# Investigation of Mechanical and Thermal Behaviour of Aluminium Hydroxide/Epoxy composite filled with Silica Aerogel Material

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***Abstract***

*In Aerogels, nanoparticles are connected together to form loosely connected network, leaving very high fraction of empty space (or porosity). Due to this high porosity, aerogels have exceptional properties such as low density, low dielectric constant and low thermal conductivity. Traditional Silica Aerogels, however, have limited use as thermal insulation material because of its cost. The present study is aimed at investigation of mechanical properties such as Tensile Strength, Stiffness and Compressive Strength of Aluminium Hydroxide / Epoxy composite filled with Silica Aerogel material. The Thermal Conductivity is also evaluated experimentally. As per ASTM standards, the test specimen's preparation and testing is carried out, and results are presented.*

**Keywords —** *Silica Aerogel, Aluminium Hydroxide, Thermal Conductivity, Mechanical strength.*

## I. INTRODUCTION

In aerogels, nanoparticles are connected together to form loosely connected network, leaving very high fraction of empty space (or porosity) [1]. Due to this high porosity, aerogels have exceptional properties such as low density, low dielectric constant and low thermal conductivity. Its Density is 120kg/m$^3$ and Aerogels were initially developed in 1931 by Samuel Stephens Kistler [1] however the curiosity in these materials was replenished in 1970s. At present, these materials are being considered for probability of using them as thermal and electrical insulators, ballistic amours, and structural materials. The Stardust mission of NASA utilized aerogel for the purpose of capturing and gathering interstellar and comet dust particles which are from comet [1]. Traditional Silica Aerogels, however, have only found limited use as thermal insulation material because Silica Aerogel is very costly. The main aim of this project is to synthesize Aluminium Hydroxide / Epoxy Composite Filled with Silica Aerogel Material as per ASTM standards and to investigate the effect of Aluminium Hydroxide and Silica Aerogel on mechanical and thermal behavior of composites with different proportions. The Aluminium Hydroxide $Al(OH)_3$ enhances the fire resistance of the composite material and Silica Aerogel is expected to reduce the thermal conductivity of the composite material.

## II. MATERIALS AND EXPERIMENTATION

### A. *Materials*

The composites are prepared from commercially available Epoxy Resin (L-12) along with the Hardener K-6, manufactured by M/s.Atul Industries Ltd, and are used as the matrix material and the curing agent. Silica Aerogel particles (Lumira LA1000) supplied from Cabot Corporation are used. These particles are hydrophobic in nature having a average pore diameter of 20 nm, particle size range of 0.7- 4.0 mm, density of 120 kg/m$^3$ and thermal conductivity of 0.018 W/m K$^0$ as suggested by the manufacturer. These particles are shown in Fig.1. Aluminium Hydroxide a white amorphous powder with a density of 2420 kg/m$^3$, which is used as common fire resistant material.

**Fig. 1 Silica Aerogel Particles**

### B. *Specimen Preparation*

The specimens of Aluminium Hydroxide / Epoxy composites filled with Silica Aerogel material of different proportions were prepared. The Resin to Hardener volume proportion is kept up at 100:9 as suggested by the manufacturer. Silica Aerogel will be used as filler material in Aluminium Hydroxide / Epoxy composite. Stir-mixing is the most generally utilized technique for manufacturing of the particulate composites. Fabrication of the composites was done at the room temperature by Hand Lay-up technique. Initially, wooden Moulds were prepared for specimen preparation as per ASTM standards. Firstly during preparation a glass sheet is placed then the mould is placed on the glass sheet. Now the mixture is poured into the mould and a glass sheet is placed on the mould filled with the mixture then a load of 10kg is applied and is allowed for curing for 24 hr. Following compositions are prepared as depicted in Table I.

