

## **Performance of Polycarbonate Concrete Panels in Construction: A Critical Research Review**

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**Abstract:** A unique category in polymer heat and thermal conductivity conjures a huge leap in sustainable construction by emphasizing the thermal insulation system. Combining polycarbonate with concrete panels to create a new manufacturing method called concrete panels. Polycarbonate concrete panels offer excellence and thermal comfort insulator. In a building, energy efficiency is the most essential element in converting a building system to a green building plan. This study includes the evaluation of Precast Concrete Sandwich Panels (PCSP), the junction of the concrete panel to bind to a wall or a roof with polycarbonate panels, and easy temperature insulation in concrete panels. By following the Green Building Index (GBI) rate, issues that have been faced including harmful gas emissions such as CO<sub>2</sub> resulting in an impact on atmospheric temperature or termed greenhouse phenomena. By reviewing such critical research on sustainable building or technologies, many articles will be discussed such as compliances of foam concrete as wall panels, isolation mechanism in concrete panels, heat transfer properties in the vacuum insulation wall, and CO<sub>2</sub> emission effect to the environment. A comprehensive evaluation of current literature on thermal, optical and acoustic performance of polycarbonate concrete panels for sustainable built environment is explored in this study.

**Keywords:** Polycarbonate, Thermal, Optical, Acoustic

### **1. Introduction**

By reviewing such critical research on sustainable building or technologies, many articles will be discussed such as compliances of foam concrete as wall panels, insulation mechanism in concrete panels, heat transfer properties in the vacuum insulation wall, and CO<sub>2</sub> emission effect to the environment. This research explores a thorough assessment of existing literature on thermal, optical, and acoustic performance of polycarbonate concrete panels for sustainable built environment. Reducing energy usage in buildings is one of the most important problems facing modern construction industry. In residential buildings, individuals use air conditioners to decrease indoor temperature to improve thermal comfort. In industrial and other buildings, air-conditioners are used to improve thermal comfort. However, energy use has negative consequences on both home owners and the country, including rising

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electricity costs, energy consumption due to electricity use, and electricity plant emissions during electricity generation [1].

On the other side, the sun sends ultraviolet radiation (UV) to the earth's surface, harming both the building and humans. Excessive UV exposure, however, is detrimental to human living tissue [2]. The right option is to build the finest and greatest materials to limit harmful rays, the excellent usage in polycarbonate material. Polycarbonate is a kind of beneficial material recognized as a particular structure inheriting many helpful effects, such as the type of transparent insulating material. To become green and sustainable structures, the use of polycarbonate panels as part of building material may be enhanced by their thermal characteristics. A substance that is a collection of thermoplastic polymers having groups of carbonates in its chemical structures. Solid, strong materials are producing polycarbonates and certain grades are optically clear [3] They are easily worked, melded, and thermoformed. In severe winter climatic circumstances, the interior of the building must preserve the usage of energy to maintain indoor temperature. By particle components of polycarbonate, panels may efficiently absorb and reflect heat [4]. Polycarbonate panels are a specific kind of transparent material that may be fully integrated into their usage. Envelop building structures as uses for such systems are increasing, and study was needed. A comprehensive evaluation of current literature on thermal, optical and acoustic performance of polycarbonate concrete panels for sustainable built environment is explored in this study.

In hot countries like Malaysia, heat passes through concrete panels and experiences high thermal levels on a hot day owing to wall and ceiling heat. Daily and continuous use of air conditioning, however, leads to increased energy usage, power prices, and CO<sub>2</sub> emissions [5]. Carbon dioxide influences atmospheric water vapor, thus the degree of greenhouse effect. However, isolation in buildings is still uncommon owing to lack of information on thermal performance and its beneficial cost and environmental effect. This research aims to investigate the current reviews in thermal, optical and acoustic performance of polycarbonate concrete panels

## 2. Literature Review on Thermal/Energy Performances

This section details and discusses several kinds of materials and past research related to thermal and energy performance of polycarbonate concrete panels. Based on prior thermal properties investigation, combine with literature review to create an original for this research review.

