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Aerojelin Tuğla Üretiminde Kullanımı: Bir İnceleme

Use Of Aerogel In Brick Production: A Review

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ÖZET

Tuğla, geçmişten günümüze varlığını sürdürmüş yapı malzemelerinden biridir. Zaman içerisinde ihtiyaçları karşılayamamış ve iyileştirilmiştir. Bu iyileştirmeler organik atıklar, endüstriyel atıklar ya da bunlardan türetilen yeni malzemelerle yapılabilmektedir. Son yıllarda iyileştirme için kullanılan popüler malzemelerden biri de aerojeldir. Birçok alanda kullanılan aerojel, inşaat sektöründe de kullanılmaya başlanmıştır.

Bu çalışmada, aerojelle tuğla iyileştirilmesi yapılan çalışmalar irdelenerek aerojelin tuğla üzerindeki etkilerinin araştırılması amaçlanmıştır. Çalışmada aerojel hakkında yapılan makale ve tezler irdelenmiştir. Çalışma sonucunda, aerojelin tuğlanın bazı özelliklerini iyileştirirken bazı özelliklerini olumsuz yönde etkilediği görülmüştür. Ayrıca aerojelin miras yapılarının yeniden işlevselleştirilmesinde de kullanılabileceği sonucuna varılmıştır. Aerojel kullanımı ile sürdürülebilir ve mükemmel termal özelliklere sahip tuğlalar üretilebileceği tespit edilmiştir.

Anahtar Kelimeler: Tuğla, aerojel, katkı maddesi, yapı malzemesi

ABSTRACT

Brick is one of the building materials that has survived from the past to the present. It has not been able to meet the needs over time and has been improved. These improvements can be made with organic waste, industrial waste or new materials derived from them. One of the popular materials used for improvement in recent years is aerogel. Aerogel, which is used in many areas, has also started to be used in the construction industry.

In this study, it was aimed to investigate the effects of aerogel on bricks by examining the studies on brick improvement with aerogel. In the study, articles and theses about aerogel were examined. As a result of the study, it was seen that aerogel improved some properties of the brick while negatively affecting some of its properties. It was also concluded that aerogel can be used in the re-functionalization of heritage structures. It has been determined that sustainable bricks with excellent thermal properties can be produced by using aerogel.

Keywords: Brick, aerogel, additive, building material

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1. INTRODUCTION

Human beings need shelter to protect themselves from environmental conditions and feel safe (Aldakshe et al., 2020). They had to build structures to meet their shelter needs (Tezel et al., 2020). The most important element of these constructed structures is the material (Al-Hasani et al., 2023b). Among these materials, concrete comes first (Palta et al., 2020), and brick comes second. Brick is a building material obtained by mixing clay soil with water and, if necessary, sand and burning it in ovens at high temperatures (Çağlar and Çağlar, 2019; Al-Amara and Çağlar, 2023). The transformation of brick into building material by heat treatment from adobe dates back to the times of protohistoric societies (2500-1750 BC). Fired brick is a block that has been used for thousands of years, especially until the discovery of reinforced concrete (Çağlar et al., 2018).

The abundance of soil, which is the raw material for bricks and the ease of production stages have made the use of bricks attractive in the construction sector (Çimen et al., 2020; Kale et al., 2021). In the construction industry, bricks are generally used in the construction of exterior and interior walls (Al-Amara and Çağlar, 2022).

As the world population increases rapidly (Demircan, 2020a), almost half of the world's population builds its load-bearing structures with bricks. For this reason, it is improved by substituting different materials into the brick structure. The number of these studies has been increasing significantly in recent years (Al-Hasani et al., 2023a, Demircan, 2020b).

Recently, the most popular additive for brick improvements has been aerogels (Çağlar, 2023). Aerogel is a unique material with nanostructure, high porosity and ultra-low density (Stojanovic et al., 2021; Ng et al., 2016). Aerogels are used as additives in the construction industry in high-performance plaster (Buratti et al., 2014; Bianco et al., 2015), mortar (Jia et al., 2023; Tay et al., 2024; Bostancı, 2020), plaster (Melita et al., 2024; Gavrila et al., 2023), cement (Shah et al., 2021; Du et al., 2023) and concrete (Wu et al., 2023; Welsch et al., 2023; Chen and Yu, 2024).

In this study, it is aimed to determine the changes that may occur in the brick when aerogel is used in brick production. For this purpose, the studies in the literature were examined in detail.

2. AEROGEL

Aerogels, the lightest solid material ever made by mankind (Çimen, 2023), are nanoporous solids with a fine, open pore structure that makes them extra lightweight. Aerogels are porous and very light materials because they contain 99% air. Their densities vary between 0.001 and 0.5 g/cm3 (Çimen, 2021).

