Investigation of Fire Effect of Reinforced Aerated Wall (ACC) System Produced by Using Sustainable Construction Material

Pınar Usta¹, Başak Zengin²
¹Isparta University of Applied Science, Technology Faculty, Isparta, Turkey
²Nisantasi University, Faculty of Architecture and Civil Engineering, Istanbul, Turkey
basak.zengin@nisantasi.edu.tr

Abstract. Reinforced Aerated Concrete panel building systems are preferred as wall elements in residences and industrial facilities due to their advantages. The signal issue encountered in industrial facilities is caused by fires that occur. Fire resistance of sustainably reinforced aerated concrete panels was investigated. The wall G3/05 class reinforced panel model to be used for the test was preferred. The panel wall has been subjected to a 120-minute fire resistance test. In this process, 1050 °C temperature was measured on the surface exposed to flames, while the wall temperature was read 50 °C on the other surface, and the heat temperature increased to 70 °C only at the panel joints. The data obtained from showed that the reinforced aerated concrete panels maintain their integrity under fire and resistant to high temperatures. These data that reinforced aerated concrete systems should be preferred, in buildings with human population and high fire risk.

1. Introduction

Nowadays, while designing a building, important to design of points are as sustainable, besides being economical and reliable. Recycling materials are widely used in sustainable structures. Recycled reinforced concretes are preferred due to their lightness, strength properties and thermal conductivity. Generally, recycling powder forms of building materials were used during production [1]. Concrete, cement, silica sand, lime, gypsum and aluminium powder were used in the production of aerated concrete [2]. The aerated concrete of structure is similar to Tobermory system in which water molecules absorbed between crystallographic planes [3]. Aerated reinforced concrete is used as a masonry unit, as well, produced the carrier system panels. These special production systems are widely used in both residential and industrial buildings.

These wall blocks according to the profile structure that called "single plug", "double plug" and "flat wall blocks". The harmony of the physical values of the wall blocks (such as heat storage capability, thermal conductivity value, dry unit weight) provides a high thermal inertia to the outer shell of the building, allowing for spontaneous comfort conditions in the indoor environment in summer and winter months [4]. Extensively, the studies were shown that the mechanical properties of aerated concrete were primarily investigated [5-7]. On other hand, there were carried out on panel systems. For instance, Pehlivanlı et al. (2016) [8] investigated that the thermal and mechanical properties of ACC walls using G3 / 05 and G4 / 06 types. Using examined in more detail the effects of fibber used in production [8].

However, aerated concrete panel systems are preferred in industrial buildings commonly. There is not too to different proportion’s investigate about aerated concrete panel systems. When the problems encountered in the industry are examined, energy efficiency, thermal conductivity, lightness, fast
production led to the need for rapid repair of the damaged place. In addition to impact damages, explosion or high temperature damages caused a so problem [9]. In earthquake country seems Turkey, fire has been a major problem that occurs after an earthquake Therefore, precautions should be taken for the subsequent fire damages caused by the earthquake in industrial buildings. When designing industrial buildings, fire-resistant material and carrier element selection has gained importance

The ACC effect of high temperature has been studied. In study, Andreini et., al., (2014) [10]. obtained the general properties of ACC and the mechanical behaviour of the ACC material depending on the fire effect [10]. Keyvani, (2014) [11] explorative the amount of moisture contained in the ACC building material and how it would resist high temperatures [11]. Wakil et.,al.(2015) [12] investigate thermo-physical properties of ACC material's response to fire at multi-dimensional scales. For this, they measured the thermal conductivity of the samples between 120 C° and 720 C°[12]. Nguyen et., al, (2018) [13] in the studies experimented the fire resistance performance of specially designed light aerated concrete prefabricated systems (PLAC). Different types of panels were produced. Data related to the burning process were obtained. Aerated concrete panels have been produced in high-risk areas that can reach a strength period of 30 minutes [13]. With the support of these studies, the behaviour of the panel under high temperature was determined by choosing the G3 / 05 panel in ACC form.