**Table 1: Properties and description of Thermal and Energy performances of PC**

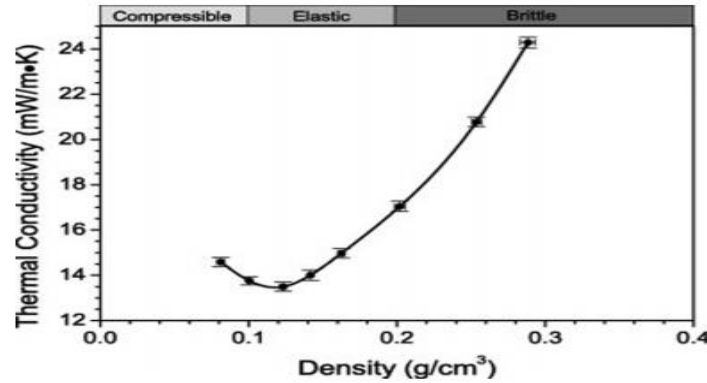
| <b>Properties</b>    | <b>Description</b>                      |
|----------------------|---|
| Thermal conductivity | Low thermal conductivity in rigidities  |
| Thermal insulation   | Low heat transfer due to high porosity  |
| Water proofing       | Has high hardening foam pore structures |

Several types of building parts are including in this chapter were recognizing the parts of, silica-aerogel foam concrete wallboards [6], mortar and aerogel combination [7], polymeric aggregates [8], and granular aerogel structure [9].

### 2.1 Silica-aerogel foam concrete wallboards

Silica aerogels offer remarkable thermal insulation characteristics in buildings, particularly translucence/transparency and extremely low heat conductivity and density. They reduce the building envelope's overall weight while increasing its thermal resistance when incorporated in composites or frame systems, making them very useful for energy-efficiency [6]. The equipment and testing methodology of the guarded hot plate (GHP) method is specified in several standards, including ASTM C177, European Standard EN 12667, and International Standard ISO 8302. The Transient Plane Source

(TPS) method, especially the "Hot Disk" variants, was used to characterize fast thermal properties. The tools and procedures are specified by ASTM D7984 and ISO 22007-2 [10]. According to studies, the TPS method can detect thermal conductivities ranging from 0.005 to 500  $\text{mW}\cdot\text{m}^{-1}$  [11]. The two sample pieces required, however, must be identical and have a flat surface that may be difficult for aerogel samples. Figure 1 displays thermal conductivity as density.



**Figure 1: Thermal conductivity of aerogels [11]**

### 2.1 Uses of Clay hydrogel

The authors mentioned the cross-linking agent of different chemical compounds and strains such as N-isopropylacrylamides (NIPAM), azobis (isobutyronitrile), toluene and ethylene glycol dimethacrylate (EDGMA) [17]. Clay hydrogels were frozen using a rotating shell freezer in 2L glass lyophilization shells. A Virtis Freeze Mobile 35EL freeze-dryer was used to frozen clay hydrogels. Half-filled shells were frozen at 30 rpm at  $-80^\circ\text{C}$ . The freeze-dryer was then used to extract the frozen shells for 36 hours. On a heating/cooling stage, in-situ evaluation of specimen dehydration was performed utilizing SEM wet mode imaging, enabling imaging at a range of relative humidity. By decreasing chamber pressure and increasing temperature, the relative humidity surrounding this sample was changed [12].

### 2.2 Polymeric aggregates

Silica-containing compounds can offer building thermal wall insulation. Silica aerogels offer remarkable thermal insulation characteristics in buildings, particularly translucence/transparency and extremely low heat conductivity and density. They reduce the building envelope's overall weight while increasing its thermal resistance when incorporated in composites or frame systems, making them very helpful for energy-efficient. Typically, silicon alkoxide hydrolysis is done using a catalyst and involves converting alkoxide groups to silanol groups ( $\text{Si-OH}$ ) [13]. During condensation reactions, two processes may occur: i) condense silanols, generate siloxane linkage and one water equivalent (water condensation), and ii) condense silanol and alkoxide group, generate siloxane bond and one alcohol equivalent (alcohol condensation).

