THERMAL PERFORMANCE & FIRE RESISTANCE OF AUTOCLAVED AERATED CONCRETE EXPOSED HUMIDITY CONDITIONS

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Abstract

Autoclaved Aerated Concrete (AAC) is also being produced for many years, there are still some points that need to be clarified. One of these points needs to know is humidity intrusion effects on AAC members in areas with high relative humidity levels of Mediterranean climates which are important in durability and insulation properties of AAC. Therefore, some tests on mechanical and physical properties of ACC concrete carried out. These include thermal insulation and fire resistance tests under different level of humidity ACC blocks. According to the test results; increasing in humidity condition inside the chamber during heating procedure under steady state condition, caused increasing in average temperature change on outside surface of AAC wall. AAC losses its mass and mechanical properties subjected to the high elevated temperature above 500°C.

Keywords: *Thermal performance, AAC, fire resistance test, humidity*

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1. INTRODUCTION

Building design and material properties influence thermal performance and energy consumption for residential and commercial buildings. It is important to remember that thermal performance of any building material is the result of several factors and may not be assumed either effective or ineffective on the basis of any one factor. There are many definitions of the various thermal properties that are used to determine the overall thermal efficiency of any building material. Autoclaved aerated concrete (AAC) offers specific favorable properties in the context of sustainable development in the construction industry. AAC production technologies are energy-efficient and consume low quantities of raw materials as compared to the production of other construction materials, which can be attributed to low density and a special waste-free and environmental friendly production formula of AAC, [1]. Typical AAC density is between 300 and 1,000 kg/m^3 (in a dry condition). Aerated concrete has no coarse aggregates in its mixture, and it can be mentioned that aerated lightweight concrete is the concrete mortar which is aerated with fine and small bubbles from a chemical process or by using air entraining agent. Autoclaved aerated concrete is made of cement, silica sand, quick lime & gypsum and aluminum powder [2].

2. EXPERIMENTAL PROCEDURE

Experiments were carried out in order to investigate thermal performance and humidity intrusion effects and fire resistance test. The moisture content at equilibrium for AAC depends on the bulk density and climate conditions. Usually the moisture content ranges from 3 to 5% if the surrounding conditions are 23°C and 80% relative humidity.

This paper includes briefly descriptions about experimental procedure of tests which were carried out according to TS pr EN [3] and ASTM [4, 5].

2.1 Fire Resistance Test

Fire resistance test was done to find out effects of fire on the properties of AAC. Test was done on 50x50x50 mm cubes at six different temperatures. These temperatures were fixed to be 100°C, 300°C, 500°C, 700°C, 900°C and 1000°C, and were on the electrical muffle furnace. Three AAC samples were tested for each temperature.

AAC blocks were cut by using a cutting machine; all the blocks were dried at temperature of 60°C for the period of three days by using electrical oven.

Each of the three samples selected for testing should be faced to desired temperature inside the furnace for 30 minutes. Each sample was weighted before and after testing for determining effect of fire on the weight loss of AAC blocks.

After fire resistance test, compressive strength of the samples was determined to detect effect of fire on strength properties of AAC blocks [5], figure 1.

2.2 Thermal Performance Tests

Thermal performance tests were carried out for evaluating thermal insulation properties of AAC panels under three different humidity conditions. For this test special chamber made of galvanized steel plates was set with dimensions of 700×850×600 mm. Distance between two steel panels of chamber was filled with lightweight material and gypsum mortar to increase its insulation against any thermal convention and also to avoid heat transmission from door of chamber polyurethane foam injected inside the door panel.

Thermal performance tests were carried out at three different conditions:
1) Three different humidity conditions.
2) AAC panel tested with and without coating. Gypsum coating was applied on the both faces of the panel with a thickness of 10 mm.
3) AAC walls tested at three different temperature levels under steady state conditions. Samples were kept at specified temperatures for 95 minutes.

Fig-1: Fire resistance test apparatus

Fig-2: Set up of thermal conductivity test inside the chamber

Tests were carried out at 40°C, 60°C and 70°C temperatures and three different humidity conditions of 55%, 70% and 100%.

Hot-Box device was used for determining coefficient of thermal conductivity of AAC walls. Procedures of this test were performed according to TS EN ISO 8990 [6].

Hot-Box contains two well insulated chambers as cold chamber and hot chamber that were conditioned by heating and cooling equipment to attain desired temperatures on each side of the wall. Both cold and hot chambers were cycled among different temperatures. These temperature cycles were programmed to simulate outdoor climatic conditions. Temperatures were determined by thermo-couples with a 0.1°C sensitivity. There were 9 thermo-couples existing on each chamber for measuring surface temperature of wall sample and 3 thermo-couples were available on each chamber for measuring temperature of chambers. Dimension of AAC wall which used for thermal conductivity test was 1200×1200x100 mm, figure 4.

