EFFECT OF MUNICIPAL HEATING SYSTEM COAL ASH ON THE INSULATION PROPERTIES OF LIGHT WEIGHT CONCRETE

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Abstract: Large quantities of coals have been used as fuel use for central heating system in Turkey. It has been causing a considerable waste that has been dumped into landfills. On the other hand enhanced construction activities, shortage of conventional building materials and abundantly available industrial wastes have promoted the development of new building materials. In this study, usage of coal ash as supplementary building material in light weight concrete was investigated. For this purpose, chemical analyses of the coal ash, perlite, and silica fume samples were determined. Lime was added to the coal ash as a binder. The binder (slaked lime) ratio was kept constant at 45% throughout this study. In order to get comparable results samples were prepared with five different compositions. Expanded perlite and silica fume added some mixtures.

After certain time of curing, physical and mechanical tests were conducted. It was concluded that, coal ash can be used economically for the production of lightweight building blocks (LWBB). Optimal strength-thermal conductivity combination was obtained by the usage of silica fume and expanded perlite together. Improved strength properties were obtained by using hydrothermal curing conditions and super plasticizer addition.

Keywords: Coal ash, silica fume, expanded perlite, lime, lightweight concrete blocks.

Introduction

Lightweight aggregates have higher water absorption rate and lower relative density according to normal aggregates. In addition to being light, it has good strength, fire resistance and heat insulation. Apart from the density of the aggregates, the density of the concrete also depends upon the grading of the aggregates, their moisture content, mix proportions, cement content, water-to-binder ratio, chemical and mineral admixtures, etc. Besides the material, it also depends upon the method of compaction, curing conditions, etc (Neville, 1987). The use of lightweight aggregate in concrete has many advantages, for examples; reduction of dead load, high thermal insulation, reduced the handling and transporting costs, improved the fire resistance etc.

Lightweight concrete (LC) is generally used to reduce the dead weight of a structure as well as reduce the risk of earthquake damages. Earthquake forces that will influence the civil engineering structures and buildings are proportional to the mass of those structures and buildings. Thus, reducing the mass of the structure or building is of utmost importance to reduce their damage risk due to earthquake (Yaşar *et.al,* 2003). But perhaps the most significant potential advantage of the use of lightweight aggregates for concrete and building in general is the environmental value. When the raw materials needed for lightweight production are derived from industrial by products, the environment and economy of the producing locality and country are deemed to benefit. Housings are usually heated with central heating system in Turkey. Coal is used mostly as fuel. The resulting ash is usually collected in municipal solid waste depot. The aim of this study was to study the possibility of using coal ash as aggregate to manufacture cement free lightweight concrete block (LWCB) and determine the effects on the insulation properties.

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Experimental

Municipal heating system coal ash was used in the study. Coal ash, expanded perlite and silica fume were taken from the solid waste storage in Afyonkarahisar city (Turkey), Etibank Perlite Enterprise in İzmir and Antalya Electro Metallurgy Enterprise in Turkey respectively. First furnace ash was milled in the porcelain ball mill. Furnace ash is appropriate to the C class according to ASTM C 618, since total oxide of SiO_2+Al_2O_3+Fe_2O_3 is 77.48% and CaO is less than 10% (Table 1). The mineral composition of the coal ash is mainly quartz, sodium aluminium silicate, hematite and magnetite (Figure 1). Commercial grade slaked lime was used as bonding material in the experiments. The chemical composition of the coal ash, expanded perlite and silica fume is given in Table 1. The particle size distribution of the fly ash, silica fume and expanded perlite was measured with Laser Size Distribution Analyzer-Master Sizer X1.2b (Figure 2).

Table 1. Chemical analyses of coal ash (CA), silica fume (SF) and expanded perlite (EP).