The authors developed a low-cost approach fiber insulating material. As shown in Figure 2, a 20 mm thick aerogel insulation panel was utilized to analyze the impacts of composite retrofitting.

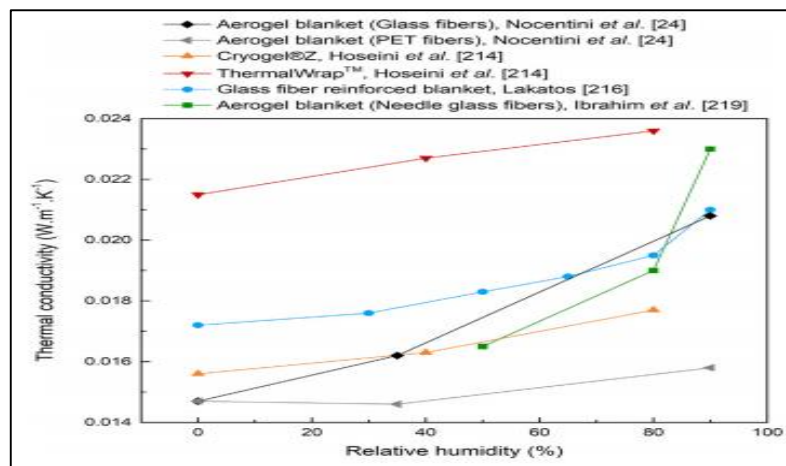


Figure 2: Thermal conductivity of aerogel blankets for different moisture contents [13]

### 2.3 Granular aerogel’s structure

The thermal and optical performance was assessed while taking into consideration the performance of male-female interlock junctions (used for in-situ installation). Due to geometrical and structural complexity, as well as scattering issues in non-regular materials, thermal property tests indicated the need for a large integration sphere [15]. Each sample consists of three walls: two outer walls (1 mm thick) and one inner walls (0.4 mm thick), with aerogel granules sandwiched in between. They vary in geometry (difference between orthogonal layers) and thickness. Granular aerogels have particle sizes ranging from 0.7 to 4.0 mm. Polycarbonate panels have a maximum width of 2100 mm and a length of 7000 mm and are mounted on male-female connectors.

The results of the study are presented in Figure 3 below, showing sample comparisons with and without aerogel (polycarbonate). For double or triple glazing systems, multiwall PC systems are characterized by an air gap between PC layers where convection has a significant temperature impact.

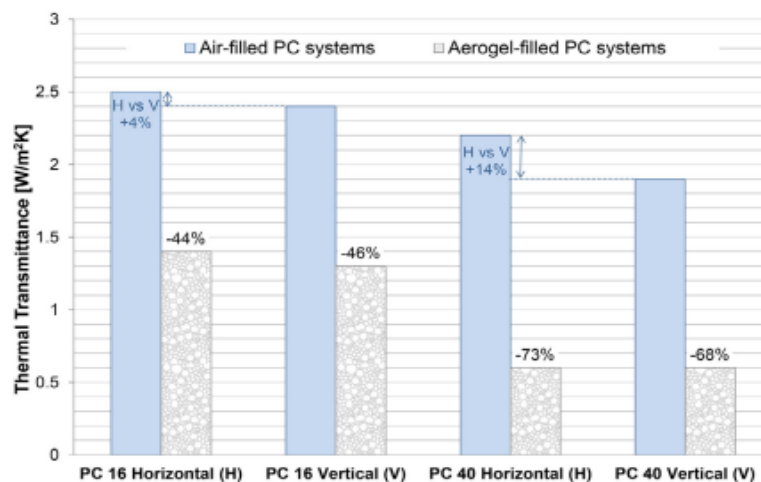


Figure 3: Thermal transmittance comparisons of samples with and without aerogel [15]

Modeling energy exchanges between a building and its surrounding environment is termed thermal performance of a building. Different building components, including walls, roofs, doors, and total heat transfer rate are estimated using a generalized stable state approach. Daylight, the utilization of natural light and façade glazing may be enhanced. Through greater insulation, heat conservation is feasible inside the structure.