All data (surface and ambient temperatures) were transferred to a PC and coefficient of thermal conductivity was calculated.

Fig-3: Thermal conductivity test setup outside the chamber

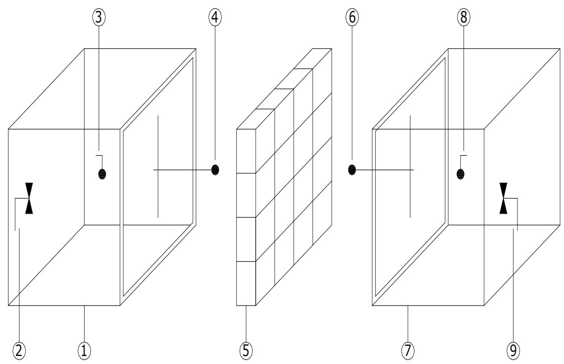

Fig-4: Hot-Box test apparatus

1. Cold chamber, 2. Freezer fan, 3. Thermo couples (3unit) to measure the ambient temperature of cold chamber, 4. Thermo couples (9unit) to measure the surface temperature (cold) of wall sample, 5. Wall specimen (1200 mm× 1200mm), 6 Thermo couples (9 units) to measure the surface temperature (hot) of wall sample, 7. Hot chamber, 8 Thermo couples (3 units) to measure the ambient temperature of hot chamber, 9 Heater fan

3. RESULTS AND DISCUSSION

Thermal performance tests were carried out at three different humidity conditions to determine effects of humidity on thermal properties of AAC panels. The main propose of this test was detecting temperature changes on outside surface of AAC wall when the heating procedure was carrying out inside the chamber. Heating procedures were carried out at three different temperature conditions; each temperature condition was kept constant for a duration of 95 minutes.

At 55% humidity condition of inside the chamber, temperature level on the outside surface of AAC wall without coating after 95 minutes of heating procedure with 40°C was increased from 23.2°C to 24.9°C. After increasing temperature of inside the chamber up to 60°C, within 95 minutes of heating procedure, temperature on the outside surface of AAC wall increased from 24.9°C to 27.3°C. Third 95 minutes of heating process was carried out when inside temperature was 70°C, after this process temperature on the outside surface of AAC wall was 30.2°C, figure 5.

After applying gypsum coating on the both surfaces of AAC wall heating process at 55% humidity condition were carried out. At the end of 95 minutes of heating process at 40°C, outside surface of AAC wall's temperature increased from 22.7°C to 23.2°C. Second 95 minutes of heating process started when temperature of inside the chamber raised 60°C, the temperature on the outside surface of AAC wall increased from 23.2°C to 25.3°C. Temperature of inside the chamber at 70°C, showed the outside surface of AAC wall temperature variation from 25.3°C to 27.1°C after 280 minutes totally heating process, figure 6.

At 70% humidity condition inside of the chamber, temperature on the outside surface of AAC wall at 40°C was increased from 22.9°C to 24°C. And when the temperature of inside of the chamber raised to 60°C within 95 minutes, the outside surface of AAC wall increased from 24°C to 27.4°C. Third 90 minutes of heating process was carried out when inside temperature was 70°C after this process temperature on the outside surface of AAC wall was 31.2°C, figure 7.

After applying gypsum coating on both surfaces of AAC wall heating process at 70% humidity condition were carried out. At the end of 95 minutes of heating process at 40°C, outside surface of AAC wall's temperature increased from 20.5°C to 22.1°C.

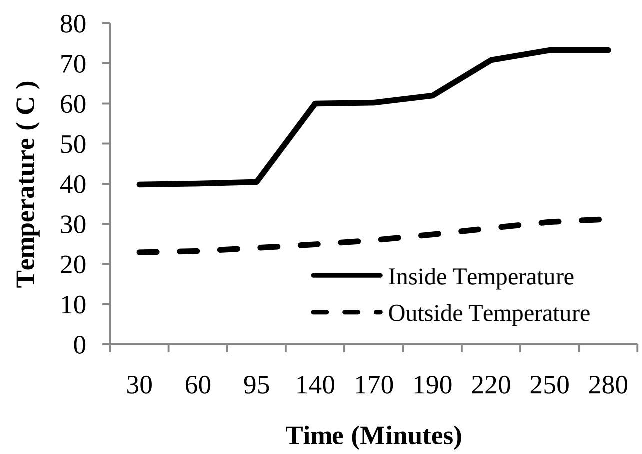

Fig-5: Temperature variations inside and outside surface of AAC wall without coating- 55% humidity.

