Utilization of aerogel in building construction – A Review

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Abstract. Aerogel are synthetic light weight material obtained in a gel form with gas without any shrinkage. The first form of aerogel is produced by using Silica gels. There are several other types of aerogels such as carbon-Based aerogel, clay-Based aerogel and silica- Based aerogel. Aerogel are mostly in solid form with extremely low conductivity and possess very low density and high porosity (<100nm). Aerogel are water repellent material. In recent years, Aerogel have attracted towards various sectors, including building construction based on their promising properties and surprising applications in wide range of technical spaces. Aerogel based materials are prepared for its high-performance thermal insulation applications in building sectors. Despite, it also used in manufacture of chemical products, Electronics, thermal and acoustic insulations, energy absorbers, space suits and in building systems. This paper reviews the properties, formation and applications of aerogel in various sectors and its abundant utilization in building construction.

Keywords: Aerogel, material, construction.

1. Introduction

The buildings emit huge amount of carbon dioxide as a part of greenhouse gas emission strategy every year. Though the building energy demands increases by raising the demand for energy saving materials and systems with the concern of Greenhouse gas emissions [4]. The thermal insulation materials are mostly employed to protect the buildings from emission. In order to decrease emission in buildings, a new material under research is aerogel that plays a vital role in providing insulation materials [1]. In addition to the requirement for energy saving, insulating materials are now manufactured with high comfort levels to increase the life of building [5]. The thermal characteristics of buildings rely on thermal conductivity of the walls and roofs. To overcome the issue of traditional plaster techniques SiO2 aerogel is used by many developed countries. Aerogel was introduced by Steven Kistler in 1931, material of today’s interest by several scientists in last decades due to its light weight and versatile nature [6]. Aerogel is defined, as a synthetic gel comprised of a microporous solid with low density and thermal conductivity in which dispersed phase is a gas, as per IUPAC [14].

However, aerogel technologies are off deliberate importance in global insulation market nowadays and employed for construction industry includes façade systems, plasters, boards, translucent panels and aerogel panels for ventilation systems [2]. Aerogel manufacturers are focused mainly on cost optimized products to develop new types of aerogel products where the global growth for aerogel is
mainly focussed on applications such as thermal and acoustic insulation [3-6]. Aerogel has proven to be better characteristics with lower density and thermal conductivity though it was embedded in the thermal barrier layer of fire protection clothing [25]. The comprehensive literature reviews on several aspects of aerogel, their applications, materials by numerous investigations that has been reported [7–12].

2. Review from past research

2.1 Properties of silica aerogel

Silica aerogel comprises of a cross-linked internal structure of SiO$_2$ chains with a large number of air-filled pores. The pore size of silica aerogel is between 5 to 70 nm, depends on purity and fabrication method [11]. Silica aerogel panels are also manufactured with different kinds of matrix such as melamine foam and different types of Fibers. The aerogel panels of thickness 30mm having its size 300mm by 400mm were tested through different kinds of analysis. The Table 1 shows the measured thermal conductivity of aerogel panel for different kinds of matrix material and its density [3] [20]. The aerogel exhibits its significant physical, thermal, optical, and acoustical properties due to its fine pore sizes. Silica aerogel represents very low tensile strength and high compression strength with load-bearing abilities. The physical properties of silica aerogel are formulated in table: 2

Table 1 Summarizes in detail about the aerogel materials and its thermal conductivity

| Reference | Aerogel Material | Density $\rho$ [kg/m$^3$] | Thermal Conductivity $\lambda$ [W/(m.K)] |
|-----------|------------------|---------------------------|-----------------------------------------|
| [3]       | Aerogel panel with melamine (10mm) | 98.7 101.0 | 0.0137 0.0136 |
| [3]       | Aerogel panel with PET fiber (13mm) | 118.2 116.6 | 0.0148 0.155 |
| [3]       | Aerogel panel with glass fiber (30mm) | 98.0 106.1 | 0.0148 0.0151 |
| [3]       | Aerogel panel with needle glass fiber (7mm) | 182.5 194.9 | 0.0142 0.0156 |
| [13]      | Aerogel Blanket | | 0.015 |
| [13]      | Solid aerogel | | 0.012 - 0.020 |
| [24]      | Aerogel from flyash and bottom ash | | 0.0385 |
| [26]      | Aerogel based mortar coating | 150.0 | 0.0268 |
| [27]      | Aerogel using industrial solid wastes and dislodged sludges | | 0.03-0.032 |
| [28]      | Aerogel based plaster | 200 | 0.025 |
Table: 2 Physical properties of silica aerogel [4]

| Property                  | Value                        |
|---------------------------|------------------------------|
| Density                   | 3 to 350 kg/m³              |
| Pore diameter             | 1 to 100 nm                 |
| Porosity                  | 85-99.9 %                   |
| Thermal Conductivity      | 0.01-0.02 W/m K             |
| Primary particle diameter | 2-4 nm                      |
| Surface area              | 600-1000 m²/g               |
| Tensile strength          | 16 kPa                      |
| Coefficient of linear expansion | 2.0 - 4.0 \times 10^{-6}   |