**TABLE I. Compositions used for Specimen Preparation**

| Sl. No | Sample Designation | Epoxy % | $Al(OH)_3$ % | Silica Aerogel % |
|---|---|---|---|---|
| 1 | A1 | 80 | 20 | 0 |
| 2 | A2 | 85 | 15 | 0 |
| 3 | A3 | 90 | 10 | 0 |
| 4 | A4 | 80 | 15 | 5 |
| 5 | A5 | 85 | 10 | 5 |
| 6 | A6 | 90 | 5 | 5 |

### *C. Compression Test*

The fabricated specimens of Al $(OH)_3$ / Epoxy Composites filled with or without Silica Aerogel material (A1, A2,..., A6) are tested in the Computerized Universal Testing Machine (UTM) of capacity 100 kN. This test is to determine the strength of the material under Compression. Each test specimens of dimension 20 mm cube are prepared as per previous studies [1]. The specimen details are shown in Fig. 2. From stress-strain experimental data, the properties, compressive strength and modulus are obtained.

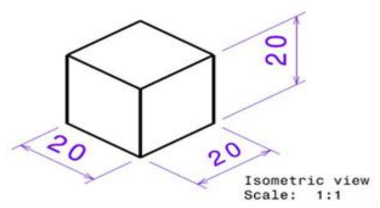


**Fig. 2 Compression Test Specimen**

### *D. Tensile Test*

The Tensile test of Al $(OH)_3$ / Epoxy Composites filled with or without Silica aerogel material (A1,A2…,A6) has been performed using UTM. The experiment is done according to the American Society of Testing and Materials (ASTM). As per standard, ASTM D3039 the specimens with dimensions 250mm length 25mm width and 10mm thickness were prepared. The specimen was loaded under tensile load until the failure occurs. This test is carried out to determine tensile strength and modulus of elasticity of the specimen. The tensile test specimen is shown in Fig. 3.

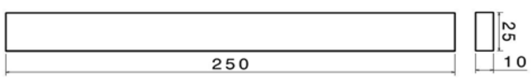


**Fig. 3 Tensile Test Specimen**

### *E. Thermal Conductivity Test*

The Thermal conductivity of the composite is determined according to ASTM E1530 guarded heat flow meter under steady state condition. In this experimental setup, the composite specimen to be tested is held under a compressive load between two metal slabs so that there is a good contact resistance between the specimen and slab surfaces. A heat flux transducer is provided at the lower surface as the heat flows through the slabs an axial temperature gradient is established between the slabs. To measure the temperature the thermocouples are placed between the slabs. By measuring the temperature change over the composite specimen along with the output from heat flux transducer the thermal conductivity of the specimen is determined for the known specimen thickness. As per ASTM standards the specimen dimensions are of 100 mm diameter and 6mm thickness. The thermal conductivity is determined by employing one-dimensional Fourier's law of conduction. The specimen dimensions are shown in Fig. 4.

$$Q = -K\ A\ dt / dx \qquad (1)$$

Where,

Q= Heat transfer rate (W)

K= Thermal conductivity (W/m°C)

A=Area ($m^2$)

dt/dx = Temperature gradient

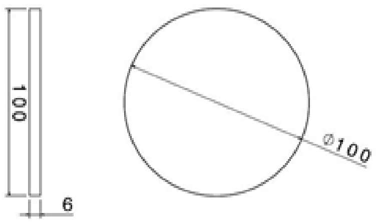


**Fig. 4 Thermal Conductivity Specimen**

## III. RESULTS AND DISCUSSION

### *A. Compression Test*

The experimental results of compression test for different compositions are shown in the Table II.

Table II Compressive Properties of the Composites

| Sample No | Composition | Compressive Strength (MPa) | Young's modulus (MPa) |
|---|---|---|---|
| 1 | A1 | 26.085 | 169.71 |
| 2 | A2 | 27.458 | 95.53 |
| 3 | A3 | 25.889 | 42.59 |
| 4 | A4 | 37.853 | 164.007 |
| 5 | A5 | 29.714 | 156.55 |
| 6 | A6 | 36.574 | 280.72 |

Fig. 5 shows the stress versus strain graph plot obtained in UTM for the compositions A1, A2, A3 without the addition of filler material Silica Aerogel. The compressive strength for compositions A1, A2, A3 are 26.085, 27.458, 25.889 MPa. It is observed that the composition A2 is having slightly high compressive strength than A1 and A3 compositions. It is observed that A1 composition has higher modulus of 169.71 MPa than A2 and A3 compositions. This may be due to good reinforcing effect of Al $(OH)_3$ with matrix polymer. The elastic modulus indicates the stiffness of the material. With increase in amount of Al $(OH)_3$ ,the particle/matrix surface area increases and the aggregates are formed which results in higher modulus[2].

