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The Investigation of Heat Performance and Thermal Conductivity of Different Wall Materials at High Temperatures

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High temperature,
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Clay brick,
Common plaster,
Rice husk brick

Abstract: The current study investigated heat transfers at high temperatures and compressive strength after exposure to high temperatures of gas concrete, clay brick, rice husk bricks used as wall materials, and gypsum plaster and common plaster used as coating materials. Tests measuring apparent porosity, water absorption, bulk density and compressive strength were performed on the samples prepared in 100 mm x 100 mm x 100 mm size. In the high-temperature experiment, the samples with K-type NiCr-Ni thermocouple were placed in a specially designed laboratory furnace. The internal temperature of the furnace was set at 800 °C. The researchers found that out of the samples exposed to high temperatures compressive strength and thermal conductivity of the gypsum plaster mortar were better than those of the common plaster mortar. Furthermore, the gas concrete, a wall material, was found to have a low thermal conductivity. As a result, the gas concrete and common plaster mortar, which were exposed to high temperature, were found to be more durable than other materials and, therefore, more advantageous when used in construction.

Yüksek Sıcaklıklarda Farklı Duvar Malzemelerinin Isı İletkenliği ve Termal Performansının Araştırılması

Anahtar Kelimeler
Yüksek sıcaklık,
Gaz beton,
Kil tuğlası,
Normal sıva,
Pirinç kabuklu tuğla

Özet: Bu çalışmada, duvar dolgu malzemesi olarak kullanılan gazbeton, kil tuğlası, pirinç kabuklu tuğla ile duvar kaplama malzemelerinden olan alçı sıva ve normal sıva gibi malzemelerin yüksek sıcaklık durumunda gerçekleştirdikleri ısı transferleri ve yüksek sıcaklığa maruz bırakıldıktan sonraki basınç dayanımları incelenmiştir. 100 mm x 100 mm x 100 mm boyutlarında hazırlanan örneklere; görünen porozite, su emme, birim hacim ağırlık ve basınç dayanım testleri uygulanmıştır. Yüksek sıcaklık deneyinde, özel olarak dizayn edilmiş laboratuvar tipi fırında K tipi Ni-Cr thermocouple örnekler içine yerleştirilmiş ve fırın iç sıcaklığı 800 °C'ye ayarlanmıştır. Yüksek sıcaklığa maruz bırakılan örneklerde alçı sıva harcının, basınç dayanımı ve ısı iletkenlik özellikleri bakımından normal sıva harcına göre daha iyi özelliklere sahip olduğu belirlenmiştir. Bununla birlikte duvar dolgu malzemelerinden gazbetonun en düşük ısı iletkenlik değerine sahip olduğu görülmüştür. Sonuç olarak, yüksek sıcaklığa maruz bırakılan gazbeton ve alçı sıvanın diğer malzemelere oranla daha dayanıklı oldukları ve bu nedenle yapılarda tercih edilmesinin faydalı olacağı düşünülmektedir.

1. Introduction

Walls are constructional elements composed of porous materials and should have the performance of thermal insulation and loading in the event of a fire according to building codes. Fire resistance should be desired in partitioning solutions, overall insulation properties, mechanical strength, and fire resistance parameters should be taken into account for the proper design of the partition systems (wall, panel, etc.) [1].

Combustion is the abstraction of hydrogen from other materials and its transformation to heat and light leading to the absorption of oxygen. Therefore, other materials melt due to the increased temperature. The amount of heat required depends on the material's components. Fire is usually effective

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** Corresponding author: ggorhan@aku.edu.tr* for all materials. However, combustion time and temperature depend on the composition of the material. Knowing the behaviour of the materials at high temperatures, such as fire, is important in order to take fire safety precautions [2].

Physical and mechanical properties in general as well as the water content of refractory products are very important. Moreover, the moist material is also known to have a good fire performance [3]. Notwithstanding that sintered clay bricks are commonly used in the manufacturing step of civil engineering, structural wall elements are made up of the connection between bricks and conventional mortar [4]. The density of mortared brick walls with high water content can be as high as 2000 kg/m^3. This density value is too high for partition walls. Therefore, decreasing the density without reducing the fire resistance of the wall is preferred [5].

The properties of the porous material (gas concrete, brick,and so on) used in structures vary depending on the effect of humidity and temperature. As is the case with concrete and reinforced concrete structures, it is also important to predict the behaviour exhibited by porous materials when exposed to the effects of fire. Understanding heat and mass transfer processes of porous materials at high temperatures is therefore very important [6]. Nowadays, buildings and structures may be exposed to high temperature in case of fire due to their locations and functions [7]. Thus, in most cases, the fire resistance of structural elements is controlled from the design phase onwards [4].

The fire resistance of masonry walls can be detected using a standardized test method (EN 1363-1, ISO 834-1, EN 1364-1, EN 1365-1, ASTM E119) [8-12] or semi-empirical methods (EN 1996-1-2, ACI 216.1) [13-15]. However, these methods have several limitations. For example, semi-empirical methods often require design of structural elements, incur additional costs, and provide limited design flexibility in terms of fire resistance requirements [4].