2.2 Formation of silica gel

Aerogel can be prepared using silica, alumina, chromium, Tin oxide and Carbon. Though the preparation of aerogel based on silica is much easier and reliable. The one form of production processes of silica aerogel panels are represented in the Figure 1. The aerogel panels are produced from silica sol obtained from hydrolysing alkoxyisilane added with hydrochloric acid and ammonia, poured on sheets of melamine foam impregnated with fibers in a tailor made reactor. After gelation process, alcogel is reacted with hydrophobization agent introduced into the chamber. The reaction mixtures are separated from the hydrophobic silica alcogel composite and condensed alcogel reinforced by the melamine foam and fiber dried in a pilot scale dryer [3]. It can also be prepared by adding water to Tetraethylorthosilicate (TEOS) in the presence of ethanol leads to the chemical reaction with its end product depends on the concentration of silicon alkoxide monomers. After gelification process, the gel is undisturbed in the solvent for 48 hours to complete the reaction. Once reaction will complete the alcogel product will form as shown in figure: 2. Inorganic aerogels can also be prepared via sol-gel processing technique that requires alcoxides or metal salts in alcoholic or aqueous solutions as shown in figure: 2[6].


3. Building applications

Silica aerogels have wide applications in building sector as thermal insulation material due to their improvements in thermal performance even though the materials remain with high cost [20] [30]. Silica aerogel is destroyed by contact with liquids [18]. Several researches are in progress to develop the insulation materials with better performance and lesser production costs of aerogels [19] [29]. Presently available insulation materials for building applications includes opaque, translucent silica aerogels and transparent insulation with utilization of solar radiation. The translucent aerogel insulation is applied in new buildings for daylighting purposes are shown in Figure: 3. The opaque aerogel insulation materials are applied on old brick building as a retrofit techniques. Aerogel as vacuum insulation panels with promising high-performance insulation materials for possible building applications in limited as shown in Figure 4. In fact, several aspects of aerogel, their applications, and related areas under various investigations have also been conducted [11]

![Figure: 3 Translucent aerogel for building insulation](image1)

![Figure: 4 Thermal insulation material](image2)

A granular aerogel-based window and glazing system has its wide applications in buildings. The semi-transparent spheres with a solar transmittance and highly translucent granulates are provided. The granular aerogel is stacked in polymethylmethacrylate (PMMA) double-skin sheet between two gaps filled with krypton or argon and glass panes as shown in figure: 5a[11][16]. The new idea of light aerogel mortar has been patented, as thermal insulated coating applied to the external surface of a building as shown in figure: 6. It comprises of water, granules of hydrophobic silica aerogel, mineral and structuralizing filler, additives are of optional. It is applied for exterior wall surface insulation of new and old buildings. It can be installed in simple and easier manner as compatible to the traditional masonry facades techniques. It is too flexible with respect to unevenness surface and it allows continuous thermal insulation as plastering and facilitates the buildings’ rehabilitation works [10] [26].

![Figure: 5a Glazing system](image3)

![Figure: 5b Aerogel glazing](image4)

![Figure: 6Aerogel coating](image5)

Aspen product called pyrogel, most effective high-temperature insulation material in industrial applications such as refineries, petrochemical, and gas processing plants. This insulation material is versatile, efficient, durable, and simple to install. It is hydrophobic used in vessels and large bore piping [7] [22]. Aerogel insulation for roof cavities is employed in buildings to reduce thermal
bridging in roof rafters. To have complete insulation from outside the buildings for both masonry and under shingles and it has high insulating value. In wooden buildings thin strips of aerogel can be applied to prevent thermal bridging where heat escapes through the walls’ framing [6].

4. Aerogel- Retrofit in buildings

The aerogel-enhanced systems namely aerogel glazing systems, aerogel plasters, aerogel concrete tiles and panels and aerogel fiber blankets are used as retrofitting techniques in buildings.

4.1 Aerogel-based blankets

Silica aerogels have fine pores with significant physical, thermal and acoustical properties as blanket. It ensures low mechanical strength and stability. Several attempts have been made to develop panels and blankets composed of synthetic amorphous silica dioxide impregnated with fibers to ensure better tensile property. Space loft is mostly suitable for thermal performance of solid walls, floors, and roofs. Proloft is a type of thermal barrier strip provided to bridge the thermal interruption for door and window frames.

4.2 Aerogel-incorporating plasters

The aerogel based plasters are used to increase the thermal performance of the building wall assemblies, especially for the retrofitting of old buildings as shown in figure: 7. The insertion of aerogel in fibrous panels and mats under different approach is applied in glazing and window panes. The aerogel plasters are made water repellent, for changing the volumetric composition and thermal performance. Many researchers developed an aerogel plaster based on silica with different types of mineral obviously cement free and some additives are added to enhance the workability of the rendering.

5. Conclusions

In this paper, the application of aerogel in building construction has been discussed in detail. A lot of materials are used for various applications in buildings as thermal insulation and to satisfy the demands of energy efficiency. The exclusive properties of aerogels offer different applications in building sector. Though the silica aerogel is costlier often used for its low thermal insulation and optical transparency in window and glazing applications. Aerogel based materials are applied to a building wall as plaster and tiles to attain better thermal comfort. They are user-friendly, simple to use, recyclable and reusable materials. Many researchers are manufacturing aerogel with optimal and environmental costs to have an appropriate alternative to traditional building insulation materials. When compared to traditional building insulation materials, the thermal conductivity of aerogel is about two to three times lower. The high potential for aerogels found in its translucent states and...
possible satisfactory transparent states, as the aerogels may provide large energy savings in future windows and skylights.

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