Asian Journal of Chemistry Vol. 22, No. 5 (2010), 4104-4110

Effect of Moisture and Temperature on Thermal Conductivity of G2/04 Class Autoclaved Aerated Concrete

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In this study, the thermal conductivity value of G2/04 class autoclaved aerated concrete (AAC) material used as wall as in constructions and the change of material according as moisture and temperature were examined experimentally. The thermal conductivity value of autoclaved aerated concrete samples was measured experimentally in between 0 and 45 ºC temperatures and between 0 and 41.5 % moisture content. The thermal conductivity values of materials were measured according to the heat flow meter method using Lasercomp Fox 314 device. As a result of the study, it has been observed that the thermal conductivity of G2/04 class autoclaved aerated concrete material increased comparatively with temperature and moisture content. With the help of these experimental results, regression study was made for the change of thermal conductivity of G2/04 class AAC material according as the temperature and moisture content and k = 0.0926 + 0.00013 T + 0.00214 nm + 0.00007 T nm (W/m K) relation was obtained.

Key Words: Autoclaved aerated concrete, Thermal conductivity, Moisture content, Temperature.

INTRODUCTION

For decreasing the energy loss in constructions, the importance of the usage of light construction materials with thermal insulation has been increasing day by day. One of the usage aims of light construction materials is providing thermal insulation in constructions. These are usually porous materials with weak carrying characteristics and one of these construction materials is autoclaved aerated concrete. Autoclaved aerated concrete is a porous construction material and the proportion of macro and micro level porous in all construction has been changing between 69-88 %[1,2]. This high rate of pore quantity provides low autoclaved aerated concrete density and also low thermal conductivity value. The autoclaved aerated concrete density as pore quantity is between[3,4] 300-800 kg/m^3 and its thermal conductivity value changes between 0.07-0.16 (W/m K)[4]. Autoclaved aerated concrete with certain density value reaches its lowest thermal conductivity value in its dry situation but while the moist value in material is increasing, the thermal conductivity of the material starts to increase, too. So, low thermal conductivity value of dry air which stays

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dry in pores has been effective on replacing with moist air whose thermal conductivity value is higher by the effect of temperature, pressure difference and the cracks in the material.

When the studies in literature are examined, it has been observed that the thermal conductivity of different construction materials are examined theoretically, experimentally and numerically[5-9] and also the effect of moisture and temperature on thermal conductivities of autoclaved aerated concrete and similar porous construction and composite materials are studied in different studies[10-14].

In this study, the change of the thermal conductivity of G2/04 class autoclaved aerated concrete material (its pressure strength is 2.5 N/mm^2 and its density is 400 kg/m^3) according as temperature and moisture content has been examined. The aim of this study is to determine the thermal characteristics of G2/04 class autoclaved aerated concrete, to improve it and to provide contribution for energy gain.

Production of autoclaved aerated concrete: Autoclaved aerated concrete is a porous construction material which is obtained as a result of plaster's, which occurs by mixing quartzite, lime, aluminum powder and cement with water, hardening under the compressed steam.

The porous structure of autoclaved aerated concrete whose general chemical components are given in Table-1 has been occurring as a result of chemical reactions of AAC's components. Lime and cement used for connecting material is grinded as a very thin powder mixed by silicic sand (quartzite) and the water is added. When quicklime makes a reaction with the water (eqn. 1), a great amount of heat and quicklime is obtained. When the temperature of mixture is on the desirable level by the effect of the energy coming out, pore creator aluminum powder is added. Gas particles (eqn. 2) puff the clay of autoclaved aerated concrete out and form its micro porous structure[14].

TABLE-1
CHEMICAL COMPENENT OF AAC

CaO (%)	SiO_2 (%)	Fe_2O_3 (%)	SO_3 (%)	K_2O (%)	TiO_2 (%)
56.98	31.89	5.06	3.72	1.97	0.38

$$CaO + H_2O \rightarrow Ca(OH)_2 + 278 \text{ Kcal/kg CaO} \quad (1)$$

$$2Al + 3Ca(OH)_2 \rightarrow 3CaO\cdot Al_2O_3 + 3H_2 + 3676 \text{ Kcal/kg} \quad (2)$$

$$5Ca(OH)_2 + 6SiO_2 + 5.5H_2O \rightarrow 5CaO\cdot 6SiO_2\cdot 5.5H_2O + 5H_2O \quad (3)$$

Hardening starts as a result of calcium hydro silicate and aluminum hydro silicate occurring in the material and when it reaches to certain hardness, it is cut on desirable measures by separating the material from its mold. After that, it is hardened with the steam in high pressure and temperature by taking it to autoclave (eqn. 3). So, autoclaved aerated concrete reaches to its final physical value.