Aerogels have many excellent physical properties, such as high specific surface area, low bulk density, high cross-linking structures, high porosity, small thermal conductivity, small density and large acoustic resistance (Mohannan & Brock, 2004; Yang et al., 2011). An image of the aerogel is given in Figure 1.

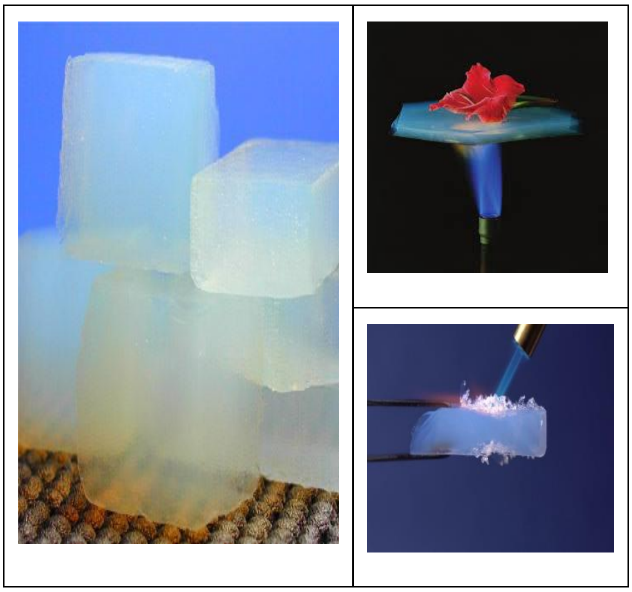

Figure 1. Aerogel

Aerogel is one of the important materials preferred today due to its high physical properties. Aerogel is important because it has high porosity and low density due to the exchange of liquid matter with air inside it. Aerogels have high specific surface area and high nanoporosity structure. In addition, its thermal insulation properties came to the fore with the porosity rate reaching 95% (Öztürk, 2012; Gürsoy, 2019).

Aerogels have much more superior and efficient properties than other insulation materials. It is a type of material that can insulate even the fire reflected directly from the oxygen source (Çimen, 2021). In fact, aerogels are a very good insulation material due to their high porosity and high air voids, and they are ultra-lightweight. This is another desired feature in the construction industry (Figure 1) (Çimen, 2023).

These properties enable aerogels to have application value in many areas such as efficient superthermal insulation systems (Cuce et al., 2014; Koebel et al., 2012), drug delivery (Simirnova et al., 2004), acoustic insulation, oil spill cleanup (Reynolds et al., 2001), catalyst supports (Kogel et al., 2006) and other advanced technologies (Schmidt et al., 1998; Gao et al., 2009; Engel-Herbert et al., 2007).

Aerogel, which can be used for many purposes in buildings, is a highly waterproof and lightweight material (Kistler, 1941). It is almost three times denser than air and has over 95% porosity. Aerogels are characterized by both good temperature resistance (Ghazi and Wakili, 2017; Wei et al., 2016) and a simple production process (Koebel et al., 2016; Huber et al., 2017).

2.1. Aerogel Types

The most convenient way to classify aerogels is to determine according to their chemical composition. Therefore, considering the number of components they contain, aerogels are divided into single-component and multi-component (composite) aerogels (Gürsoy, 2019). Aerogels can be obtained from silica (Çimen, 2023), carbon (Job et al., 2005), different organic materials (Liu et al., 2002) or organic-inorganic composites (Chen et al., 2013; Wang et al., 2014).

Aerogels commonly used in the construction industry are graphene aerogel (Lin et al., 2011), silica aerogel (Dorcheh and Abbasi, 2008), carbon aerogel (Lee et al., 2010) and cellulose aerogel (Sehaqui et al., 2011).

2.1.1. Organic (Carbon) aerogels

Carbon aerogels are covalently bonded, nanometer-sized materials. The network structure can be three-dimensionally symmetrical and asymmetrical. High porosity and high surface area are among its features. Thanks to its controllable porosity feature, it can be produced in different forms such as powder and solid state. Carbon aerogels have become the subject of research of scientists in recent years because they are inert, environmentally friendly, non-toxic, have a porous structure and are easy to control (Çimen, 2021).

Aerogels, most of which are synthesized from inorganic materials, are also synthesized from organic materials. Organic aerogels have properties such as high specific surface area, low dielectric coefficient, high porosity structure, heat and mechanical resistance. Another feature of organic aerogels is that they keep the amount of porosity within the structure under control. This feature of organic aerogels allows them to be synthesized differently in various fields. Carbon aerogels exist in a covalently bonded 3D structure. Organic aerogels do not cause any environmental problems or pollution due to the components they contain (Gürsoy, 2019).

Organic aerogels have different areas of use. These are;

- ✓ Studies to reduce environmental pollution,
- ✓ Space industry
- ✓ Insulation material in daily used white goods

In addition, organic aerogels are promising for future studies because they have the ability to absorb kinetic energy. An example of a carbon aerogel image is given in Figure 2 (Radha, 2008).