2. Post-earthquake fire hazard

Apart from earthquake-related damages, different problems were encountered after the earthquake. When the problems that occurred after the earthquake were examined, the damage caused by the fire was reported. Many factors such as explosions caused by leaking gases during the earthquake, damage to warehouses and pipelines, natural gas installations, open systems such as stoves and fireplaces, short circuit in the electrical installation cause fires. These fires have the power to destroy buildings that were not damaged by the earthquake in an instant. Although there was no high seismic acceleration after the earthquake, the fires increased with the effects of the wind. According to studies, fires that occurred after the earthquake mostly occurred in industrial facilities, refineries, commercial buildings and wooden buildings. In history the great Lisbon earthquake in history (1975) examine when the fire occurred after the earthquake lasted 5 days. The only reason signed that people left the house in a panic state. In Northridge, California, USA, after the 1994 earthquake, the gas pipeline was damaged and caused an explosion. After the 1995 earthquake, Fire hazard results that have been among 500 deaths and 7000 buildings burned in Hyogoken -Nambu, Kobe, Japan. Fire of a floating roof tank of crude oil caused due to a large earthquake and full-face fire of another floating roof tank two days later after Tomakomai, Hokkaido Japan (2003) earthquake [14]. In Turkey, after the Golcuk-Izmit (1999) earthquake and Elazığ earthquake have been fired suddenly.

When the damages are examined in general, pipelines, electrical installations, active and passive fire protection systems, structures were damaged due to explosions after the earthquake. After the earthquake, the work area of firefighters was complicated by the blockage of roads, multiple fires and difficulties of water supply. Occupant’s moving speed is decreased in fire conditions due to the impact of earthquakes on the interior environment which generates obstacles in the path of movement.15 The probability of fire occurrence in a building following an earthquake is greater than normal and there may be multiple simultaneous ignitions [16,17]. Structural and non-structural building components including fire safety measures can be damaged by earthquakes and may not perform as intended in post-earthquake fire conditions [18]. Mousavi et al (2008) [19] have researched that review of post-earthquake fire hazard to building structures [19]. Park et al (2014) [20] studies that fire performance of full-scale building subjected to earthquake motions: fire test program and outcomes [20]. In the studies, in order to obtain the damages in the carrier system and materials that may occur after the fire that may occur after an earthquake, detailed researches have been made by both experimental and simulation methods [21-24].

Industrialization that started in the second half of the 18th century is the most important factor affecting the economies of the country today. Therefore, the sustainability of industrial facilities is of great importance for the national economies. Damage to industrial facilities for any reason puts
businesses in economic difficulties and harms the country's economy [25]. Industrial facilities are faced with certain risks as in all other businesses and residences. These risks include financial, political, natural disaster, operational or hazard risks, etc. risks are included. Although, studies reveal that the risk that most affects and damages industrial facilities is the risk of fire. Fires are one of the most dangerous problems encountered during production in industrial facilities. Especially these facilities are exposed to fire for various reasons during their production. [26]. The annual number of cases for the last 3 years is shown in Figure 1. The number of fire incidents in industrial facilities in the last 3 years, the number of people affected by the fire (dead and wounded) are shown in Figure 2.

![Figure 1. Annual number of cases occurring in industrial facilities [27].](image1)

![Figure 2. Annual fire incident and impact comparison in industrial facilities [27]](image2)

As seen in Fig. 2; When the industrial fires and explosions in 2019 are compared with the previous years; There was a decrease in the number of wounded labourers, but the death toll shows the severity of the fires and explosions [27]. Fires have a great material and non-material effect, causing accidents that will last for a long time. Construction materials used to prevent fires that may occur in buildings and min damage are so important. Between 2005 and 2011, investigations after fire’s workshops, factories, factories show that fires occur in mostly reinforced concrete buildings (Figure 3).