### 3 Literature review on Optical Performances

This section covers and analyses various types of materials, as well as previous studies on the optical performance of concrete panels and explores optical performance monitoring (OPM) and its potential to enhance a self-managed optical network's stability, reconfigurability, and flexibility.

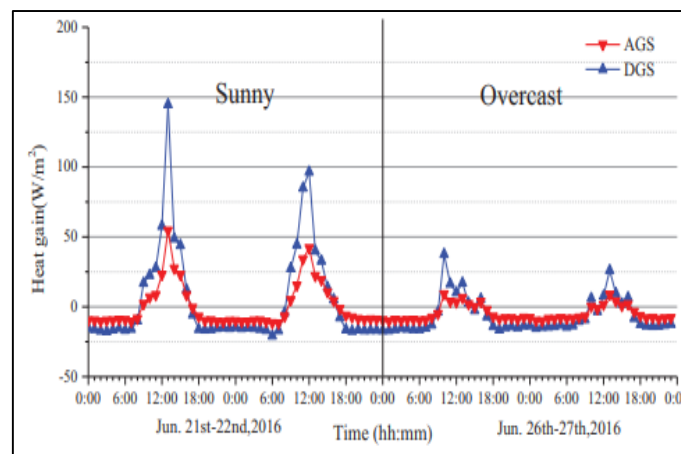
**Table 2: Properties and descriptions of optical grade of PCs**

| Properties              | Descriptions   |
|-------------------------|--|
| Optical performances    | Uses as thermal insulation panel                                     |
| Clear visualisation     | Acts as window in buildings  |
| High thermal insulation | Used as warehouse window for storage                                 |
| Low heat loss           | Used in gymnasium and shopping malls for conserving room temperature |

Several types of building parts are including in this chapter were recognizing the parts of optical clarity of aerogel glazed skylight [6], granular aerogel [16], aerogel layer heat transfer [17] and aerogel coating systems [18].

#### 3.1 Aerogel-glazed skylight (AGS)

The study performed a comparative experiment between AGS and double-glazed skylight (DGS) under real-world climatic conditions. This research covers optical and thermal performance experimental comparisons between AGS and DGS in real-world climate conditions. The sun angle is the greatest on the summer solstice, and daylight is the longest of the year. Moreover, the summer solstice solar altitude angle at noon is the highest of the year [19]. Consequently, without cloud influence, the summer solstice's horizontal solar irradiation is the greatest of the year. Figure 4, shows total heat gain comparisons via AGS and DGS under various weather situations.



**Figure 4: Comparisons on heat gain through AGS and DGS [19]**

#### 3.2 Granular aerogel

Numerical analyses and field studies indicate that the method may provide substantial energy savings compared to conventional glazing systems, especially in cold-dominated regions. Long-term performance evaluations show the reliability of the technology, with minor functionality issues to

address. Granular aerogel was treated in a climatic chamber at six months of accelerated ageing. Common tests were performed at various European facilities, measuring the k values accordingly, with differences in measurement errors. Figure 5 illustrates Italian stakeholder cost study (Euro/m<sup>2</sup>) and Glazing solution prices vs. heat transmission under two different situations [20].

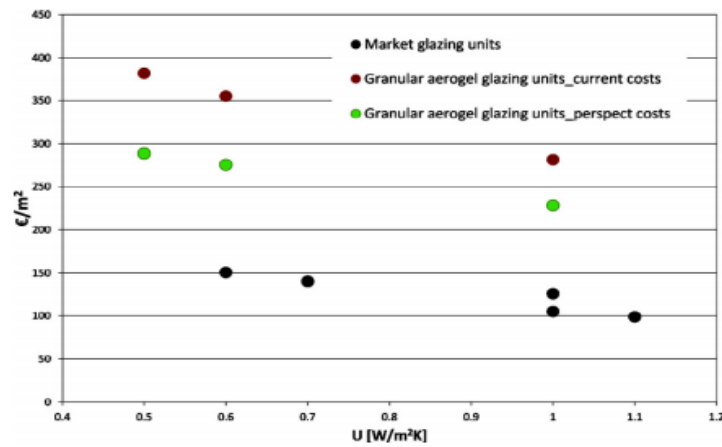


Figure 5: Cost of glazing solution and thermal transmittance [20]