Figure 2. Carbon aerogel

2.1.2. Inorganic (Silica) aerogels

Inorganic aerogels are synthesized from cross-linked and transparent hydrogels produced by the polycondensation of metal alkoxides (Gürsoy, 2019). The properties of inorganic aerogels are; high porosity structure, high surface area, low dielectric coefficient and low density. In addition, inorganic aerogels have low thermal conductivity and are preferred for use in the production of insulation materials.

Inorganic aerogels are produced by sol-gel technique. In this technique, the starting material silica is mixed with a mixture of water and alcohol. After mixing, sol is formed. The sol structure consists of colloidal-cross-linked particles. The resulting sol fills the voids of the particles with liquid material, forming a long bond and gelation occurs. Acid or base catalyst can be added to make gelation more efficient (Öz et al., 2018). Table 2.1 shows the general properties of inorganic aerogels.

Table 2.1. General properties of silica aerogels (Çimen, 2021).

Feature	Value
Porosity	%80-99,8
Porosity diameter	20-150 nm
Thermal conductivity	0,017-0,021 W/mK
Dielectric constant	1,1
Intensity	0,003 g/cm^3
Surface area	500-1000 m^2/g
Primary particle diameter	2-5 nm
Refractive index	1-1,05
Coefficient of thermal expansion	4-4.10-6 1/K

Silica Aerogels can be used as potential materials in sensor materials, adsorbents, insulation materials, catalysts, architecture, space and aviation, and construction applications (Bakış et al., 2006). It is preferred due to its superior qualities such as having an open cell structure, low density, large surface area, high thermal insulation properties, high porosity, refractive properties and very low dielectric constant.

2.1.3. Alumina aerogels

Alumina aerogels with large specific surface area are abundantly available as raw materials. Alumina aerogels are formed by hydrolysis reactions (Mackenzie, 1992). Metal oxide aerogels are produced by using the starting material metal elements with the sol-gel method and extending the process time. Alumina aerogels produced by hydrolysis reaction have begun to be used frequently in recent years. The metal species and hydroxyl used in the hydrolysis reaction come together at the center of the metal to form the Al-OH structure. As the process progresses, it is observed that hydroxyls increase in the center of the metal. As a result of the process operations, a metal-oxide-metal structure (Al-O-Al) emerges. As a result of drying of metal alkoxides, metal (alumina) aerogel is obtained (Çimen, 2021). An image of alumina aerogel is given in Figure 3.

Figure 3. Alumina aerogel

2.1.4. Other aerogels

There are aerogel types other than organic, inorganic and alumina. These are: Borasilicate, Zirconia Carbonized, Formaldehyde, Chalcogenide, nanotube, semiconductor metal aerogels, polymer aerogels and Gradient aerogels (Gürsoy, 2019). In addition, copper-doped metal aerogels were first produced in 2002 and have a unique structure with the advantages of transparency, permeability and photoluminescence properties (Bozoğlu, 2014). Examples of other aerogels are given in Figure 4.

a) Graphene aerogel

b) Nano aerogel

Figure 4. Other aerogel examples

In recent studies, graphene, carbide and silicon aerogels have been synthesized and taken their place under the aerogel class. X-aerogels with very good properties have been synthesized by NASA and these synthesized aerogels have very high elastic and mechanical properties. Its density is very low. Its strength is quite high compared to other produced aerogels. X-aerogels are used in heating fuels and rocket industry (Bozoğlu, 2014).

2.2. Historical Development of Aerogels

The historical development of aerogels, which are called frozen smoke because they create a smoke-like image, is given below.

- It was first synthesized by Steven Kistler in early 1932, based on silica gels (Çimen, 2021; Çağlar, 2023).
- After his studies at the University of the Pacific between 1940 and 1945, Monsanto commercialized his product under the name Aerogel Santocel (Çalapkulu, 2024).
- In 1970, the subject of research at a university in France on rocket fuel or hydrogen storage in porous structures increased the interest in aerogels again (Yılmaz, 2013).
- After their production began in 1980, carbon aerogel was obtained in 1990. After the production of composite aerogels, studies on aerogels have increased. Today, there are types of aerogels such as silica, carbon, alumina, and composite aerogels (Çimen, 2021).
- In 1990, carbon aerogels began to be synthesized, and with the good chemical and physical properties of the aerogels obtained, their importance in terms of use increased.
- Nickel aerogel, synthesized in a study conducted in the USA in 2011, is the lightest material of recent times (Gürsoy, 2019).