SEM view showing porous and crystal structure of G2/04 class autoclaved aerated concrete that completed its production level and is used in the experimental study has been given in Fig. 1.

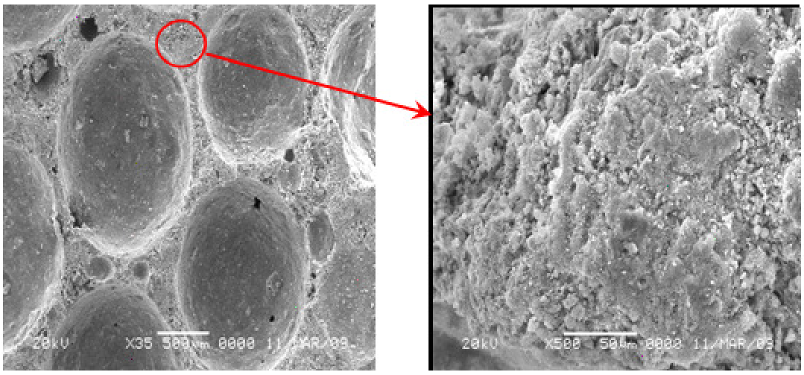

Fig. 1. SEM images of autoclaved aerated concrete (AAC)

EXPERIMENTAL

The porous structure of AAC material occurs in consequence of its swelling in casting mold. As a result of swelling, density starts to fall from the underside of the mold to the head. Because of this, in this study, G2/04 class AAC samples produced according to the standard of EN 771-4 were taken from the middle sides for its representing the whole production block. Samples were prepared properly for Lasercomp Fox 314 device with 300 mm^2 × 300 mm^2 cross sectional area and about 30 mm thickness. First, these samples were dried in a drying oven until they came to a stable mass then, they were measured at five different temperature points between 0-45 ºC by putting them into the thermal conductivity value measuring device. After the measurements of samples, they were put into air conditioning device and moisturized. After that, moisture content of the moisturized sample was measured by the help of the equation 4.

$$nm = \frac{(m_2 - m_1)}{m_d} \times 100 \quad (4)$$

The sample whose moisture content was found was put into the thermal conductivity measurement device and its thermal conductivity was measured again on the same temperature values. So, far 8.4, 17.3, 25.3, 29.9, 35.5, 41.5 % moisture values of samples moisturized gradually, the thermal conductivity values were measured at average temperatures 0, 5, 15, 25, 35 and 45 ºC.

Measurement of the thermal conductivity by heat flow meter method: Heat flow meter method is one of the experiment methods which are often used for determining the thermal conductivity coefficients of materials like insulation materials, polymers, construction elements, glass and ceramic. Heat flow meter method is a steady state measuring method and its base relies on the equation of

$$q'' = k \times \frac{T_2 - T_1}{\Delta x} \; (W/m\,K) \quad (5)$$

which is one-dimensional Fourier heat conductivity.

In the heat flow meter device (Fig. 2), the sample in a certain thickness is put between two plates with different temperatures and axial heat flow value passing from the sample is determined. After that, the heat conduction coefficient is determined by the help of the equation 5, using the heat flow value, thickness of sample and the temperature difference between cold and hot surfaces. Thickness should be chosen as low as possible because one-dimensional heat crossing acceptance is made in the measurement method.

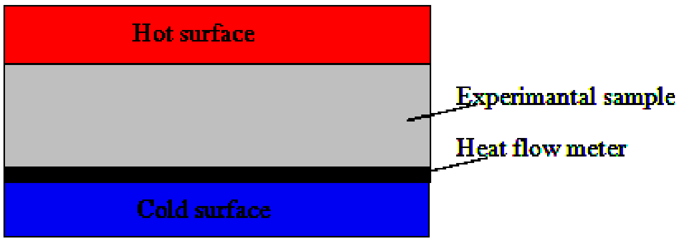

Fig. 2. Schematic view of heat conductivity measurement device

Determining the general equation by the regression analyze: Regression is a technique that is used for guessing the unknown situations with the help of known values. By the usage of experimental data taken from this experimental study, it is aimed that dependent variable (thermal conductivity coefficient, k) should be expressed in the form of independent variables [moisture quantity (nm) and temperature (T)] by multiple regression analyze.