The fragmentation of the material at high temperatures is due to high intensity [16]. Thus, it is important and necessary to know the behaviour of the components of the material in order to better understand the behaviour of the material at high temperatures [17]. Engineering properties of construction materials at high temperatures are of even greater importance in high-rise buildings [18].

Wall covering materials are usually used on the interior surfaces of buildings exposing to high temperatures for decoration, acoustical correction, surface insulation, or structural fire resistance. Furthermore, during a fire, these materials provide a separation between the wall surface and the source of fire. They provide security of life and property by preventing the spread of heat, smoke, and toxic gases from one part of the building to the other parts. Hence, the fire performance of such materials should be evaluated as well [19].

Previously conducted studies have focused primarily on the effects of high temperature on normal strength concrete [7]. Emerging technology has rendered possible the investigation of the effects of high temperature on high strength concrete with chemical and mineral admixtures. It is also necessary to know well the behaviours of these types of materials at high temperatures. The heat within the material reduces the fire resistance and makes high-strength concrete more risky than common concrete [7, 16, 20].

The fragmentation of the material at high temperatures is due to high intensity [16]. Lightweight concrete is more resistant than common concrete because lightness reduces the thermal conductivity of such concrete, and, in this way, the fire resistance of the material increases [17]. Although concrete made up of lightweight aggregates have lower thermal conductivity [21], various parameters may have an effect on it [16]. At this point, it is important and necessary to know the behaviour of the components of the material in order to better understand the behaviour of the material at high temperatures [17]. At the same time, engineering properties of construction materials at high temperatures are of great importance in high-rise buildings [18].

Some deterioration may also occur in concrete exposed to high temperatures, due to wear and harmful chemical effects. Therefore, the lifetime of the material is shortened and the problem of repair costs is raised. In order to avoid this, the materials referred to as refractory should be used at the place exposing to high temperatures. It was also reported that reactions at high temperatures lead to dehydration in the pore structure and the degradation of hydration products. Because of this, porosity is expected to be as low as possible and defined as apparent porosity [22].

Studies on high temperature in the related literature generally focus on concrete. Some studies investigated the effects of high temperature on high-strength concrete properties [20, 23-25] while others concentrated on its effects on polypropylene and steel fiber reinforced concrete [26, 27]. Moreover, the changes in the properties of normal-weight and light-weight aggregate concrete at high temperatures were examined [28, 29]. The pore structure and the mechanical properties of normal strength and high strength concrete as well as the permeability of the concrete exposed to high temperature were investigated [30, 31]. Another study examined the changes in pressure and colour of the concrete exposed to high temperatures [32].

As a result, fire and high temperatures lead to aesthetic and functional deformation of the structures [33]. Therefore, the protection of these materials, as far as possible, from the effects of high temperature constitutes an important issue in terms of the service life of this type of materials. Preventing the materials used in reinforced concrete structures from being affected by fire or high temperatures or reducing their effects is something which is of great importance.

The current study investigated the heat transfers at high temperatures and compressive strength after exposure to high temperature of gas concrete, clay brick, rice husk bricks used as wall materials, and gypsum plaster and common plaster used as coating materials. Through this way, it will be possible to determine which material is more favourable for use in structures by showing their thermal and mechanical behaviour in case of fire or high temperature in reinforced concrete structures. In addition, high-temperature behaviour is considered to be an important parameter in the choice of material.

2. Material and Method

2.1. Materials

The first of the wall materials used in the current study was a G2 classified gas concrete produced according to TS EN 771-4 [34]. Muscovite clay and rice husk were used as raw materials in the production of the other two wall materials and these materials were obtained from Çorum, Turkey. Two different types of bricks were manufactured as wall materials. They were composed of 100% clay and clay substituted by 15% rice husk by volume. 18.2% and 29.7% plasticity water (for shaping) was used in the mixtures, respectively. Two types of mortars - gypsum plaster and common plaster - were prepared as coating materials. Gypsum plaster mortar was manufactured in accordance with TS EN 13279-1 [35] and TS EN 13279-2 [36]. In the common plaster mortar, crushed sand from the Afyonkarahisar region was used. The sand was prepared by sieving between the washed mesh screens (No.18 and No. 200). Hydrated calcium lime powder in accordance with TS 4022 [37] and CEM II 32,5 N-type portland cement in accordance with TS EN 197-1 [38] were used as binders.

2.2. Method

From the materials used in this study, the gas concrete was the only blocks obtained from local market. The other materials were shaped in dimensions of 100 mm x 100 mm x 100 mm under laboratory conditions. The components of the mixtures were determined by weight, and the samples were prepared by taking the amounts in Table 1 into account. In the production of samples, some materials such as clay (Cl), rice husk (RH), gypsum (G), lime (L), cement (C), sand (S), and water (W) were used.

