Fire Resistance of Fly Ash Blended Lightweight Concrete

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***Abstract* – An experimental study was carried out to examine eight mixtures made with pumice powder and fly ash in order to produce lightweight materials. Additionally, textile fiber was utilized to increase strength of the lightweight concrete. It was found that 28 days compressive strength, thermal conductivity, sound transmission speed, water absorption and unit weight varied from13.0 to 20.9 MPa, 0.34 to 0.43 W/mK, 2.52 to 3.11 km/s, 14.3 to 17.5 % and 1.19 to 1.40 g/cm^3, respectively. It was seen form SEM pictures of samples that reaction products of cement were formed. In all samples, there was no deformation due to temperature from 300 to 700°C. However, at 900°C, all samples were deformed and showed cracks of 3 mm. The compressive strengths of cracks samples were obtained from 8.1 to 10.2 MPa. The results showed that pumice and fly ash decreased thermal conductivity and sound transmission. Also, samples were not decomposed at high temperature when pumice and fly ash used as admixtures in lightweight concrete.**

***Keywords* – Fly ash, Lightweight concrete, Fire resistance, Microstructure, Thermal conductivity.**

1. Introduction

The lightweight aggregate concrete made with pumice has low density. This leads to a relative weight reduction of structures and foundations and so it will reduce the dead load. This is a significant factor for high rise buildings. Lightweight concrete is also very attractive material for repairs of the old buildings because it does not cause an increase in the total load of the structure [1]. Thermal characteristics of lightweight aggregate concrete are related to its thermal conductivity and density which, in turn, is influenced by its porous structure (i.e., the air-void system, aggregates and the matrix) carried out an experimental study to determine the thermal conductivity of light-weight concrete and they observed that thermal conductivity of lightweight concrete contained pumice was between 0.1378 W/mK and 0.3099 W/mK [2].

An experimental study on fire resistance of normal and lightweight concrete was performed by Chandra et al [3]. The fire test was carried out on 2.5 cm thick plates of normal and lightweight concrete, 5.0 cm thick slab of lightweight aggregate concrete and 15 cm thick reinforced lightweight concrete beam. Test results showed that the thermal expansion coefficient of normal weight concrete was higher than lightweight concrete. Residual compressive strength showed the same tendency. However, the decrease in the strength of the normal weight concrete is much higher than lightweight concretes.

Hossain et al also found out that the strength and density of the lightweight concrete is suitable to be used in the production of the lightweight building members if lightweight concrete is produced with volcanic pumice [4].

In this experimental study, properties of lightweight paste, which was produced by white Portland cement, pumice powder and fly ash from Afsin-Elbistan Thermal Power Plant (AEFA) in Turkey, were investigated. Annually 4 million tons of pumice and about 1 million tons of White Portland Cement (WPC) are produced in Turkey. This cement is generally used for decorative purposes. Eight lightweight concrete samples were prepared and tested for 28 days compressive strength, thermal conductivity, sound transmission speed, water absorption and unit weight.

2. Materials

In the production of lightweight paste, fine pumice was used due to its lightweight and insulation characteristics. Pumice is a textural term for a volcanic rock that is a solidified frothy lava composed of highly micro vesicular glass pyroclastic with very thin, translucent bubble walls of extrusive igneous rock pumice has sound and heat insulation characteristics due to its porous structure. Hardness of fine pumice is between 5 and 6 according to Mohs scale and unit weight is varying from 600 to 800 kg/m^3. Fine pumice (FP) does not contain any crystal water. It has silica up to 75% in its composition. The fine pumice of which specific gravity is 2.36 was obtained from Kayseri in Turkey and it was grinded in cement factory. Its fineness is 0% residue on 250 μm, 50% residue on 125 μm, 90% residue on 63 μm.

White Portland cement is a white colored hydraulic bonding material produced by grinding of white clinker, which is obtained by white clay, limestone and calcium sulfate ($CaSO_4.2H_2O$). In this study, WPC 42.5 was employed with pyrophyllite which was substituted in place of kaolin. Chemical and physical properties of WPC were given Table 1.