![Figure 3. Type of burning industrial facilities according to construction material [26]](image3)

The preference of fire-resistant materials during the construction phase of industrial facilities reduces the damage to the facilities, allows evacuation and prevents loss of life. The fact that the components of the structural system in industrial facilities are resistant to fire prevents fires, reduces the damage or prevents the building from serious damage. As can be seen in Figure 4, damage occurred in two different facilities with different construction materials as a result of the fire in the adjacent industrial facility. Petroleum products that are not resistant to fire were preferred on the roof and walls of the building, and the building became completely unusable after the fire, as it can be seen (Figure 4), there was no damage after the fire in the facility built using reinforced aerated panels on the walls.
Figure 4. Post-fire view of the adjacent industrial facility with different construction materials [28]

Generally, places where industrial facilities and factories are located are not established far from living areas. Most of the fires and explosions in many metropolitan cities, including Istanbul, occurred in facilities close to the city centre. This situation turns industrial fires and explosions into a social problem. For this reason, the use of materials with high fire resistance is critical in buildings with fire risk, residences and industrial facilities clearly [27].

In the studies, researches have been made on the damages that may occur in the structural elements after high temperature or fire. In these studies, it has been investigated to obtain the behaviour of the structural element damaged after fire against loading [29, 30]. Especially in such structures, the use of autoclaved aerated concrete provides the highest safety against fire and meets the strictest fire safety requirements AAC is classified as a non-combustible building material due to its mineral composition. AAC is both fire resistant up to 1200 ° C and heat resistant unlike other building materials [28].

3. Aerated Concrete Reinforced Panels

Aerated concrete building elements produced by industrial methods mainly consist of quartz sand or quartzite as raw material, lime and cement as binder, gypsum that regulates the properties of the material, aluminium powder and water as a pore regulator. After the main raw materials are mixed with water until a certain consistency is obtained, aluminium powder is added to the mixture and then the mixture obtained is poured into steel models. Steel reinforcement is prepared in separate units for Aerated Concrete Reinforced Panels.

The reinforcements, whose diameter and dimensions are determined statically, are then welded by automatic machines and turned into mesh. The mats combined with the help of welding are protected against rusting with anti-corrosive coating material. These mats are cast by mounting on casting cars after rust protective coating. After the mixture is poured into the bar, a series of chemical reactions begin and the mixture swells to the desired form and height. During this process, which lasts for about half an hour, air is filled in the pores with a diameter of 0.5 to 1.5 mm, created by the hydrogen gas and water vapor released. The material that has reached the hardness to carry itself after 2.5 to 3 hours is removed from the bar. The material taken from the bar is grid in different sizes with the help of steel wires and profile blades in the automatic cutting unit. The final form of the grid aerated concrete occurs as a result of hardening in autoclaves under 12 atmospheric pressure and 190 C° [31]. Reinforced aerated concrete building elements is seen in Figure 5.

Figure 5. Reinforced aerated concrete construction element [31]
4. Material and Method
In the study, the wall G3 / 05 class reinforced aerated concrete panel model to be used for the test was preferred. The reinforced aerated concrete panels used were woven into a frame of the test furnace, 4020 mm x 4026 mm (high x wide). The reinforced panels used in wall production have a dimensions of 4000 mm x 600 mm x 125 mm (Figure 6). There are material’s physical properties material in Table 1.

![Figure 6. Reinforced aerated concrete panel reinforcement details](image)

| Material Strength Class | G3 |
|-------------------------|----|
| Average Compressive Strength | 35 kgf/cm² |
| Highest Dry Unit Volume Weight | 500 kg/m³ |
| Elasticity Module | 22500 kgf/cm² |
| λ (thermal conductivity) in the laboratory | 0.13 W/mK |
| λ (thermal conductivity) TS 825 | 0.15 W/mK |
| Static Calculation Self-Weight | 720 kg/m³ |
| Water Vapor Diffusion Coefficient (u) | 5-10 |
| Fire Resistance Class | (>15 cm thickness) REI180 |

The experimental sample was assembled and prepared in accordance with TS EN 1364-1: 2015[32] standards. Panel experimental sample is shown in Figure 7.