Table 1. Mixing ratio of the samples by weight (g)

Sample	Cl	RH	G	L	C	S	W
Clay brick	846	-	-	-	-	-	154
Rice husk brick	690	80	-	-	-	-	230
Common plaster	-	-	-	26	108	779	87
Gypsum plaster	-	-	606	-	-	-	394

The mixtures were brought to a homogenous consistency by manual and mechanical mixers and were placed into the molds by compression with the help of a vibration table. Coating materials were removed from the molds after a 24 hours setting period. The clay brick and the rice husk brick were dried to constant weight in a laboratory oven and then sintered at 2.5 °C/min firing speed and at 900 °C for one hour. Plaster mortar samples were subjected to a water cure for 28 days. In order to determine the physical properties of the samples, they were saturated in water for 48 hours. The samples were then weighed in accordance with TS EN 772-4 [39]and their water absorption, apparent porosity, and bulk density values were determined. The compressive strength tests of the samples were performed at ± 500 g/s rate of loading and in a computer-controlled automatic pressure machine. Three samples from each material group were used for all tests.

The ultrasonic sound velocity was obtained by direct transmission based on EN 12504-4 [40]. In this method, ultrasonic impulses are generated by a signal generator and transmitted to the sample surface utilizing a transmitter. The movement of impact on the sample surface is measured by the stimulation of the receiver on the opposite side. The ultrasonic velocity of the samples was measured with 0,1 µs-wave diffusion time through 54 kHz transducers at the mid-point.

The hot wire method defined in ASTM C1113 [41] was utilized for the measurement of thermal conductivity. In this modified version of the method, a single thermal sensor and the distance between this sensor and the surface exposed to the heat were taken into account instead of the two different thermal sensors and the distance between them. This was done in order to develop a more practical approach and determine the relative relationship between the materials instead of determining their thermal conductivity value.

In order to perform temperature measurements in the high-temperature experiment, the cube samples were drilled out from the centre to a depth of 80 mm and K-type NiCr-Cr thermocouples are placed into samples as shown in Fig. 1b. As can be seen in Fig. 1a, the samples are placed into a furnace specifically designed for this study. A heated room was built at the bottom of the furnace, and four boxes with the dimensions of 100 mm x 100 mm x 100 mm were placed at the level of the upper lid for the samples. The boxes in which the samples were placed were also insulated with thermal blankets on the top. The rising temperature in the heated room affected the samples, and the measurements were carried out by the thermocouple situated 20 mm down, inside the heated room. The samples were exposed to high temperatures (28 days). The internal temperature of the oven was set at 800 °C, and the oven regime was not interfered. In this test, the specimens kept at 800 °C for one hour. After the test, the specimens were taken when the furnace internal temperature reached room temperature. Three samples from each material group were used for this test. The data acquisition speed was designed to have one piece of data every 5 seconds during the measurements.

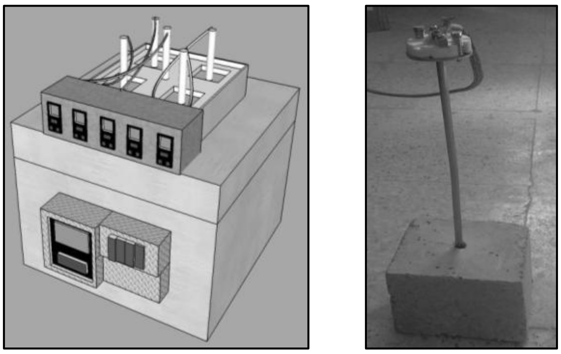


Figure 1. a) Furnace, b) Thermocouple and sample.

3. Results

3.1. Material properties

Of the materials used in the study, the structure of the gas concrete was the most porous. The porosity and water absorption rates of the gas concrete were 74.5% and 83%, respectively. The lowest porosity was observed in the common plaster. The porosity and water absorption rates of the common plaster were 18% and 9.4%, respectively (Fig. 2).

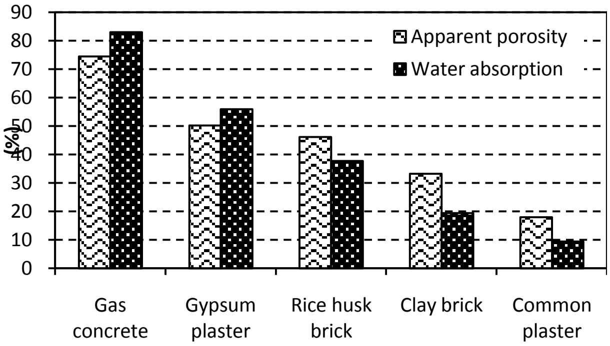


Figure 2. The porosity and water absorption rates of the samples

In relation to porosity and water absorption values, the density of 1905.8 kg/m³ was obtained from the common plasters which had the lowest porosity while the lowest density values were observed in the gas concrete. The density values varied according to the porosity of the material, so that an increase in the porosity significantly reduced the density (Fig. 3).