### 3.3 Aerogel layer heat transfer

This research by Zhou et al includes an outside glazing layer, aerogel layer, and an inner glazing layer. Conduction, convection and radiation are aerogel-layer heat transfer techniques. Meanwhile, owing to the thermophysical and optical characteristics of granular aerogel, the impact of absorbed heat and transmitted solar radiation on thermal performance of the aerogel glazing system was also investigated. Two advanced optimization techniques (Teaching Learning-Based Optimization (TLBO) and Particle Swarm Optimization (PSO)) were used to determine the optimum geometric parameters of the aerogel glazing system to assess variations in optimal design using different optimization methodologies. As demonstrated in Table 3, the optimum TLBO solution has a 3.79° lower orientation angle and 0.02436 W.m<sup>-1</sup>K<sup>-1</sup> greater thermal conductivity than the best PSO solution.

Table 3: Minimum total heat gains optimal design of aerogel glazing [21]

|      | Orientation angle [°] | Extinction coefficient [mm] | RoC [JK <sup>-1</sup> m <sup>-3</sup> ] | Thickness [mm] | Thermal conductivity [W.m <sup>-1</sup> . K <sup>-1</sup> ] |
|------|-----------------------|-----------------------------|---|----------------|---|
| PSO  | 26.62                 | 0.09                        | 306920.2                                | 26             | 0.01634   |
| TLBO | 3.79                  | 0.09                        | 306596.3                                | 26             | 0.02436   |

### 3.4 Aerogel coating system

Gunay et al. proposed an alternative atmospheric pressure method utilizing simple, black, absorbent materials [20]. Solar thermal collectors capture incoming solar energy while minimizing thermal losses. Most techniques use a vacuum separation between the solar absorber and surrounding environment to minimize conductivity and convection losses and surface coatings to reduce re-radiation losses. The coating transmits sunlight to the absorber while minimizing environmental heat losses from the heated absorber. Due to ultra-low heat conductivity and optical adjustability, silica aerogels were selected. First make hydrophobic silica aerogel using 0.017:0.091:1:6.71:12.23. Tetramethyl orthosilicate (TMOS): water (H<sub>2</sub>O): methanol (MeOH)). The observed thermal conductivity may be explained by the changed microstructure affecting phonon on transport.

Initial insight into the optical behavior of multi-wall polycarbonate panels and a very large collection of data that may be utilized to make cautious use of these parameters in future thermal analysis of building integration, especially with respect to their specificity and time-dependent features. The optical clarity of a building may affect the building's temperature and the eyesight of individuals from inside or outside.

#### 4 Literature review on Acoustic performances

Acoustic reflection is strong in extremely elastic materials, regardless of porosity. Acoustic transmission in low-elastic, low-porosity materials. High elastic module leads to large reflecting coefficients, particularly at low frequencies. Elastic module and porosity affect a material's acoustic response.

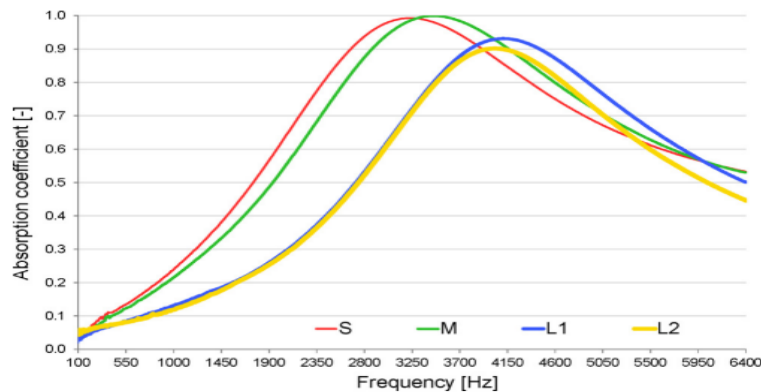
**Table 4: Influence of elastic modulus and porosity on a material’s acoustic response [21]**