3. USE OF AEROGEL IN BRICK PRODUCTION: LİTERATURE REVİEW

Mazın (2024), in his master's thesis, investigated the effects of rice husk ash and silica aerogel on the properties of bricks. In the study, 0.5%, 1.0% and 1.5% aerogel and 10%, 20% and 30% rice husk ash were used. He applied physical and mechanical experiments to bricks. As a result of the study, it was determined that the thermal properties of the brick improved with the increase in the silica aerogel ratio. He reported that some of the samples he produced (B1, B2, B3 and B4) were classified as medium strength bricks, while some samples (B5, B6 and B7) were classified as low strength bricks. He also stated that silica aerogel is a suitable substitute material for brick production.

Buratti et al., (2022), In their study, examined the effect of granular aerogel in clay-aerogel blended bricks on both thermal and acoustic properties. In the study, they used 5% granular aerogel at a rate of 5%. As a result of the study, they revealed that the thermal conductivity of the clay sample with 5% aerogel decreased to 0.212 W/(mK), while the reference sample had a thermal conductivity of 0.310 W/(mK).

Çağlar (2023), in his study, examined the effect of silica aerogel produced from boron waste on the compressive strength and thermal performance of the brick. She carried out her work in three stages. In the first stage, silica aerogel was produced using boron waste supplied from the Eskişehir/Kırka region of Türkiye. In the second stage, the silica aerogel produced was substituted into the brick structure at different ratios by volume (0% (REF), 15% (AB1), 25% (AB2), 35% (AB3), 45% (AB4)). They produced mixed brick samples by firing the samples at 900 oC and 1000 oC. In the third and final stage, She applied to the produced samples to compressive strength and heat transfer coefficient determination tests.

Additionally, SEM images were taken to examine the internal structure of the samples. In conclusion;

✓ At both temperatures, with the increase of amount of aerogel resulted to decrease in the compressive strength and heat transfer coefficient value,

✓ In SEM images, it is seen that as the amount of silica aerogel increases, the amorphous structure increases and voids and cracks form in some places,

✓ It has been reported that the use of silica-containing wastes such as boron waste in aerogel production is a suitable solution for the disposal of wastes.

Ganobjak et al., (2023), in their study, investigated the thermal and structural characterization of aerogel glass bricks providing high level of insulation. In their study, they aimed to create an aesthetically pleasing building component that can transmit daylight and has excellent thermal insulation properties. As a result of the study, they compared to obtained the data with traditional brick material. In their studies, they found that aerogel glass bricks can significantly reduce energy consumption and transmit daylight. They also stated that aerogel glass brick is a suitable option for architects and engineers looking for a sustainable and efficient building component.

Wernery et al., (2017), In their article, replaced with aerogel to the perlite filling of insulation bricks commercially available. In other words, it has produced perlite and aerogel filled insulation bricks. They determined the heat conduction coefficient of produced bricks. As a result, it was reported that the U value of the produced brick samples was 0.157 W/(m2K). They also stated that the thickness of the insulation bricks could be reduced with aerogel filling.

Joo et al., (2021), In their study, produced two-component aerogel and 3D printed load-bearing polymer bricks. The aerogel that used was derived from fully cross-linked SLA resin and fully cured epoxy resin. They discussed the flexural and compressive strengths of the produced samples.

Ganobjak et al., (2020) investigated the technical properties of plate, boards and plasters to commercially available. They examined that the usage scenarios of these materials in heritage buildings and considering heritage criteria such as authenticity, integrity, recyclability and compatibility. The study was carried out in two stages: theoretical evaluation and the study with calculated U values. As a result of the study, they reported that aerogel materials, which provide excellent insulation, would be an excellent alternative in the renovation of heritage buildings. In their renovations using aerogel, they stated that aerogel is an easily applicable material. In addition, they observed that an excellent improvement was achieved in terms of both comfort and thermal properties.

4. CONCLUSION AND RECOMMENDATIONS

In this study, the effects of aerogel substitution on brick, which is an interior and exterior wall element, were investigated. The results obtained from the study conducted in the form of a literature review are listed below.

- ✓ Since the unit volume weight and density of the aerogel are very low, the unit volume weight and density of the brick decreases.
- ✓ Aerogel with high porosity increased the porosity value of the brick.
- ✓ The increase in porosity value caused an increase in water absorption rate.
- ✓ Due to the fact that its porous structure traps heat, the heat conduction coefficient of the brick has been greatly reduced.
- ✓ Aerogel improves not only the thermal insulation properties of the brick but also its acoustic properties.
- ✓ Aerogel, which has a brittle structure, caused the compressive strength of the brick to decrease.
- ✓ It is thought that the compressive strength of the brick can be improved by using wastes such as silica fume, fly ash, etc. as additives in brick production.
- ✓ It has been seen that aerogel can be easily used not only in structures that are being built for the first time but also in heritage structures.
- ✓ It has been determined that aerogel can be easily used in the production of sustainable and energy efficient building materials.
- ✓ It has been observed that aerogel is not used sufficiently in brick production.

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