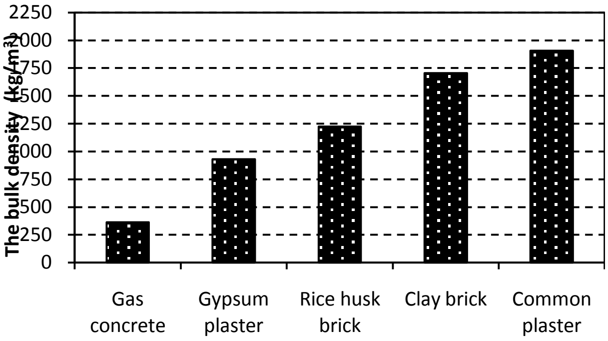


Figure 3. The bulk density values of the samples (kg/m³)

3.2. The effect of high-temperature on material properties

Unlike prior studies, the present study investigated the changes in the values of the thermal conductivity of some building materials when exposed to high temperatures. Furthermore, previous studies generally focused on the effects of high temperature on the properties of the concrete. Therefore, there is more information on concrete materials regarding the effects of high temperature than other wall materials. Previous studies reported that high temperatures led to cracks and ruptures on the concrete, therefore decreasing compressive strength of the material. The stiffness in the internal structure of the material reduces fire resistance and causes more damage to materials of high density. As an example, when common concrete was subjected to high temperatures (800 °C), it lost 60% of its resistance value [42]. CSH gels in the cement, which is one of the components of concrete, are dehydrated from 110 °C onwards. The water in the capillary voids and the adsorption water evaporate between 100 °C and 300 °C and as a result it leads to shrinkage of the material [8]. The material melts or undergoes chemical degradation due to high temperatures. The amount of heat required for this depends on the type of material [15].

Some expansion occurs in the materials exposed to high temperatures. The expansion coefficient is associated with the water in the material. Of the materials used in the current study, brick has the lowest expansion coefficient as shown in Table 2.

Brick has a very low rate of moisture due to the fact that it is sintered at certain temperatures (900-1100 °C). However, greater amounts of moisture are naturally available in the plaster and concrete materials because they are not subjected to sintering, and their thermal expansion coefficient values are higher than that of brick.

Table 2. The thermal expansion coefficient values of the materials [43]

Material	α (cm/cm °C) 10^{-6}
Gypsum	25
Brick	5-8
Concrete	10-12

The common mortar samples having the lowest values of porosity were expected to have the highest values of ultrasonic pulse velocity because an increase in the porosity led to an increase in the ultrasonic pulse time. Moreover, the rate of open pore in the brick samples was higher at the end of the sintering process than that of the common plaster, and the liquid phases in the body were thought to have an effect on the ultrasonic pulse velocity and therefore have the highest values. Gas concrete was also considered to have higher ultrasonic pulse velocity values due to the fact that it has a better internal structure than those of plaster and rice husk bricks (Fig. 4).

Despite the high porosity rate, the ultrasonic pulse velocity in the gas concrete specimens was slightly higher than the gypsum plaster and rice husk bricks. Studies in the related literature indicated that decreases or increases in void ratios in materials gave variable results on ultrasonic pulse velocity [44]. In addition, ultrasonic pulse velocity values of gas concrete samples varied between 1.7 and 1.9 Km/s [45, 46].

In general, it was observed that the ultrasonic velocity of the samples decreased following the high temperature exposure (Fig. 4). It was maintained that the effect of high temperature led to deterioration in the sample structure and that the cracks in the matrix of the sample structure led to an increase in the porosity, and as a result, the ultrasonic velocity decreased.

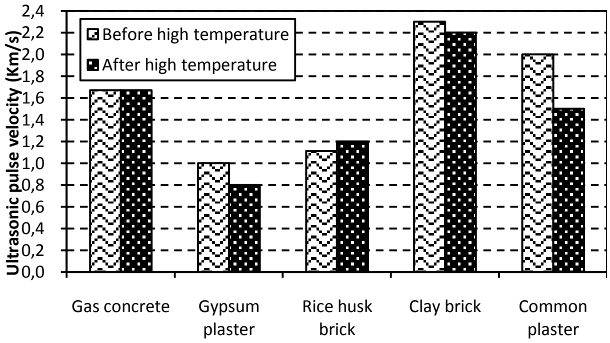


Figure 4. The ultrasonic pulse velocity values of the samples (Km/s).

The compressive strength of the gas concrete increased by 13% while no change was observed in the rice husk bricks in the compressive strength tests (Fig. 5) conducted before and after they were exposed to high temperatures. However, the compressive strengths of the gas concretes were increased when high temperatures (up to 600 °C) were applied to the samples. At this point, it was stated that the size of the gas concrete specimens was slightly decreased compared to the original dimensions after cooling [47]. High temperature decreased the compressive strength values of the clay brick by 23.6%. It was about 64.4% and 40% in the common plasters and gypsum plaster, respectively.

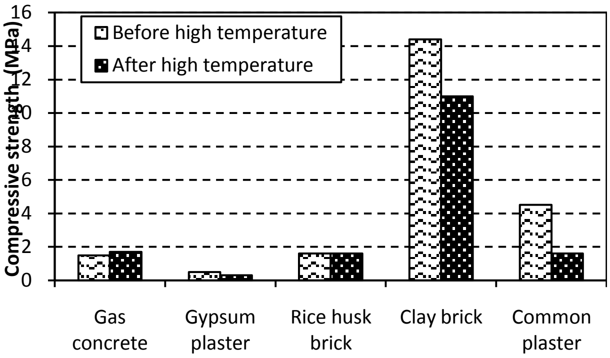


Figure 5. The compressive strength values of the samples (MPa).