Oxides (%)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	TiO_2	SO_3	LOI	Total
Coal ash	51,90	18,18	7,40	1,75	1,17	0,72	1,32	0,4	2,35	9,55	94,74
Silica fume	87,66	0,42	0,64	3,77	0,89	0,29	0,31	0,01	-	3,70	97,68
Perlite	73.16	12.87	0.88	-	0.85	2.35	4.76	-	0.29	2.58	97.71

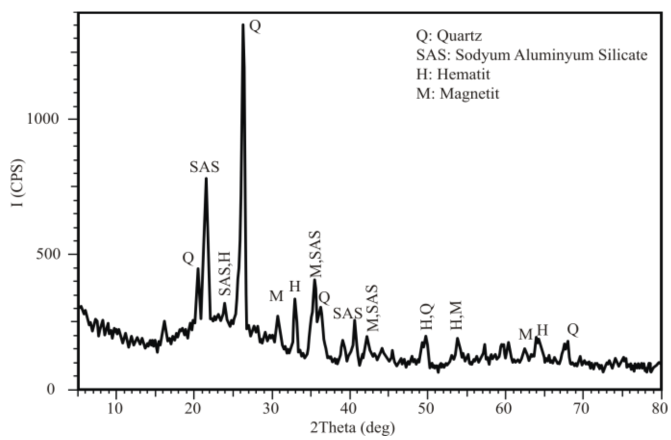

Figure. 1. Mineral structure of the coal ash.

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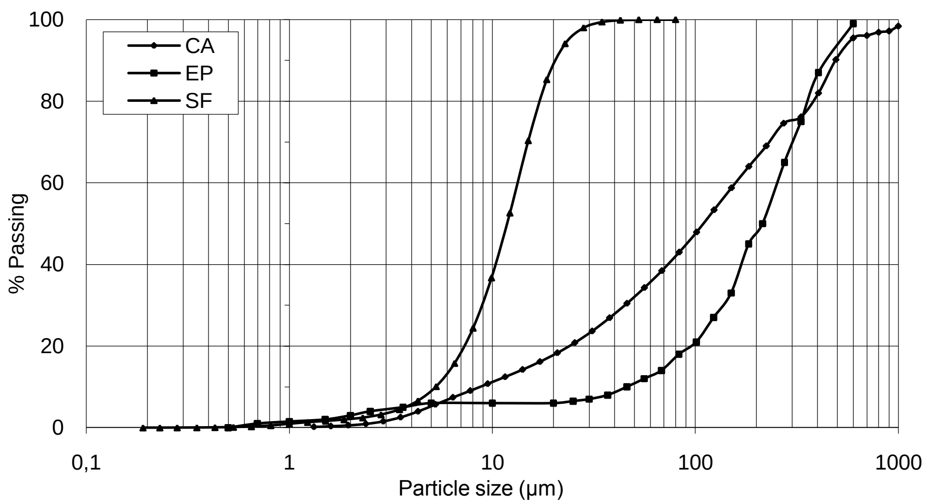

Figure. 2. The particle size distributions of coal ash (CA), silica fume (SF) and expanded perlite (EP).

Sample preparation and test methods

Five series samples were produced. The mix proportions of coal ash, silica fume, perlite and lime are given in Table 2. The mix proportions were prepared in condition of dry weights of the ingredients. The CaO/ SiO_2 ratio was adjusted on 1.6 to by weight all mixtures. Water was added to the mixture of dry materials and the water content was decided as defined below. The water to solid ratio was adjusted to obtain pastes of normal consistency. Then water/binder ratios were determined on test series for 75-80% by weight. Naphthalene sulphonate type super-plasticizer was used of 0.7% of binder (lime) in the series, compatible with ASTM C 494.

Table 2. Mix proportions of the samples (in wt %).

	A	B	C	D	E
Coal ash	55	52.5	51.25	50	52.5
Lime	45	45	45	45	45
Silica fume	-	2.5	2.5	2.5	-
Perlite	-	-	1.25	2.5	2.5
W/B (%)	0.80	0.77	0.75	0.75	0.75

Water was added to the mixture of dry materials. The water/binder ratio was adjusted to obtain pastes of normal consistency (TS EN 12350-2). Water/binder ratio was varied between 0.75% and 0.80% respectively. Slump was kept constant at 25 ± 5 mm. For each mixture, average 24 samples of 100x100x100 mm3 cubes were cast in to steel mould. The mixture was first mixed for 5 minute in a mixer and then placed in mould and it was properly compacted for 2 minute on a vibration table. After 24 hour, the specimens were taken out from the moulds and specimens were covered with moist bags for additional 48 hour. Afterward each group was divided into four parts. Steam curing treatment were applied the first part samples in a laboratory type autoclave for 6 hour. The autoclave has 20 liter volume and operated at 1.5 Bar pressure and at 120 oC temperature. Other series (2., 3. and 4.) specimens were cured for 7, 28 and 90 days respectively in a laboratory curing tank at 21±2 oC , then removed and were put in an oven as far as constant weight obtained for tests. Physical and mechanical tests for each series were applied on at least 6