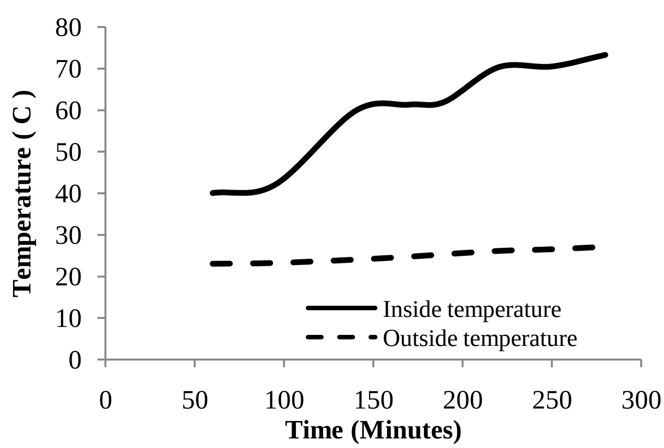

Fig-6: Temperature variations inside and outside surface of AAC wall with coating - 55% humidity.

Second 95 minutes of heating process started when temperature of inside the chamber was 60°C and after this process temperature on the outside surface of AAC wall increased from 22.1°C to 24.6°C .When the temperature of inside the chamber reached to 70°C, the temperature on the outside surface of AAC wall increased from 24.6°C to 27°C after totally 280 minutes of heating process, figure 8.

At 100% humidity condition of inside chamber, temperature level on the outside surface of AAC wall after 95minutes heating procedure at 40°C was increased from 22.7°C to 23.1°C. After increasing temperature of inside the chamber up to 60°C, within 95 minutes heating procedure, temperature on the outside surface of AAC wall increased from 23.1°C to 29°C. The third 95 minutes of heating process was carried out when inside temperature was 70 °C and after this process temperature on the outside surface of AAC wall was measured to be 32.3°C, figure 9.

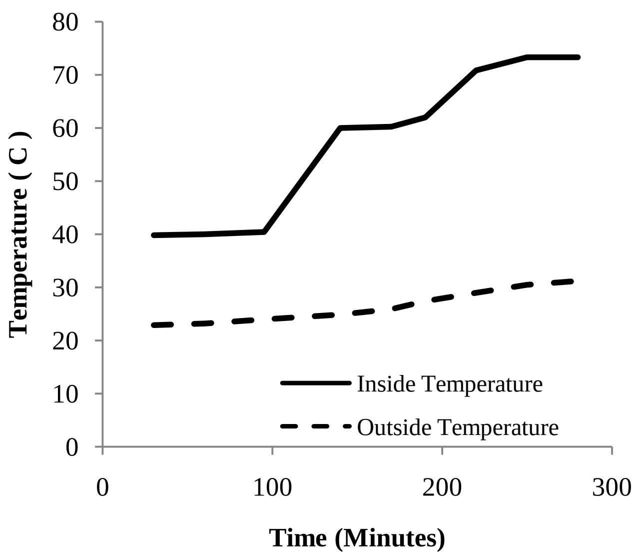

Fig-7: Temperature variations inside and outside surface of AAC wall without coating- 70% humidity.

After applying gypsum coating on the both outside and inside surfaces of AAC wall, heating processes in 100% humidity condition were carried out. At the end of 95 minutes heating process at 40°C, outside surface of AAC wall's temperature increased from 23.5°C to 26°C.

Second 95 minutes of heating inside the chamber was 60 °C and after this process, the temperature on the outside surface of AAC wall increased from 26°C to 28°C. With increasing temperature inside the chamber up to 70°C, the temperature on the outside surface of AAC wall increased from 28°C to 30.7°C after totally 280 minutes of heating process, figure 10.

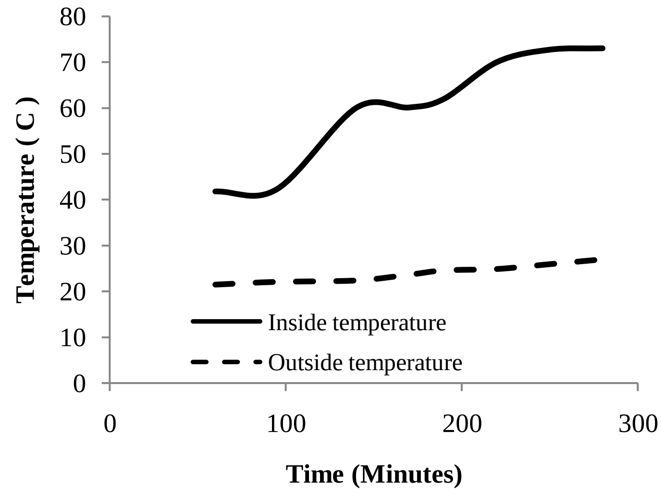

Fig-8: Temperature variations inside and outside surface of AAC wall with coating- 70% humidity.