The common plaster was the material which was worst affected by high temperature. With an increase in temperature, first, water is released from the material and then absorbed water and chemically bound water are released. In addition, shrinkage and expansion occurring in the structure lead to the formation of micro cracks in materials and to a decrease in their compressive strength [17]. It was thought that when the mortars were subjected to high temperature, the capillary void volume increased. For this reason, the compressive strength of specimens decreased after high temperature [48]. As can be seen in Table 2, the gypsum plaster has the highest expansion coefficient value and the lowest compressive strength value. It was thought that more expansion occured in common plaster and this led to a dramatic reduction of the compressive strength due to the fact that the common plaster structure contains cement.

Of the materials used in this study, more accumulation of heat was observed in common plaster while the least accumulation of heat was observed in gypsum plasters (Fig. 6). This situation was thought to result from the differences in specific heat between the materials (Table 3).

Therefore, it was thought that the gypsum plaster mortar might have a lower rate of thermal conductivity than that of common plaster. Of the wall materials, clay brick was considered to have the highest rate of thermal conductivity while it was followed by rice husk bricks and gas concrete samples, respectively. Under these circumstances, it was thought that gas concrete could display better material properties in case high temperature effects and in terms of heat transfer, the gas concrete and gypsum plaster pair could be the ideal wall group. According to the time-temperature graph of the high temperature application, the indoor temperature of the oven was observed to reach 800 °C at 4 °C/min (Fig. 6).

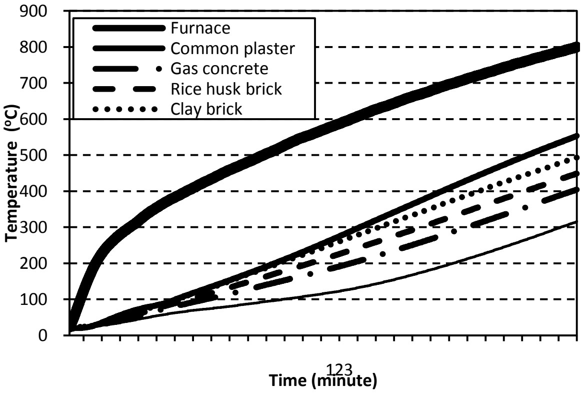


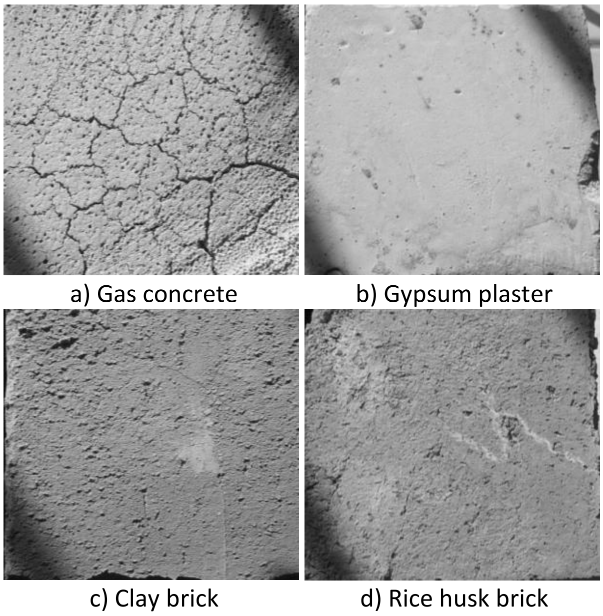
Figure 6. The oven regime and the graph of the change in the material temperature

Table 3. Thermo-physical properties of various materials [49]

Material	Density (kg m^{-3})	Specific heat (J kg^{-1} K^{-1})	Thermal conductivity (W m^{-1} K^{-1})
Limestone	2600	920	2.1
Plaster	1440	800	0.5
Cement mortar	3100	840	0.85
Concrete	2400	1008	1.65
Red brick	2025	800	0.6

Fig. 7 shows the images of the samples exposed to high temperature. While well-defined cracks were observed on the gas concrete samples, the gypsum plaster mortar broke down easily when touched by hand even though no significantly great cracks occured on its surface. However, fewer cracks were observed on the rice husk brick samples than on the clay brick samples. The presence of rice husk was considered to be the main factor that prevented the formation of cracks in the body.

The thermal conductivity coefficient value of each sample was calculated with the help of Eq. 1 given below [50]. Heat transfer amount (Q) was calculated as 3010 W by measuring the current flow from the oven and utilizing the resistance. The thermocouple was lowered to a depth of 8 cm into the material and the measured material thickness (L) was 2 cm. The surface area of the furnace was 60 cm x 60 cm, and the surface area of the heat (A) was taken as 0.36 m^2. Because did the present heat reached not only on the surfaces of the material but also the oven lid. ΔT represents the difference in values between the heat of the oven when it reaches a certain temperature and the temperature values obtained from the thermocouple found in the materials. The thermal conductivity coefficients of the materials were determined by the mathematical operations and are shown in Fig. 8.