Fig. 6 shows the Stress v/s Strain graph plot obtained in UTM for the compositions A4, A5, A6 with the addition of 5% of Silica Aerogel filler material. The compressive strength for compositions A4, A5, A6 are 37.853, 29.714, 36.57 MPa. It is observed that with the addition of filler material, the compressive strength and Modulus have increased. The composition A4 is having slightly high compressive strength than A5 and A6. This is because there is a good interfacial bonding between Al $(OH)_3$ / Epoxy composite filled with Silica Aerogel material.

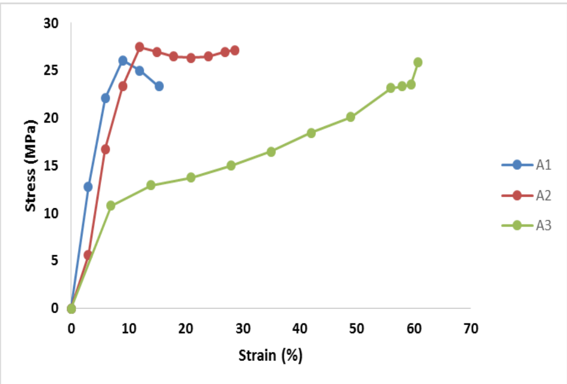


**Fig. 5 Stress Vs Strain Plot of Compression Test for The Compositions A1, A2, And A3**

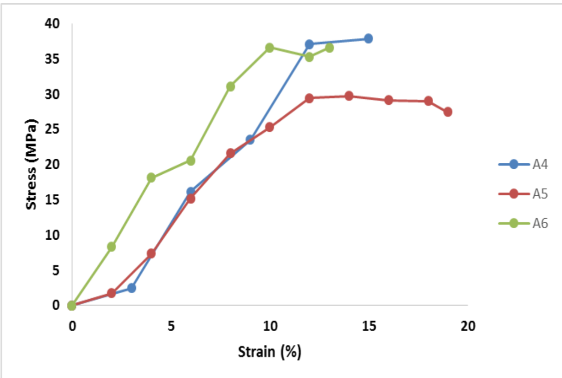


**Fig. 6 Stress Vs Strain Plot of Compression Test for The Compositions A4, A5, And A6**

Since Silica Aerogel is a Mesoporous material. It has a greater specific surface area, larger pore diameters [3, 10] , therefore the $Al(OH)_3$ particles tend to accumulate [8] in the pores of Silica Aerogel resulting in a good reinforcing effect. This may be the reason for compressive strength and modulus enhancement.

Thus from all the six compositions it is observed that the compositions A4, A5 and A6 with the addition of filler material Silica Aerogel showed the increased compressive strength when compared with the compositions A1, A2 and A3. It is compared in the Fig. 7.

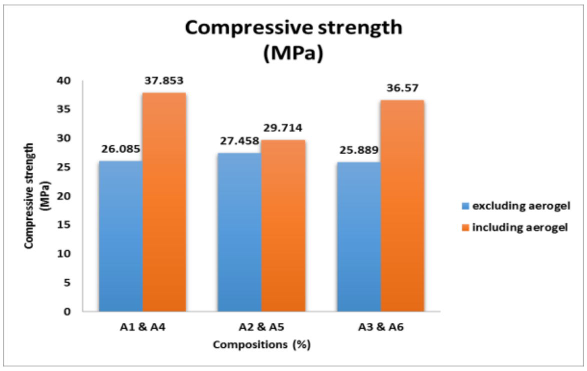


**Fig. 7 Comparison of Compressive Strength With Different Compositions**

### *B. Tensile Test*

The experimental results of tensile test for different specimen compositions of the composite are reported in Table III.