Chemical composition of the pyrophyllite, which were obtained in Poturge province of Malatya, was obtained from as SiO_2 (54.5%), Al_2O_3 (37.9%), SO_3 (0.1 %), Na_2O (0.1%), K_2O (0.5 %) with L.I. = 2.6%, SM=1.4% and other minor compounds [5]. WPC 42.5 produced in Turkey was classified according to level of whiteness and the compressive strength of paste prism at 28 days [6]. Chemical and physical characteristics of WPC 42.5 were given in Table 1. In terms of oxide ratio, WPC 42.5 shows similarities with CEM 1 as shown In Table 1. Calcium silicate hydrate (CSH) gel, which is main component with binding properties, is formed by the reaction of calcium silicates (C_3S and C_2S) with water. C_3A and C_4AF components also affect the binding properties of cement to some extent in early ages. However, the actual binding property of cement is provided by C_3S and C_2S components [7]. The average compressive strength of cement at 3, 7 and 28 days were found as 37, 51 and 63 MPa, respectively.

In this study, calcareous AEFA (CaO =53.44%)) was used and its physical and chemical characteristics were shown in Table 1. Chemical composition of AEFA is not suitable to ASTM C 618 Standard criterion [8]. AEFA has high CaO and SO_3 ratio. Due to high SiO_2 ratio, pumice was used to increase the amount of CaO react with SiO_2. Specific gravity of AEFA is 2.76. It was obtained from the sieve test that the fineness is 10.8% residue on 90 μm and 27.7% residue on 45 μm. City drinking water was used in mixtures.Polyester fiber used in mixtures was taken from the waste fiber of textile factories.

3. Methods

Setting time of cement paste and soundness of cement + fly ash + pumice powder paste were determined according to [9]. Workability of samples was determined according to [10]. Microstructure of 28 days hardened samples were determined by electron microscope. Compressive and flexural strength of lightweight paste, which produced by white cement, pumice powder, fly ash and textile fibers, were found according to [11]. Mixture ratios for eight different lightweight paste samples were given in Table 2 and samples, which were placed into mould and immersed cure tank, were shown in Figure 1 and 2.

Oxides (%)	WPC	AEFA	ASTM C 618 FV	ASTM C 618 CW
L.I.	2.58	2.12	<6	<6
MgO	1.12	1.75		
SO_3	3.19	11.41	<5	<5
Cl	0.005	0,012		
CaO	66	53.44		
SiO_2	22.2	18.27		
Al_2O_3	4.3	9.16		
Fe_2O_3	0.2	3.26		
K_2O	0.5	0.38		
Na_2O	0.2	0.19		
Specific gravity	3.03			
Whiteness (%)	85.6			
S+A+F		30.69	>70	>50
Free CaO		11.62		
Reac.SiO_2		15.4	>25	>25
Reac.CaO		37.32	<10	>10

Table 1. Chemical and physical properties WPC AE FA

Mix No	Pumice (g)	WPC 42.5 (g)	AEFA (g)	Water (g)	Fiber (g)	Flow (%)
A_1 (ref.)	1000	500	-	765	0	106
B_1	1000	250	250	765	0	107
C_1	1000	400	100	765	0	106
D_1	1000	300	200	765	0	106
A_2	1000	500	-	765	5.8	105
B_2	1000	250	250	765	5.8	106
C_2	1000	400	100	765	5.8	107
D_2	1000	300	200	765	5.8	107

Table 2. Mix design of lightweight concrete

Figure 1. Samples production process

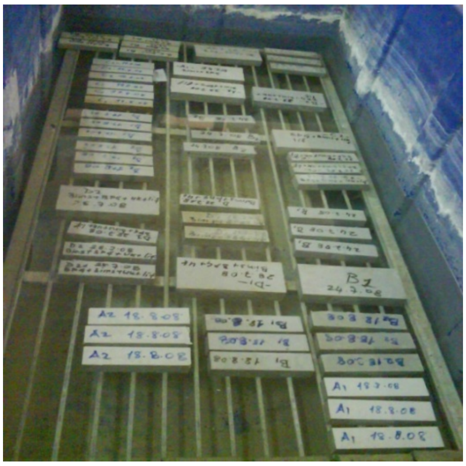

Figure 2. A group samples in the cure tank

Three samples were prepared for each age group and mixtures in the size of 40 x 40 x 160 mm and 50 x 90 x 190 mm prism. Water absorption, sound transmission speed, thermal conductivity, of the samples were obtained according to [12, 13] with ultra-sound instrument, [14] with KEM QKTM-500 instrument, respectively. Fire resistance of the samples was obtained by an oven, which can be heat up to 1200°C.