a) Gas concrete b) Gypsum plaster

c) Clay brick d) Rice husk brick

Figure 7. The surface images of the samples exposed to high temperatures

$$Thermal\ con.\ coefficient\ (k) = \frac{QxL}{A\ x\ \Delta T}\left(\frac{W}{m\ °C}\right) \qquad (1)$$

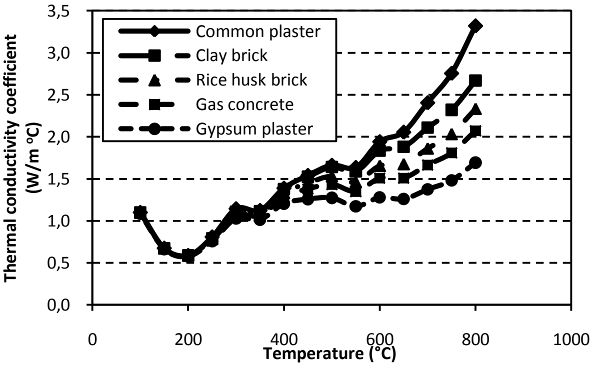


Figure 8. The thermal conductivity coefficients of the materials

Since the thermal conductivity of a material is associated with the internal structure, the thermal conductivity coefficient is expected to be low in materials with low bulk density values. Additionally, the thermal conductivity coefficient of materials varies according to an increase in moisture [43]. Fig. 8 shows the changes in the thermal conductivity coefficient of the materials exposed to high temperatures in relation to their densities. Accordingly, as stated in the related literature, the thermal conductivity of materials with high density is higher than that of materials with low density. High porosity in the material body leads to an increase in the moisture or water retention capacity. The thermal conductivity of the material is kept low when the pores in the material body are filled with air. Moreover, an increase of the moisture in the pores increases the thermal conductivity. Additionally, temperature appears to be a factor which negatively affects thermal conductivity [51].

According to the coefficients of thermal conductivity, the materials differed from each other in terms of heat transfer after 400 °C (Fig. 8). Furthermore, common plaster showed more conductivity features than gypsum plaster. Of the wall materials, gas concrete, rice husk brick, and clay brick were the materials that had the lowest rates of thermal conductivity, respectively. It was reported that there was a 44% increase in volume due to the fact that CaO was hydrated in the body [17]. This increase in volume gave rise to cracks in the material body and therefore led to reductions in the strength values. Clay bricks were thought to have higher thermal conductivity than the rice husk bricks due to the fact that fine bricks contain more CaO.

Significant differences emerged between the samples due to the changes in temperature. Because of the high temperatures reached during fire, thermal conductivity coefficients of the materials differed at 800 °C. A thermal conductivity coefficient of 3.32 W/m °C was obtained from common plaster at 800 °C while it was 1.69 W/m °C for gypsum plaster. Under these circumstances, gypsum plaster transmitted heat 49% less than common plaster. Among the wall materials, clay brick had 22.5% and 12.7% more thermal conductivity value than gas concrete and rice husk brick, respectively (Fig. 8).

The heat conduction resistance of the plane wall was calculated according to TS 825 [52] and with Eq. 2. In the light of the data obtained, common plaster, which has the highest heat transfer coefficient, naturally had the lowest thermal resistance. The heat conduction resistance of the material decreased as the thermal conductivity increased. An increase in temperature will increase the thermal conductivity values of the materials because the applied temperature time and the amount of heat transfer are directly proportionate to each other. Therefore, the thermal resistance of the materials will eventually decrease (Fig. 9).

$$Thermal\ resistance\ (R_{wall}) = \frac{L}{k} \quad (m^2 °\mathrm{C}/W) \qquad (2)$$

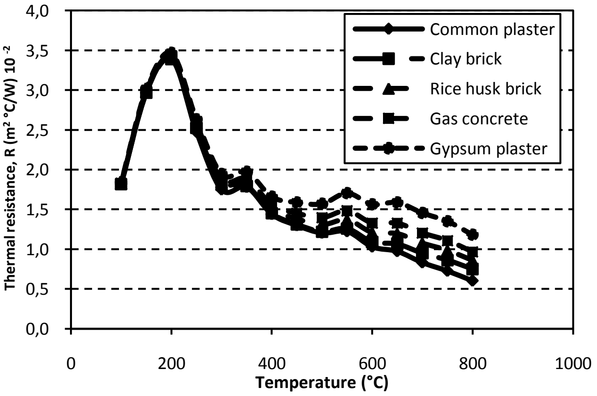


Figure 9. The thermal resistance graphs of the materials

4. Discussion and Conclusion

In the light of the data obtained from the wall coating and wall materials exposed to high temperatures, gypsum plaster mortar was observed to have better features than common plaster in terms of thermal conductivity values. Gypsum plaster was found to transmit heat 49% less than common plaster. However, of the three types of materials used as wall materials, gas concrete was found to have the least thermal conductivity. Clay brick and rice husk brick showed higher thermal conductivity than gas concrete while rice husk brick was observed to have higher conductivity than clay brick.

Given that 800 °C or above was considered to be high temperature condition, materials which are to be used in structures are expected to transmit as little heat as possible when subjected to this kind of temperature. Therefore, it was thought that gas concrete and gypsum plaster should be preferred in structures since they show better performance. Heat transfer was observed to increase as the high temperature values increase. Hence, it was evident that in modern-day structure materials having low thermal conductivity capacity will be preferred and more advantageous.

