless. drop of volume weight of concrete with strength of 50 - 60 MPa below 1800 kg/m^3 can represent certain cost saving due to reduction of total construction weight. Lightweight self compacting concrete made with lightweight aggregate Liapor (maximal strength 10 MPa) with compressive strength of 50 - 60 MPa can be at present ranked among lightweight high performance concretes.

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