| Modulus | Porosity | Example  | Reflection  | Transmission | Absorption  |
|---------|----------|----------|-------------|--------------|-------------|
| ↑       | ↑        | Concrete | <b>High</b> | Low          | None        |
| ↑       | ↓        | Steel    | <b>High</b> | None         | None        |
| ↓       | ↓        | Water    | Low         | <b>High</b>  | Low         |
| ↓       | ↑        | Snow     | Low         | Low          | <b>High</b> |

Several types of building parts are including in this chapter were recognizing the parts of acoustic and sound absorption performances of granular and monolith variants of aerogel [22], polyester nonwoven fabric, chitosan aerogel [23], and transparent flexible hydrophobic aerogels [24].

##### 4.1 Granular and monolith variants of aerogel

Granular aerogel acoustic characterization was accomplished by measuring sound absorption. The transfer function technique was used to calculate the normal ISO 10534-2 incidence absorption coefficient. Granule impact was evaluated at the same thickness. Figure 6 displays findings of four 15 mm thick samples frequently utilized in construction applications. ASTM B527 was used to determine the volume-based composite density. Sound absorption of silica aerogel composites was investigated using an impedance tube Bruel et al and 29 mm cylindrical samples.



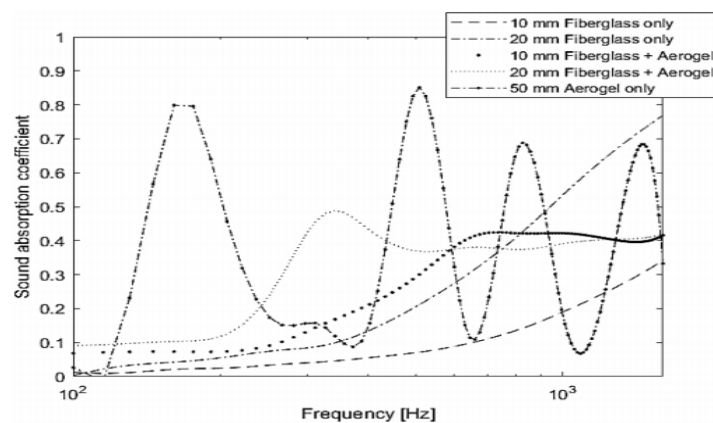
**Figure 6: Normal incidence absorption coefficient of the four samples of thickness of 15mm [22]**

#### 4.2 Polyester nonwoven fabric

Sound absorbing materials are generally low-density porous materials with moderate airflow resistance capable of absorbing most sound energy and reducing sound reflections by allowing sound to travel through their open cavities or channels. The most common method of testing a porous material's ability to absorb sound, especially during research and development phase, is to measure the normal incidence acoustic absorption coefficient in an impedance tube. The sound insulation performance of material is characterised by the sound reduction index R, given in Equation 1, where W1 is the sound power incident and W2 is the sound power on the opposite side.

$$(R = 10 \log w_1/w_2) \quad \text{Eq.1}$$

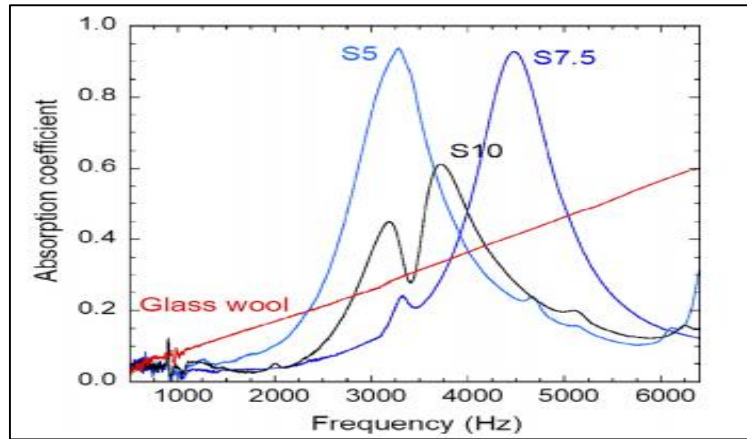
Figure 7 illustrates various thickness sound absorption coefficient of silica aerogels and silica aerogel blankets.