In terms of the relationship between the compressive strength values of the materials exposed to high-temperatures and the normal strength of the same materials, it was concluded that gas concrete and gypsum plaster materials are more durable. Therefore, using these materials in structures will be more advantageous.

References

[1] Nguyen, T., Meftah, F., Chammas, R., Mebarki, A. 2009. The behaviour of masonry walls subjected to fire: Modelling and parametrical studies in the case of hollow burnt-clay bricks. Fire Safety Journal 44 (2009), 629-641.

[2] Gündüz, L., Şapcı, N., Bekar, M. 2006. Farklı mermer türlerinin yüksek sıcaklık etkileşimlerindeki davranışları. 5. Mermer ve Doğaltaş Sempozyumu, 471-479.

[3] Vilches, L. F., Leiva, C., Vale, J., Fernandez-Pereira, C. 2005. Insulating capacity of fly ash pastes used for passive protection against fire. Cement & Concrete Composites, 27 (2005), 776-781.

[4] Nguyen, T., Mefrah, F. 2012. Behavior og clay hollow-brick masony walls during fire. Part 1: Experimental analysis. Fire Safety Journal, 52 (2012), 55-64.

[5] Leiva, C., Vilches, L. F., Vale, J., Fernendez-Pereira, C. 2009. Fire resistance of biomass ash

panels used for internal partitions in buildings. Fire Safety Journal, 44(2009),622-628.

[6] Gilani, M. S., Wakili, G. K., Koebel, M., Hugi, E., Carl, S., Lehmann E. 2013. Visualizing moisture release and migration in gypsum plaster board during and beyond dehydration by neutron radiography. Internatiolan Jourlan of Heat and Mass Transfer, 60 (2013), 284-290.

[7] Kızılkanat, A. B., Yüzer, N. 2008. Yüksek sıcaklık etkisindeki harcın basınç dayanımı-renk değişimi ilişkisi. İMO Teknik Dergi, 22 (6) (2008), 4381-4392.

[8] EN 1363-1. 2012.Fire resistance tests – Part 1: General requirements Europan Standards.

[9] ISO 834-1. 1999.Fire-resistance tests elements of building construction Part 1: General requirements International Organization for Standardization.

[10] EN 1364-1. 2010. Fire resistance tests for non-loadbearing elements: Part 1—Walls Europan Standards.

[11] EN 1365-1. 2000. Fire resistance tests for loadbearing elements—Partie 1: Murs Europan Standards.

[12] ASTM E119. 2010. Standard test methods for fire tests of building construction and materials American Society for Testing and Materials.

[13] EN 1996-1-2. 2006. Eurocode 6—Design of masonry structures. Parts 1–2: General rules—Structural Fire Design Europan Standards.

[14] ACI 216.1. 2007. Code requirements for determining fire resistance of concrete and masonry construction assemblies American Concrete Institute.

[15] Lawrence, S. 2006. Design of clay masonry walls for fire resistance Think Brick, Australia.

[16] Kalifa, P., Menneteau, F. D., Quenard, D. 2000. Spalling and pore pressure in hpc at high temperatures. Cement and Concrete Research, 30(2000), 1915-1927.

[17] Çil, İ., Çakır, Ö. A., Ramyar, K., Bilgin, A., Karaduman, N. Farklı tip çimentoların yüksek sıcaklıklara direnci TÜBİTAK 2007; Proje No: MAG 106M158.

[18] Wang, H. Y. 2008. The effects of elevated temperature on cement paste containing GGBFS. Cement and Concrete Composites,30 (2008), 992-999.

[19] Tsai, K. 2009. Influence of substrate on fire performance of wall lining materials. Construction and Building Materials, 23(2009), 3258-3263.

[20] Chan, S. Y. N., Luo, X. and Sun, W.2000. Effect of high temperature and cooling regimes on the compressive strength and pore properties of high performance concrete. Construction and Building Materials, 14(2000), 261-266.

[21] Shoaib, M, M., Ahmed, S. A., Balaha, M. M. 2001. Effect of fire and cooling mode on the properties of slag mortars. Cement and Concrete Research, 31(2001), 1533-1538.

[22] Arı, K., Erdinç, M. and Haktanır, T., 2004. Kalsiyum Alüminatlı Çimentonun Refrakter Olarak Kullanılması. Beton 2004 Kongresi İstanbul.

[23] Xiao, J., Falkner, H. 2006. On residual strength of high-performance concrete with and without polypropylene fibres at elevated temperatures. Fire Safety Journal, 41(2006), 115–121.

[24] Aydın, S., Yazıcı, H. and Baradan, B. 2008. High temperature resistance of normal strength and autoclaved high strength mortars incorporated polypropylene and steel fibers. Construction and Building Materials, 22 (2008), 504–512.

[25] Chan, Y. N., Lou, X. and Sun, W. 2000. Compressive Strength and Pore Structure of High-Performance Concrete after Exposure to High Temperature up to 800 ºC. Cement and Concrete Research, 30(2000), 247-251.