![Figure 7. Experimental system of reinforced aerated concrete panel](image)

In order to simulate the horizontal continuity of the wall, a 5 cm space (Free edge) was left on a vertical edge and this space was filled with ceramic wool. Vertical panels were fixed with frame connection plates and aerated concrete repair mortar was applied between the panels. The detail view of the experimental sample is shown in Figure 8.
In order to determine the fire resistance of aerated concrete panel walls, the surface thermocouples and deflection measurement points that are not exposed to fire are numbered and marked in the test sample. Deflection measurement points are shown in Figure 9. The thermocouples numbered 1, 2, 3, 4 and 5 show the average and maximum non-exposed thermocouples and their positions, while the thermocouples number 6, 7, 8, 9 and 10 show the positions of the thermocouples for the measurement of maximum temperature rise, "0" shows deflection measurement points in the figure.

Deflections are recorded in the furnace software. The highest measurement amount between 2, 9, 11 points on the Laser Point was recorded as 20 mm and the maximum displacement is 100 mm's gold (Figure 10).

4.1. High Temperature Studies
The test furnace has an inner measurement chamber of 3m x 4m x 1.3m dimensions. The furnace internal temperature is measured by 11 thermocouples of furnaces located 100 mm away from the sample surface according to TS EN 1363-1: 2013 and controlled by software. Standard temperature curve values in TS EN 1363-1 2013 were used in the experiment. There is time-dependent in Table 2.
Table 2. Time- Furnace Temperature

| Time (Minute) | Furnace Temperature (°C) | Time (Minute) | Furnace Temperature (°C) |
|---------------|--------------------------|---------------|--------------------------|
| 0             | 20                       | 90            | 1006                     |
| 5             | 576                      | 120           | 1049                     |
| 10            | 678                      | 150           | 1082                     |
| 15            | 738                      | 180           | 1110                     |
| 20            | 781                      | 210           | 1133                     |
| 30            | 842                      | 240           | 1153                     |
| 45            | 902                      | 300           | 1186                     |
| 60            | 945                      | 360           | 1214                     |

Furnace inner compressive is controlled according to TS EN 1363-1:2013. The compressive sensor at 1.5m position is set at 8.5 Pa. Compressive -Time Change for the furnace is given in Figure 11.

Figure 11. Compressive -Time Change

Ten thermocouple insulation pads are affixed to the surface of the test specimen, which is not exposed to fire. The first 5 thermocouples were used to measure the average temperature of the sample surface. In surface measurement values, the average surface temperature calculated from the average temperature measurement thermo pairs should not increase more than 140 °C than the ambient temperature. Regardless of whether certain thermal insulation temperature limits are exceeded or not, failure to achieve any integrity value means that thermal insulation cannot be provided.

During the 120-minute test period, the average surface temperature did not increase more than 140 °C than the ambient temperature. During the 120-minute test period, the highest increase value in any measurement point was not more than 180 °C. The graph of surface temperature-time not exposed to heat is shown in Figure 12.

Figure 12. Surface not exposed to heat thermocouple (TC) temperatures
Temperature values could not be obtained instantaneously because the thermocouple numbered 3 made a short circuit during the experiment. According to the data obtained afterwards affect the experimental results. The examination test results show in Table 3.

| Time (Minute) | TC1 | TC2 | TC3 | TC4 | TC5 | TC6 | TC7 | TC8 | TC9 | TC10 |
|---------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
| 0             | 22.1| 22.3| 23.3| 21.3| 22.3| 22  | 22.1| 22.8| 22.8| 22   |
| 10            | 22.2| 22.3| 23.6| 21.3| 22.3| 22  | 22.1| 22.7| 22.7| 22  |
| 20            | 22.3| 22.5| 23.6| 21.4| 22.4| 22  | 22.2| 22.3| 22.8| 22  |
| 30            | 22.5| 22.6| 23.6| 21.6| 22.8| 22  | 22.4| 23.1| 22.9| 22.5|
| 40            | 23.6| 24  | 23.9| 22.7| 25.8| 23.3| 26.4| 23.9| 25.5| 50.7|
| 50            | 28.4| 29.6| 24  | 28.2| 34.8| 27.4| 35.2| 26.5| 35.6| 58.3|
| 60            | 37.6| 40.8| 24.9| 37.9| 48.2| 36.1| 45.3| 31.5| 53  | 61.9|
| 70            | 48.9| 53.9| 56.5| 48.4| 59.4| 47.5| 54  | 39.3| 64.1| 63.6|
| 80            | 58.6| 64.2| 63.5| 57.6| 64.5| 57.4| 59.1| 49.9| 67.7| 64.7|
| 90            | 65.1| 69.2| 66.3| 62.9| 67.1| 64.2| 62  | 61.9| 69.8| 65.1|
| 100           | 68.4| 70.8| 67.4| 65.7| 68  | 68.2| 63  | 68.5| 69.8| 65.1|
| 110           | 69.9| 71.6| 68  | 67  | 68.7| 69.9| 64.1| 71.1| 70.5| 65.4|
| 120           | 70.8| 72.1| 68.5| 67.7| 69.6| 70.7| 64.7| 71.9| 70.6| 65.6|