**Figure 7: Sound absorption coefficient of silica-aerogel and silica aerogel blankets of various thicknesses (24)**

#### 4.3 Chitosan aerogel

Regardless of density, sound absorption patterns are peak-shaped. Sample shaking shows the extremely high flow resistance of the mesoporous structure. Regardless of density, sound absorption patterns are peak-shaped. Sample shaking shows the extremely high flow resistance of the mesoporous structure. Cross-linked gelation and supercritical carbon dioxide drying were utilized to produce three-density chitosan aerogels. Moreover, remarkable transparency indicates the absence of submicrometric structural inhomogeneity that causes Mie scattering. SEM investigations also demonstrate structural homogeneity, and Figure 8 shows findings of normal-incidence sound absorption.



**Figure 8: Normal-incidence sound absorption coefficient of aerogels and glass [23]**

#### 4.4 Transparent flexible hydrophobic aerogel

The research produced transparent hydrophobic silica aerogels by replacing the typical alcohol solvent with water, using methyl triethoxysilane (MTES) and cetyl trimethyl ammonium bromide (CTAB), using a two-step acid-base method and CO<sub>2</sub> drying. Deionized water was produced from scratch. MTES-based aerogels are cylindrical and translucent. Table 5 shows the visible-light transmittance of thick samples. The in-situ growth of MTES molecules was not uniform with the addition of ammonia, and the range of molecular condensation polymers was quite wide, resulting in a loss of aerogel transparency.

**Table 5: Preparation ration of the samples (Li et al, 2019)**

| <b>Samples</b> | <b>MTES (mL)</b> | <b>CTAB (g)</b> | <b>Acetic acid aq. (0.05 ml/L)</b> | <b>Ammonia aq. (1 mol/L)</b> |
|----------------|------------------|-----------------|------------------------------------|------------------------------|
| <b>M7-1</b>    | <b>7.5</b>       | <b>0.1</b>      | <b>30 ml</b>                       | <b>0.015 ml</b>              |
| <b>M7-2</b>    | <b>7.5</b>       | <b>0.2</b>      | <b>30 ml</b>                       | <b>0.018 ml</b>              |
| <b>M7-3</b>    | <b>7.5</b>       | <b>0.4</b>      | <b>30 ml</b>                       | <b>0.02 ml</b>               |
| <b>M7-4</b>    | <b>7.5</b>       | <b>0.8</b>      | <b>30 ml</b>                       | <b>0.03 ml</b>               |

Building acoustics is the science of controlling noise. This includes minimizing noise transmission from one location to another and regulating sound characteristics inside the areas themselves. Sound absorption, transmission, and reflection characteristics of materials used to divide regions.

## 5 Conclusion

In this research, polycarbonate may be used as a partial cement composition by percentages of partial concrete replacement by modifying variables and utilizing various compositions. For example, combining polycarbonate can help enhance the thermal and energy efficiency of polycarbonate concrete panels (silica-aerogel concrete). According to researchers' results, polycarbonate may be utilized as a partial concrete mixture to improve optical clarity while reducing heat conductivity. It may also be said that by adding the aerogel as an addition, the concrete's thermal conductivity will be decreased to 17 percent and heat insulation improved. From this research, it was determined that polycarbonate replacement or combination in specimens would provide acoustic measurements and performance.

Sound vibration may increase thermal and acoustic measurements produced by polycarbonate properties. Previous acoustic performance study showed that polycarbonate offers in-lab and in-field testing on aerogel windows confirm results.

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