4. Results and discussions

4.1. Setting time and soundness of cement paste

It was found that normal consistency water/cement ratio of WPC 42.5 paste was 30% and soundness was 4 mm. Initial and final of setting time were 140 and 165 minute, respectively. This indicates that soundness; initial and final of setting time are lower than the limit values given in TS 21. The soundness values of A_1, B_1, C_1, and D_1 mixtures 1.5, 2.0, 1.5, 1.0 mm that were very small, were obtained.

4.2. Microstructures of pastes

SEM images of the hardened samples, which were produced by pumice powder, WPC and fly ash (A_1 and B_1), were given Figure 3 and 4. Excess hydrates of cement such as calcium silicate, hydroxide, ettringite and partially hydrated and unhydrated particles were seen in Figure 3 and 4. Amount of ettringite was higher in Figure 4 due to AEFA. Also, CSH gel in Fig. 4 has more porous structure when compared to CSH gel in Figure 3.

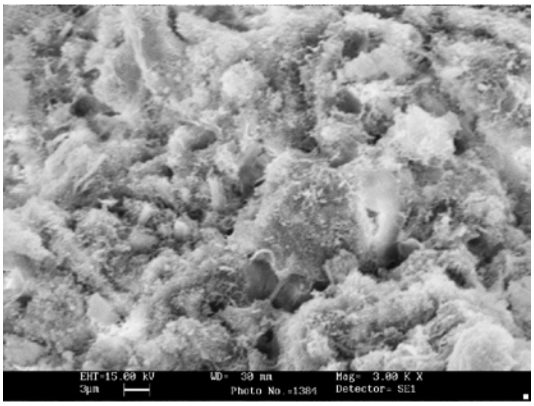

Figure 3. Microstructure of sample A_1

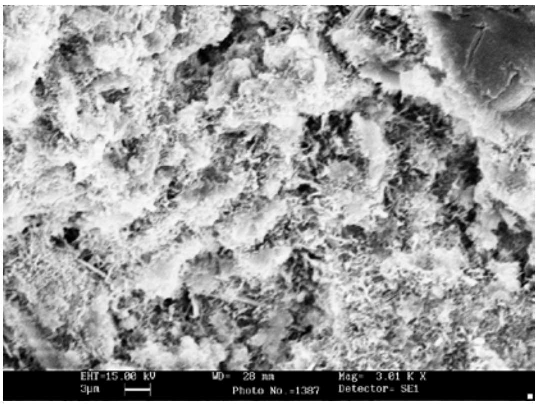

Figure 4. Microstructure of sample B_1

4.3. Water absorption of samples

The dry unit weight and water absorption ratio of the samples, which were tested according to TS 3624, were given in Table 3. The minimum dry unit weight was determined as 1.19 g/cm^3 in sample B_1 and the maximum dry unit weight was determined as 1.40 g/cm^3 in sample A_2. Due to FP and AEFA substituted in place of cement, dry unit weight of lightweight paste is lower. This means that all samples produced by FP and fly ash can be categorized as lightweight paste. Also, FP and AEFA substituted in place of cement caused an increase in water absorption capacity. The maximum water absorption ratio was determined as 17.5% in sample C_2 and minimum water absorption ratio was determined as 14.3% in sample A_1.

Mix. No	Water absorption ratio (%)	Unite weight (g/cm^3)
A_1	14.3	1.37
A_2	14.6	1.40
B_1	15.7	1.19
B_2	16.6	1.26
C_1	16.4	1.30
C_2	17.5	1.34
D_1	16.2	1.24
D_2	16.6	1.31

Table 3. Water absorption and unite weight

4.4. Sound transmission of samples

The sound transmission time of samples were obtained by PUNDIT 6 ultrasonic instrument. The length of samples was measured by micrometer. Ultra-sound transmission speed of the samples were obtained by V=L/T km/s unit. The obtained values from samples were summarized in Table 4. A relationship as shown in Figure 5 was observed between ultra-sound transmission speed and dry unit weight of samples. The minimum ultra-sound transmission speed was obtained at the minimum dry unit weight B_1. The ultra-sound transmission speed of sample B_1 was determined as 2.52 km/μs. The maximum ultra-sound transmission speed was obtained in sample A_2. The ultra-sound transmission speed of sample A_2 was 3.11 km/s. These sound transmission values of lightweight hardened paste were lower than that of normal weight concrete [15]. These results showed that lightweight hardened paste could absorb ultra-sound compared to normal weight concrete.