Humidity and temperature inside the houses are two important factors which can affect comfort and health of habitants. It was reported that temperature of 20 °C to 26 °C with humidity condition of 30% to 70% are essential for suitable living conditions inside the houses.

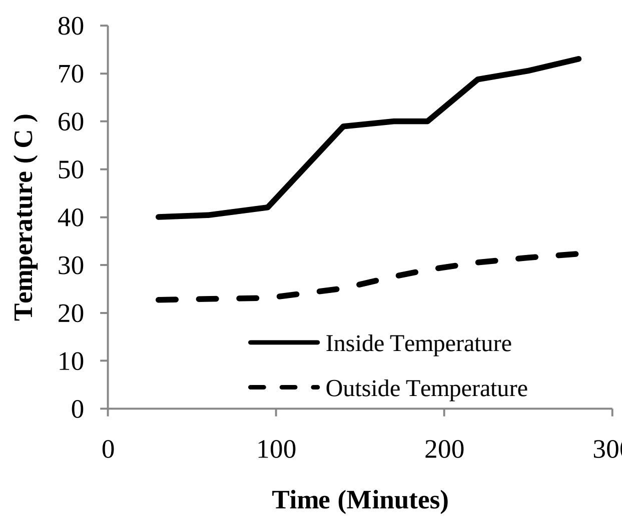

Fig-9: Temperature variations inside and outside surface of AAC wall without coating- 100% humidity.

According to the test results after 15% to 45% increasing in humidity conditions during including 280 minutes heating under steady state condition, temperature on the outside surface of AAC wall increased with average amounts of 1.3°C to 2.6°C for panel without coatings. After applying gypsum coating on the both surfaces of AAC wall, temperature on outside surface of wall decreased with average amount of 2.44 °C when it is compared with same humidity conditions for AAC wall without coating. It means, gypsum coating blocks open pores on surface of AAC wall and prevents air and humidity to penetrate inside of the wall and therefore increasing thermal insulation [7].

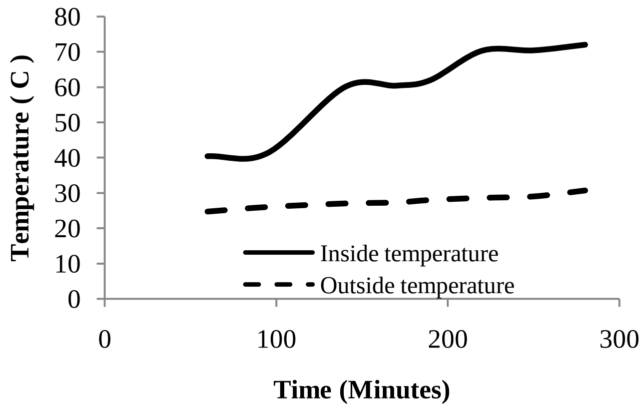

Fig-10: Temperature variations inside and outside surface of AAC wall with coating- 100% humidity.

3.1 Thermal Conductivity of AAC Walls by Using Hot-Box Device

Thermal conductivity coefficient of 0.0934 W/(mK) was obtained from test results for AAC wall systems which is 3 times less than wall systems with clay brick. This indicates that AAC wall systems with AAC blocks provide better heat insulation performance comparing to wall systems made with traditional clay brick and also about 3 times less dead load. Dead load reduction is an important issue in earthquake regions to have seismic structures.

Unit weight of material is the most important influencing factor on thermal insulation capacity. Lower unit weight of material results less coefficient of thermal conductivity which means better heat insulation performance In the other word, lighter materials provide better heat insulation characteristics. Furthermore thermal insulation property of AAC wall systems is closely related to the amount of pores and their distribution. Finer pores provide better insulation performance [7].

Experimental research findings also show that there is a considerable difference between AAC wall and traditional clay brick wall system based on thermal conductivity coefficient.

Use of autoclaved aerated concrete blocks for the purpose of heating and cooling in residential buildings allows energy savings up to 35-60 % more than other traditional masonry materials.

3.2 Fire Resistance Test

Fire resistance test was done to find out effects of different burning temperatures on the properties of AAC samples. For this purpose 50 mm cubes samples were tested at six different temperatures by using an electrical furnace. After fire resistance tests, compressive strength test was done to detect effects of fire on strength properties of AAC samples.