[26] Lau, A. and Anson, M. 2006. Effect of high temperatures on high performance steel fibre reinforced concrete. Cement and Concrete Research, 36 (2006), 1698–1707.

[27] Poon, C. S., Shui, Z. H. and Lam, L., 2004. Compressive behavior of fiber reinforced high-performance concrete subjected to elevated temperatures. Cement and Concrete Research, 34(2004), 2215–2222.

[28] Sancak, E., Sarı, Y. D. and Şimsek, O. 2008. Effects of elevated temperature on compressive strength and weight loss of the light-weight concrete with silica fume and superplasticizer. Cem. Concr. Comp., 30(2008), 715–721.

[29] Bingöl, A. F. and Gül, R. 2004. Compressive strength of lightweight aggregate concrete exposed to high temperatures. Indian J. Eng. Mater. Sci., 11(2004), 68–72.

[30] Li, M., Qian, C. X. and Sun, W. 2004. Mechanical properties of high strength concrete after fire. Cem. Concr. Res., 34(2004), 1001–1005.

[31] Noumowe, A. N., Siddique, R. and Debicki, G. 2009. Permeability of high-performance concrete subjected to elevated temperature (600 °C). Const. Build. Mater., 23(2009), 1855–1861.

[32] Yüzer, N., Aköz, F. and Dokuzer, L. Ö. 2004. Compressive strength-color change relation in mortars at high temperature. Cem. Concr. Res., 34(2004), 1803–1807.

[33] Arıöz, Ö. 2007. Effects of elevated temperatures on properties of concrete. Fire Safety Journa, 42 (2007), 516-522.

[34] TS EN 771-4. 2011. Specification for masonry units - Part 4: Autoclaved aerated concrete masonry units, TSE, Ankara - TURKEY.

[35] TS EN 13279-1. 2009. Gypsum binders and gypsum plasters - Part 1: Definitions and requirements, TSE, Ankara - TURKEY.

[36] TS EN 13279-2. 2007. Gypsum binders and gypsum plasters - Part 2: Test methods, TSE, Ankara - TURKEY.

[37] TS 4022. 1993. Hydrated lime-for use in buildings, TSE, Ankara - TURKEY.

[38] TS EN 197-1. 2012. Cement – Part 1: Composition, specification and conformity criteria for common cements, TSE, Ankara - TURKEY.

[39] TS EN 772-4. 2000. Methods of test for masonry units - Part 4: Determination of real and bulk density and of total and open porosity for natural stone masonry units, TSE, Ankara - TURKEY.

[40] EN 12504-4. 2004. Testing concrete - Part 4: Determination of ultrasonic pulse velocity, Europan Standards.

[41] ASTM C 1113. 2004. Standard test method for thermal conductivity of refractories by hot wire, American Society for Testing and Materials.

[42] Subaşı, S., İşbilir, B., Ercan, İ. 2011. Uçucu kül ikameli çimento numunelerinin mekanik özelliklerine yüksek sıcaklığın etkisi. Politeknik Dergisi, 14(2011), 141-148.

[43] Eriç, M. 2010. Yapı fiziği ve malzemesi. Literatür yayıncılık.

[44] Özel, C., İren, B., 2016. Investigation of Usage of Waste Autoclaved Aerated Concrete in Polymer Concrete. SDU Journal of Technical Sciences, 6(2016), 28-38.

[45] Hurama, H., Topçu, İ. B., Karakurt, C., 2009. Properties of the Autoclaved Aerated Concrete Produced from Coal Bottom Ash. Journal of Materials Processing Technology, 209 (2009), 767-773.

[46] Karakurt, C., Kurama, H., Topçu, İ. B. 2010. Utilization of Natural Zeolite in Aerated Concrete Production. Cement & Concrete Composites, 32 (2010), 1-8.

[47] Tanaçan, L., Ersoy, H. Y., Arpacıoğlu, Ü. 2005. Effect of High Temperature on the Mechanical Properties and Ultrasound Velocity of Cellular Gas Concrete. 10DBMC International Conférence On Durability of Building Materials and Components, Lyon – France, 17-20 April 2005.

[48] Durmuş, G., Arslan, M. 2009. Yüksek Sıcaklığın Boşluk Yapısına Etkileri (The effects of high temperature on the cavity structure of concrete). 5. Uluslararası İleri Teknolojiler Sempozyumu (IATS'09), 13-15 May 2009, Karabük, Turkey.

[49] Avdelidis, N, P., Moropoulou, A. 2004. Applications of infrared thermography for the investigation of historic structures. Journal of Cultural Heritage, 5(2004), 119-27.

[50] Bergman, L. T., Lavine, S. A., Incropera, F. P., Dewitt, D. P. 2011. Fundamentals of heat and mass transfer. Seventh Edition John Waley & Sons. Inc. .

[51] Pehlivanlı, Z. 2009. Gazbeton malzemesinin ısıl iletkenliğinin nem ve sıcaklıkla değişiminin incelenmesi. Int. J. Eng. Research & Development, 1(2009), 76-80.

[52] TS 825. 2008. Thermal insulation requirements for buildings, TSE, Ankara - TURKEY.