Mix. No	Sound transmission speed (km/s)
A_1	3.10
A_2	3.11
B_1	2.52
B_2	2.70
C_1	2.83
C_2	2.89
D_1	2.83
D_2	2.89

Table 4. Ultra-sound transmission speed of the samples

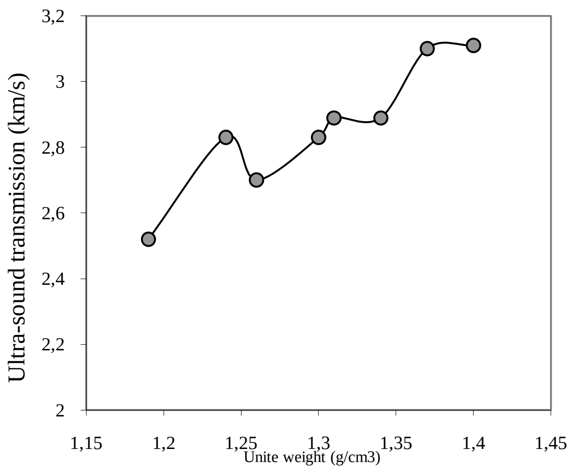

Figure 5. Unite weight and ultra-sound transmission relations

4.5. Thermal conductivity of the samples

The thermal conductivity of lightweight hardened lightweight concrete samples was measured KEM QKTM-500 instrument. The thermal conductivity of lightweight hardened lightweight concrete samples was given in Table 5. The thermal conductivity values of lightweight hardened lightweight concrete samples showed similar behavior with sound transmission values shown in previous section. Low thermal conductivity values were obtained from the samples which have low dry unit weight. The minimum thermal conductivity was obtained in sample B_1 as 0, 34 W/mK. The maximum thermal conductivity was obtained in sample A_2 as 0.43 W/mK. When these values compared with the criteria in [16], it is can be seen that lightweight hardened lightweight concrete samples produced in this study can be accepted as insulation material.

Mix. No	λ (W/mK)
A_1	0.42
A_2	0.43
B_1	0.34
B_2	0.35
C_1	0.38
C_2	0.41
D_1	0.35
D_2	0.35

Table 5. Thermal conductivity of the samples

4.6. Flexural and compressive strength of samples

The flexural strength of lightweight hardened lightweight concrete samples at 28 day was determined by taking the average of three 40 x 40 x 160 mm prism samples. The compressive strength of lightweight hardened lightweight concrete was determined by taking the average of six samples. The flexural and compressive strength of samples were depicted Figure 6 and 7.