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samples and the average value of the results was presented. Tests were performed for bulk density, apparent density, open porosity, and water absorption according to TS EN 992, TS EN 678 and TS 3624, respectively. Compressive strength test was applied in accordance with ASTM C 109 (TS EN 679). A quick thermal conductivity meter (Shotherm QTM-D2 Kyoto Electronics Manufacturing Co. Ltd., Japan) based on ASTM C 1113- 90 hot wire method was used to measure the thermal conductivity. For this purpose having dimensions of 100x50x17 mm samples were prepared. Measurement range of the test device is between 0.020 and 10 W/m.K. Measurements precision is ±5% of reading value each reference plate.

Results and Discussion

For the various mixes, the 28-day bulk density and the apparent density varied from 1.29 to 1.35 gr/cm^3 and from 2.17 to 2.34 gr/cm^3 respectively. Also, expanded perlite addition slightly lowered density of the samples. The density values are much lower than that of normal weight concrete (Table 3). Open porosity of the mixtures varied from approximately 38% and 44% while water absorption changed between 28% and 33%. For all series, addition of silica fume and expanded perlite increases the long term strength properties. It can be easily say that more reactive and finer additions caused an increase in the strength behaviour of the mixtures.

The property change of the series were compared the control series (A series). When the highly reactive silica fume was replaced instead of coal fly ash caused a decrease in the strength of the samples at B mixtures by autoclave curing (Table 3). However, silica fume replacement caused increase in the strength values at normal water curing condition. Highly pozzolanic silica fume addition may improves the expansive phase formation of Ettringite and causes a decrease in the strength at the early and fast hydration period during autoclaving condition. Strength loss due to the expansive Ettringite formation in the early hydration period was also explained by former researchers (Mulenga et al, 2003).

Replacing coal ash with only silica fume increased the bulk density, decreased the open porosity and led to increase in the thermal conductivity of the samples. This was mainly the fine particle size of the silica fume particle which filled the pores of the system. Increasing bulk density and formation of the crystalline Ettringite phase are the main possible reasons for the increase in the thermal conductivity. It has been reported that the crystalline structures show higher heat conduction than the amorphous structures.

Table 3. Physical and mechanical properties of the test samples.

	A	B	C	D	E
λ (W/mK)	0.55	0.52	0.56	0.58	0.57
Open porosity (%)	43.73	43.44	40.68	37.77	41.92
Bulk density (gr/cm^3)	1.31	1.32	1.31	1.35	1.29
Apparent density (gr/cm^3)	2.33	2.34	2.21	2.17	2.23
Water absorption (%)	33.39	32.83	30.53	27.96	32.45

Normal concrete: 2300 kg/m^3, λ:1.3 – 1.5 (W/mK)

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Table 4. Compressive Strength (MPa)

6 Hour ac*	9.67	6.82	10.31	15.07	12.56
7 Day wc**	5.01	8.92	8.45	9.64	8.61
28 Day wc**	5.47	9.72	12.01	12.52	11.83
90 Day wc**	11.62	12.88	13.71	13.90	12.30

ac*: Autoclaving curing, wc**: Water curing

When comparing the 28 day water cured sample microstructures, it can said that A and D series sample's hydration microstructures were similar to each other (Figure 3). Replacing silica fume and expanded perlite together instead of fly ash decrease the open porosity and consequently increase the mechanical properties. From the microstructures, one can say that physical and mechanical property changes of the samples were independent from the hydration properties of the mixtures. Demirboğa et al (2001) and Karakoç (2004) reported that EPA (Expanded perlite aggregate) increased the compressive strength of light weight concrete.