So, when the values taken from the experimental study are examined, it has been observed that the relationship between the thermal conductivity of G2/04 class AAC and moisture and temperature is

$$y = a + b \cdot x_1 + c \cdot x_2 + d \cdot x_1 \cdot x_2 \quad (6)$$

as a result of the searches and tests. a, b, c, d coefficients are determined by the usage of the least squares method. The comparison of regression equation and the experiment results are given in conclusion section.

RESULTS AND DISCUSSION

As AAC is a construction material with high porous quantity, it provides some advantages like low density and low thermal conductivity in dry situation. But it brings some problems because of its structure that gathers moisture and can't throw it easily. As a result of the experimental studies on G2/04 class AAC material for searching the effect of moisture and temperature on AAC material, it has been observed that moisture has an important effect on the thermal conductivity of the material. When the experimental results in Fig. 3 (Table-2) have been examined, it can be understood that the thermal conductivity of the material has been changed significantly with moisture and temperature.

TABLE-2
EXPERIMANTAL RESULTS AND REGRESSION EQUATION VALUES

Average temperature T_a (ºC)	Moisture content (%)	Sample mass (g)	k_{exp} (W/m K)	k_{reg} (W/m K)	Absolute error (%)
0.0	0	1097.81	0.0930	0.0926	0.00
5.0		1097.81	0.0942	0.0933	0.01
15.0		1097.81	0.0960	0.0946	0.02
25.0		1097.81	0.0978	0.0959	0.02
35.0		1097.81	0.0994	0.0972	0.02
45.0		1097.81	0.1007	0.0985	0.02
0.0	8.4	1189.95	0.1121	0.1106	0.01
5.0		1189.95	0.1150	0.1142	0.01
15.0		1189.95	0.1214	0.1214	0.00
25.0		1189.95	0.1290	0.1285	0.00
35.0		1189.95	0.1374	0.1357	0.01
45.0		1189.95	0.1463	0.1429	0.02
0.0	17.3	1287.92	0.1335	0.1296	0.03
5.0		1287.92	0.1381	0.1364	0.01
15.0		1287.92	0.1486	0.1498	0.01
25.0		1287.92	0.1620	0.1632	0.01
35.0		1287.92	0.1784	0.1766	0.01
45.0		1287.92	0.1961	0.1900	0.03
0.0	25.3	1375.36	0.1491	0.1468	0.02
5.0		1375.36	0.1559	0.1563	0.00
15.0		1375.36	0.1714	0.1753	0.02
25.0		1375.36	0.1917	0.1943	0.01
35.0		1375.36	0.2165	0.2133	0.01
45.0		1375.36	0.2401	0.2323	0.03
0.0	29.9	1426.38	0.1687	0.1566	0.07
5.0		1426.38	0.1633	0.1677	0.03
15.0		1426.38	0.1788	0.1900	0.06
25.0		1426.38	0.1992	0.2122	0.07
35.0		1426.38	0.2243	0.2344	0.05
45.0		1426.38	0.2517	0.2567	0.02
0.0	35.2	1484.11	0.1768	0.1680	0.05
5.0		1484.11	0.1752	0.1809	0.03
15.0		1484.11	0.1936	0.2069	0.07
25.0		1484.11	0.2186	0.2328	0.07
35.0		1484.11	0.2505	0.2588	0.03
45.0		1484.11	0.2879	0.2847	0.01
0.0	41.5	1553.66	0.1978	0.1814	0.08
5.0		1553.66	0.1930	0.1966	0.02
15.0		1553.66	0.2163	0.2270	0.05
25.0		1553.66	0.2489	0.2573	0.03
35.0		1553.66	0.2917	0.2877	0.01
45.0		1553.66	0.3453	0.3181	0.08