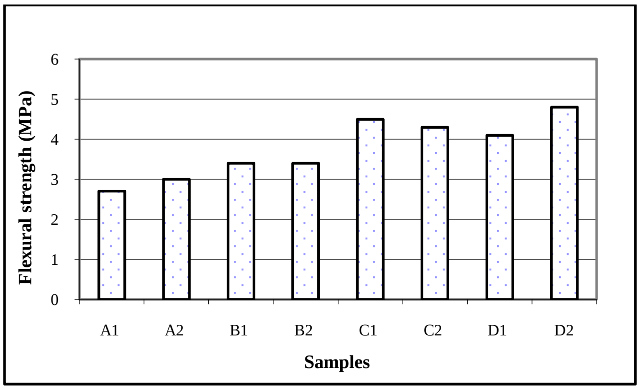

Figure 6. Flexural strength of lightweight concrete

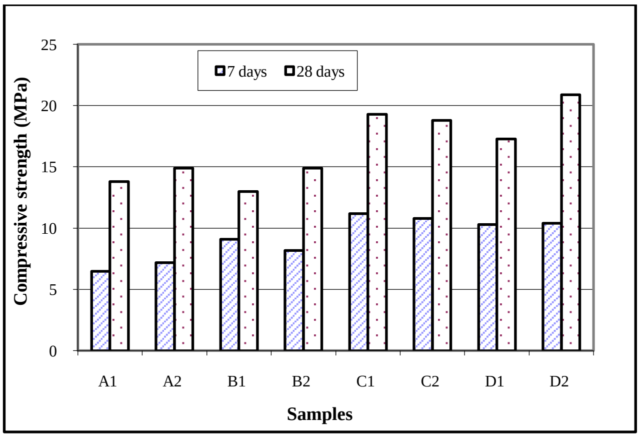

Figure 7. Compressive strength of lightweight concrete

It was observed that the flexural strengths of all samples have low flexural strength values. This was caused the fact that the pumice and fly ash are added in concrete. The maximum compressive strength was obtained in sample C_1 at 7 days. The compressive strength of hardened lightweight concrete C_1 was determined as 11.2 MPa at 7 days. As for 28 days the maximum compressive strength was obtained in sample D_2. The compressive strength of sample D_2 was determined as 20.9 MPa at 28 days. Effect of fiber could not be determined clearly on the flexural and compressive strength of samples. It was considered that the reason was that there were no coarse aggregates in sample mixtures.

4.7. Fire resistance of the samples

The samples with size of 50 x 90 x 190 mm were cured for 28 days and then dried at room temperature. Samples were held in oven at 300, 500, 700 and 900°C for an hour. The sample weights were measured before and after the samples were placed in oven. Sample surfaces were also examined for cracks. The compressive strength of samples held in oven at 900°C was determined. A group of samples held in oven at 900°C were shown Figure 8. The weight loss and compressive strength of samples were given Table 6.

Mix. No	300 °C	500 °C	700 °C	900 °C	Comp. strength at 900 °C MPa
A_1	12.6	17.7	20.2	22.5	9.8
A_2	14.5	18.2	20.6	22.6	10.0
B_1	9.4	11.1	14.9	17.0	8.5
B_2	10.5	13.3	17.2	19.5	8.8
C_1	11.3	16.9	19.2	21.9	10.2
C_2	12.1	16.4	19.2	21.2	9.1
D_1	12.9	15.6	18.9	20.5	8.1
D_2	15.0	17.5	20.1	22.1	8.3

Table 6. The weight loss % and compressive strength of samples

No surface cracks were observed for the samples held in oven at 700°C. However, surface cracks up to 3 mm were observed for all samples held in oven at 900°C as shown in Fig. 8. Weight loss was also observed in all samples when the oven temperature was increased. The rate of weight loss was occurred at 300°C and then rate of weight loss was smaller as oven temperature was increased. This behavior could be explained as the crystal water in concrete samples vanishes by evaporation before temperature reaches 700°C. The highest weight loss was observed in sample A_2 about 22.6% while the minimum weight loss was observed in sample B_1 about of 17%. Despite surface cracks in samples held in oven at 900 °C, large weight loss did not observed. Weight loss in samples was occurred in form of small flakes and powder. When the samples were crashed, the textile fiber was not observed in concrete, since it was completely incinerated. There was no deformation in samples up to temperature of 500°C. However, light and heavy deformations were observed in samples at temperatures of 700°C and 900°C, respectively.

In samples held in oven at 900°C, the highest compressive strength was obtained in sample C_1 about 10.2 MPa and the minimum compressive strength was obtained in sample D_1 about 8.1 MPa. During the compressive strength test, samples were ruptured shapely without exploding.

Figure 8. A group of samples held in oven at 900°C

5. Conclusions

Lightweight hardened lightweight concrete produced by pumice, WPC 42.5 and fly ash from Thermal Power Plant has average compressive strength and good heat and sound insulation. It also showed better fire resistance. SEM images also indicate that reaction products were formed and there were no materials which are not entering in reaction. Moreover, produced lightweight concrete has higher compressive strength, better insulation properties against sound/heat and better aesthetic view than clay bricks. So, lightweight concrete panels could be used in walls and slabs. It was also seen that use of fly ash from power plants and textile fabrics waste in concrete technology can provide environment protection.

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