**Table III Comparison of Ultimate Tensile Strength and Young's Modulus for Different Compositions**

| Sample No | Composition | Ultimate Tensile Strength (MPa) | Young's Modulus (MPa) |
|---|---|---|---|
| 1 | A1 | 2.94 | 57.54 |
| 2 | A2 | 3.20 | 30.96 |
| 3 | A3 | 4.30 | 530.864 |
| 4 | A4 | 3.39 | 26.82 |
| 5 | A5 | 3.98 | 34.57 |
| 6 | A6 | 5.50 | 393.07 |

Fig. 8 shows the Stress v/s Strain plot obtained in UTM for the compositions A1, A2, A3 without the addition of filler material Silica Aerogel. The UTS for compositions A1, A2, A3 are 2.94, 3.20, 4.30 MPa. It is observed that as the percentage of aluminium hydroxide decreases, the UTS of the composite material increases as shown in Fig. 10. This may be due to the weak intermolecular forces between Al $(OH)_3$ / Epoxy matrix.

Fig. 9 shows the Stress v/s Strain plot obtained in UTM for compositions A4, A5, A6 composite filled with Silica Aerogel material. The UTS for the compositions A4, A5, A6 are 3.39, 3.98, 5.50 MPa. It is observed that as the percentage of $Al(OH)_3$ increases the tensile strength has reduced, this is due to the weak interfacial bonding [4] between the $Al(OH)_3$ / Epoxy filled with Silica Aerogel material. But compared with the compositions A1, A2, A3 tensile strength for the compositions A4, A5, A6 are high due to the addition of filler material Silica Aerogel. The reason may be that since Silica Aerogel is a mesoporous material with high specific surface area and large pore diameter, the $Al(OH)_3$ particles tend to accumulate in the pores of Aerogel resulting in a good interfacial bonding. The incorporation of Silica Aerogel increased the Tensile Strength but Modulus of the material has decreased, this behaviour between the mesoporous Silica Aerogel and Al $(OH)_3$ / Matrix polymer cannot be understood at this stage which calls for further experiments to be conducted. Fig. 10 shows the bar chart representing the comparison of all the six compositions.