Related to the measurements made in dry situation, it is clear that the thermal conductivity of the material has been increasing linearly with temperature. The reason of this increase is that both the air in pores and the thermal conductivity of AAC matrix material increase with the temperature. It appears that the thermal conductivity of the material starts to increase together with the increase of moisture content of the material. The thermal conductivity of the material increases more according as the experimental temperature increasing together with the increase of the moisture content of the material. The most important reason of this is the moisture increasing in the material because the thermal conductivity of moist air increases more than the dry air. The thermal conductivity of the dry air is 0.024 W/m K and the thermal conductivity of the water is 0.58 W/m K (in normal conditions) explains this increase. It appears that the thermal conductivity of the material becomes 0.34 W/m K in 45 ºC ad. 41.5 % moisture quantity. This value is 3.5 fold of the thermal conductivity value in dry situation of the material. This situation shows that energy consumption increases when AAC material is moist or used in moist regions.

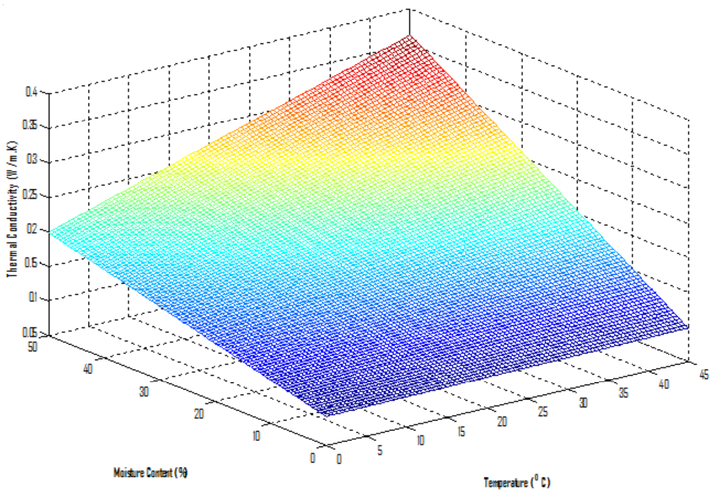

Fig. 3. Change graphic of the thermal conductivity of G2/04 autoclaved aerated concrete (AAC) in terms of moisture and temperature

Conclusion

A regression study has been made because the results after these experimental studies may be beneficial in terms of time and cost in the post studies. After the regression study, for the change dependent on the moisture and temperature, the thermal conductivity value of G2/04 class AAC material is

$$k_{reg} = 0.0926 + 1.3 \times 10^{-4}\ T + 2.14 \times 10^{-3}\ nm + 7.0 \times 10^{-5}\ T\ nm\ (W/m\ K) \quad (7)$$

In this equation, temperature is T (ºC) and moisture value is nm (%). For testing the validity of the equation, the thermal conductivity value was calculated by the help of the equation for moisture and temperature values in the experimental studies and the value is given in Table-1. When Table-2 is examined, it has been seen that the thermal conductivity values (k_{reg}) calculated by the help of regression equation overlaps to the thermal conductivity values (k_{reg}) taken after the experiment. It has been observed that error values don't exceed 8 %.

As a result, the thermal conductivity of G2/04 AAC material increases according to the moisture and temperature and for determining the thermal conductivity of this material theoretically, k_{reg} equation which is the function of moisture and temperature was obtained and given.

k : Thermal conductivity value (W/m K)
k_{exp} : Thermal conductivity value obtained from experiment result (W/m K)
k_{reg} : Thermal conductivity value obtained from regression equation (W/m K)
nm : Moisture quantity (kg moisture/kg AAC)
m_d : Mass of material in dry situation (kg)
m_1 : Mass of the material before moistening (kg)
m_2 : Mass of the material after moistening (kg)
T : Temperature (ºC)
T_1 : Surface temperature of hot plate (ºC)
T_2 : Surface temperature of cold plate (ºC)
T_a : $\left(T_a = \frac{T_2 - T_1}{2}\right)$ Average temperature (ºC)
Δx : Thickness of the sample (m)
q" : Heat flow (W/m K)
ρ : Density of the material (kg/m^3)

ACKNOWLEDGEMENT

The authors are grateful to Ministry of Industry and Trade of Turkey for the support of this work (project number of 00093.STZ.2007-1).

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(*Received*: 8 December 2009; *Accepted*: 30 January 2010) AJC-8378