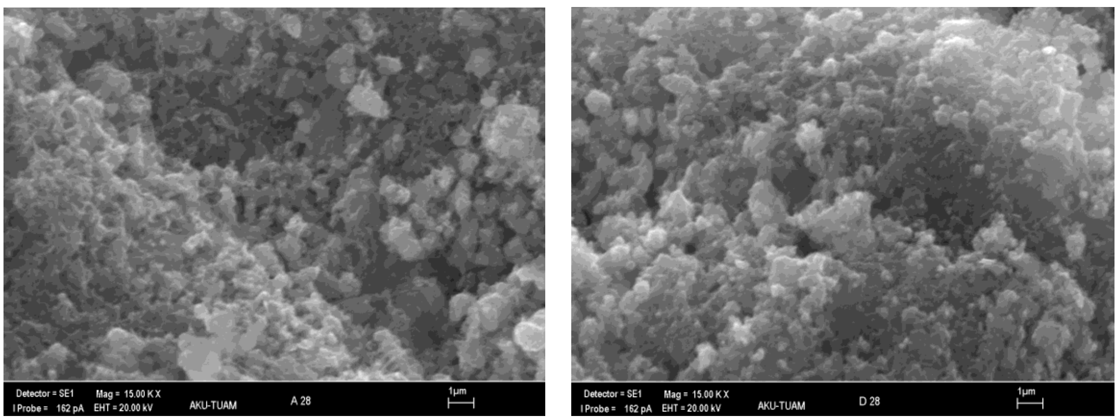

Figure 3. SEM microstructures of 28 day water cured A and D series samples.

Although the hydration properties of the different mixture pastes was same, there were regional structure differences between the series of samples (Figure 4). For example, in the control series (A series) unreacted large portlandite phases (plate like) were detected in the structure. It can be said that control series sample have lower pozzolanic reaction capacity than other series which contains silica fume and expanded perlite. Therefore free lime has not been consumed during pozzolanic reaction.

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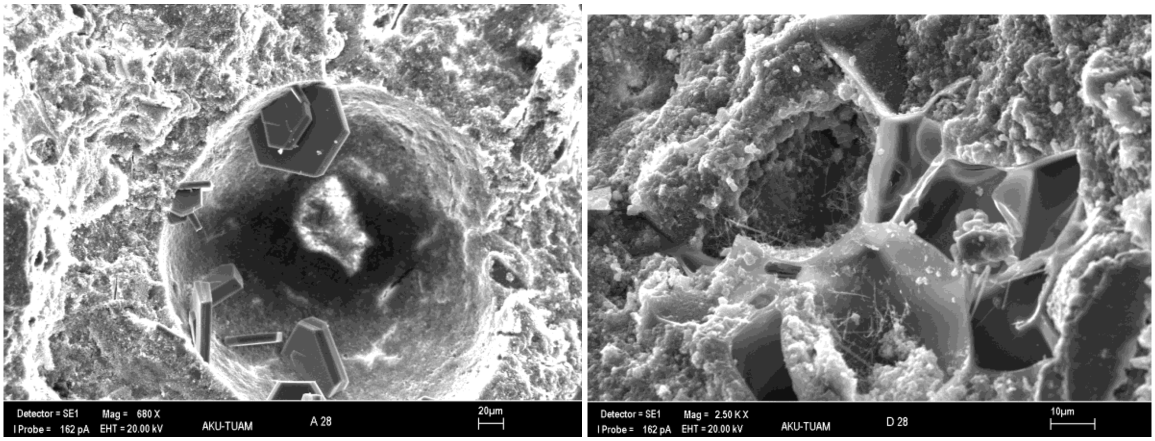

(a) (b)

Figure 4. Regional structure variance of the samples (a: A sample series, b: D sample series).

Due to the closed pore structure of the expanded perlite (Figure 4.a), water absorption and open pores of the perlite containing samples were decreased. Greater decrease in the water absorption behaviour was observed when silica fume was added simultaneously (Table 3).

Conclusions

It was concluded from the study that; coal ash from municipal heating systems can be used to produce cement free light weight concrete blocks. Pozzolanic properties of the coal ash can be enhanced by the addition of other reactive additions such as silica fume. Addition of silica fume to coal ash + lime system improves the long term strength development of the system. In addition to the possible changes in the hydration properties of the mixtures by the additions, particle size differences between the coal ash and silica fume cause strength improvement. Finer silica fume particles filled the pores better and provides better compaction. Due to the pore structure of the expanded perlite, its addition did not influence the physical properties at a given addition rate. Expanded perlite addition by replacing coal ash was increased the strength properties.

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