After 30 minutes heating procedure at a temperature of 100°C, no changes were observed on the appearance of AAC blocks and also no reduction in weight and compressive strength was detected.

After 30 minutes heating procedure with temperature of 300°C, no changes were observed on the appearance of AAC blocks but slight reduction in weight of blocks was detected. On the other hand, average compressive strength of blocks after fire test was about 22% reduction.

After 30 minutes heating procedure at the temperature of 500°C, color of AAC blocks were observed to become darker, and slight reduction in weight of blocks was detected also. The average compressive strength reduction of blocks after fire test was about 28% reduction.

Heating procedure at the temperature of 700°C, changed color of AAC blocks the darker and reduction in weight of blocks was detected. The average reduction of compressive strength of blocks after fire test shows more decrease, about 35 % reduction.

After 30 minutes heating procedure with temperature less than 900°C changed colors from light grey to grey for AAC blocks. In addition to reduction in weight of blocks, cracking appeared on the surfaces of blocks observed. On the other hand average compressive strength of blocks reduced to 46% compared to the controlled samples.

Heating procedure under temperature of 1000°C caused colors of AAC blocks to become bright white and many cracks on the surfaces of samples. This phenomenon was due to decomposition of the chemical phases of silica and lime.

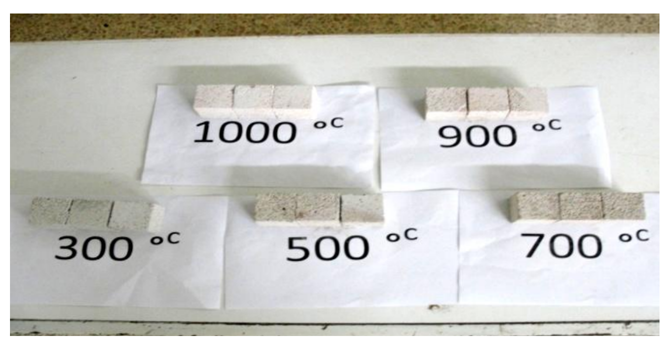

Fig-11: Color changes of AAC blocks after fire tests.

According to TS-EN 679 standard [4] optimum humidity content for AAC blocks, which are going to be tested under axial load, is 6%. On the other hand, with increasing the temperature inside of the furnace humidity content decreased because of evaporation process and caused decreasing in weight of blocks and also some degradation in pore.

4. CONCLUSIONS

Thermal performance was evaluated for different temperatures and humidity for two types of AAC walls with coating and without coating. According to the test results; increasing in humidity condition inside the chamber during heating procedure under steady state condition, caused increasing in average temperature change on outside surface of AAC wall.

Fire resistance test was carried out for determining the ability of AAC material to withstand fire in six different temperatures increasing from 100°C to 1000°C. Fire resistance tests affected color, weight and especially compressive strength of AAC blocks. Samples color start becoming darker from its original whitish color as temperature increases up 900°C, except samples subjected to 1000°C that showed a brighter white color. Weight and compressive strength of all samples started to decrease comparing to its original dry state; this indicates that AAC losses its mass and mechanical properties subjected to the elevated temperature. It has to be considered that decreasing in the mentioned properties subjected to the elevated temperatures is acceptable up to 500°C, which shows a slight reduction in AAC properties.

REFERENCES

[1]. Domingo E. R. (2008), An Introduction to Autoclaved Aerated Concrete Including Design Requirements Using Strength Design, Technical report, Kansas State University, p. 102.

[2]. Kamsiah M. I., Shazli Fathi M. and Manaf N. (2004), Study of Lightweight Concrete Behavior, Technical report, P. 35.

[3]. TS pr EN 1353 (2008), Gaz ve kopuk beton rutubet muhtevasi tayini –Determination of moisture content of autoclaved aerated concrete.

[4]. TS EN 679 Gazbeton (2008), Basınç dayanımı tayini Determination of the Compressive Strength of Autoclaved Aerated Concrete.

[5]. ASTM E119 Standard (2004), Test Methods for Fire Tests of Building Construction and Materials.

[6]. TS EN ISO 8990 Kâgir ve kâgir mamulleri - Tasarım ısıl Değerlerinin Tayini Metotları - Methods for Determining Design Thermal Values of Masonry and Masonry Products.

[7]. Narayanan N. and Ramamurthy K. (2000), Structure and Properties of Aerated Concrete, Building Technology and Construction Management Division, Madras: Department of Civil Engineering, Indian Institute of Technology.

BIOGRAPHIE:

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