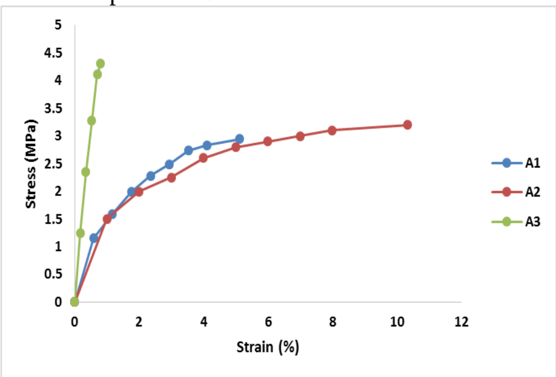


**Fig. 8 Stress vs Strain Plot of Tensile Test for the Composition A1, A2 and A3.**

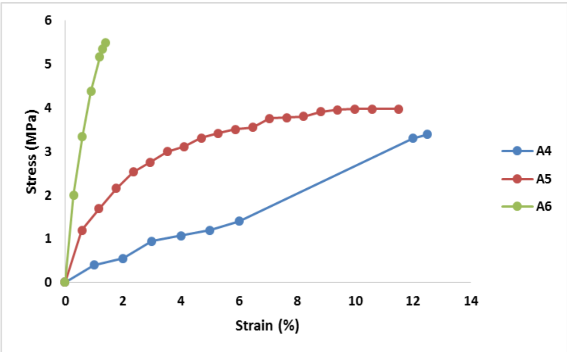


**Fig. 9 Stress vs Strain Plot of Tensile Test for the Composition A4, A5 and A6**

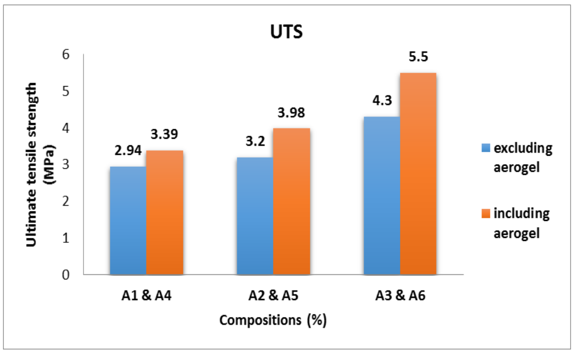


**Fig. 10 Comparison of Ultimate Tensile Strength for Different Compositions**

### *C. Thermal Conductivity Test*

The average of three specimens were taken for each compositions (A1,A2…,A6). The experimental results of thermal conductivity test for different specimen compositions are shown in the Table IV.

**Table IV Comparison of Thermal Conductivity for Different Configurations**

| Composition | Thermal Conductivity (K) W/m°C |
|---|---|
| A1 | 0.8187 |
| A2 | 0.9865 |
| A3 | 0.9854 |
| A4 | 0.6618 |
| A5 | 0.4044 |
| A6 | 0.8371 |

The Table 4 shows that the thermal conductivity for the compositions A1, A2, A3 are 0.8187, 0.9865, 0.9854 W/m°C. It is observed that the thermal conductivity values are very close to each other and the thermal conductivity of the composite material is influenced by its compositions [7]. The composition A1 is having slightly less thermal conductivity, this may be because of some chemical decomposition of Al $(OH)_3$ and release of small amount of water [5].This water is expected to reduce the heat flow.

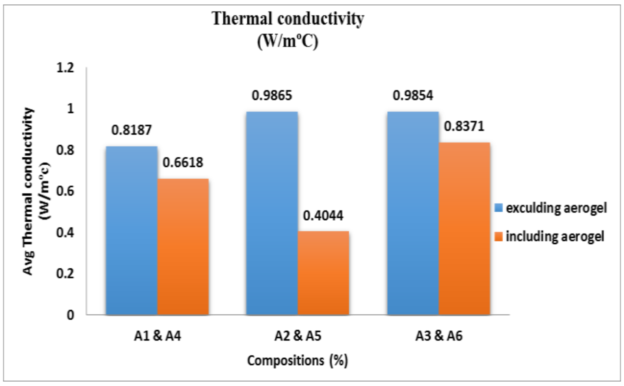


**Fig. 11 Comparison of Thermal Conductivities of all the Six Compositions**

As the filler material Silica Aerogel is added to the composite the thermal conductivity of the compositions A4, A5, A6 composite filled with Silica Aerogel material reduces to 0.6618, 0.4044 and 0.8371 W/mºC. It is observed that the composition A5 is having very less thermal conductivity than A4 and A6 this may be due to the good interfacial bonding between Silica Aerogel and $Al(OH)_3$ / Epoxy matrix polymer resulting in a good reinforcing effect when compared to other two compositions. The incorporation of silica aerogel leads to decrease in Conductivity since Aerogels are mesoporous with large diameters of 20 nm. Aerogels are good conductive insulators because they are composed entirely with air, and air is a very poor heat conductor. Fig. 11 shows the comparison of thermal conductivities of all the six compositions.

## IV. CONCLUSION

In this work the mechanical tests such as compression test and tensile tests were conducted. Thus from all the six compositions it is witnessed that with the addition of filler material Silica Aerogel, the composite material showed slightly increased ultimate tensile strength and moderate increase in compressive strength. This is due to the mesoporous structure of silica aerogel filler material.

From the Thermal conductivity test it is perceived that with the addition of only 5% of the filler material Silica Aerogel, the thermal conductivity of the composite specimen reduced to a greater extent when compared with the composite specimens without the addition of Silica Aerogel.

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