After the first 10 minutes during the experiment, none of the values measured by the furnace internal thermocouples deviates more than 100 °C, if the values specified in the standard time-temperature curve.

Depending on the time, an average temperature graph is obtained according to the data recorded with standard furnace thermocouples. The percentage deviation (de) from the area under the average temperature curve is calculated. The percentage deviation is calculated by equation 1. Table 4 shows deviation data.

\[ d_e = \frac{A-A_S}{A_S} \times 100 \]  

\( d_e \): Percentage Deviation, \( A \): Area under the actual oven temperature / time pain, \( A_S \): The area under the standard temperature / time curve, \( T \): time

| Time | Percentage Deviation |
|------|----------------------|
| 5≤t≤10 | % 15                |
| 10≤t≤30 | % 15-(0.5(t-10))   |
| 30≤t≤60 | % 5-(0.083 (t-30)) |
| t>60   | %2.5                |

According to the experimental results and deviation percentage values, no deviation from the tolerance values was observed after the first 5 minutes in the percentage deviation values. The ambient temperature measured during the experiment is shown in Figure 13.
During the experiment, when the change due to time and temperature was observed, light fumes appeared first in the upper left corner and then in the right corner after the experiment started. After 35 and 32 minutes, a small crack occurred in the wall upper frame joint in the upper right corner. Fumes exits continued throughout the test.

5. Conclusion
Considered statistics about the structural fire that took place in Turkey, the actual number of fires tends to increase. Post-earthquake fires increase this rate even more. Industrial buildings in Turkey are widely available on the earthquake belt. Moreover, one of the most important reasons for the increasing number of structural fires is the lack of suitable construction materials in terms of fire safety. Especially against fires that may occur in industrial buildings, A1 class non-combustible material can be used in wall systems to prevent possible damages.

This study was carried out to determine the fire resistance of a 12.5 cm thick wall element consisting of reinforced aerated concrete panels. For this purpose, the wall sample consisting of G3 / 05 class reinforced aerated concrete panels was tested under laboratory conditions for 120 minutes. The experimental shown was applied according to the TS EN 1364-1: 2015 [32] Fire Resistance Tests of the Elements that do not carry loads.

In the fire resistance test, the Integrity (E) and Insulation (I) values of the test sample were examined. For the radiant (W) value, the measurement was not made because the radiation criterion was also valid during the time the insulation criterion was met, and the test performed fulfilled the insulation criterion.

In regard to the experimental results were examined, there was no defect in the integrity (E) test of the sample for 120 minutes in terms of continuous flammability, void gauges, and cotton pad. At the end of the 120-minute experiment, the temperature of 1050 C° was measured on the surface exposed to flame, while the temperature of 50 C° was measured on the other surface, and the temperature temperature at the panel joints did not exceed 70 C°. In the insulation test (I), the average temperature increase was 140 C° and the maximum temperature increase was 180 C°, as in the integrity test, no damage occurred in 120 minutes. When all the results obtained were evaluated, test seen that the reinforced aerated concrete panels completely fulfilled the fire resistance test. The reinforced wall systems can be used comfortably in buildings where the major population is very dense at certain time intervals, especially in shopping malls, hotels, schools, etc.

6. References
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