

OPTIMIZING YOUNG'S MODULUS IN SILICA AEROGELS FOR ENHANCED MECHANICAL PERFORMANCE

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ABSTRACT: Aerogel is not only super insulating material but also reveal unusual acoustic and mechanical properties. They are renowned for their exceptional thermal, optical, and acoustic properties, are limited by their poor mechanical strength. Enhancing their mechanical performance is crucial for broader applications. This study focuses on optimizing the Young's modulus of silica aerogels to improve their mechanical resilience. Our findings provide insights into designing silica aerogels with optimized Young's modulus, paving the way for their use in diverse engineering applications. The technique of interferometry was applied to study elastic constant of aerogels. We have successfully studied the holograms of stressed aerogel samples. It was observed that due to mechanical stressing, number of fringes localised on the aerogel samples and these fringes were used to determine the Young's modulus (Y) of samples. Here, we report a new mode for determination of 'Y' of aerogel monoliths.

Keywords: Hologram, mechanical stressing, Young's modulus.

1. Introduction:

Silica aerogels are nano-structured materials with the bulk density as low as 0.02 g/cm³ and high porosity (> 98%) [1]. Due to the high porosity and very less solid content, determination of the various mechanical properties of the silica aerogels is the major challenge. Though methods like three-point flexural techniques, Vickers and knops tests have been applied for the measurement of the mechanical properties of the aerogels, but application of even very small loads (~0.25 N) results in the cracking of the aerogel samples [2,3]. Therefore, efforts have been made in the past to use non-destructive technique as like sound velocity measurements for this purpose [4, 5]. The aging process significantly impacts the mechanical properties of silica aerogels by enhancing their strength and stiffness. To enhance the strength and stiffness of aerogels a well-known process of aging was employed. Aging allows for the transport of silica to weaker sections of the aerogel, particularly the interparticle necks, which increases the mechanical strength and stiffness of the material [6]. This process involves the dissolution and reprecipitation of silica, leading to a more robust skeletal structure [7].

As per our knowledge there are few reports available on the use of holographic interferometry for the determination of mechanical properties of the aerogels.

Holographic interferometry has been widely accepted as a viable tool for non-destructive testing of materials. It permits the qualitative & quantitative study of minute changes in the object contours [8]. We report here the use of double exposure holographic interferometry (DEHI) [9] to study the surface deformation of mechanically stressed aerogels. DEHI has proved to be an advantageous than the other holographic techniques in the study of transient phenomenon [10]. In this technique, there is comparison of a stressed surface state relative to its unstressed state causes interference fringes to be observed on the object, which gives information of the object deformation with a very high precision [11,12]. As this technique is enough sensitive to the determination of the order of wavelength of source [He-Ne LASER 6328 Å], application of a small stress can give rise to interferometric fringes and hence the sample under test remains intact, reusable and crack free.

2. Experimental:

2.1. Preparation of Monolithic Silica Aerogels:

Two stage sol-gel processes were used. Alcolgels were prepared by hydrolysis and polycondensation of tetraethoxysilane (TEOS). Initially, TEOS was dissolved in methanol (MeOH) in order to make it soluble in 0.03 NH₄F, Methyltrimethoxysilane (MTMS) was added to this mixture to make the aerogels hydrophobic as well as diffusely reflective. The mixture was stirred for 10 minutes and the resulting homogenous sol was transferred to 25 ml pyrex glass test tubes. The test tubes were made air tight to inhibit the evaporation of MeOH from the sol. The gelation took place at an ambient temperature of 25 °C. In order to prevent shrinkage and cracks in the alcolgels, excess amount of EtOH was poured in the test tubes after gelation. All the gels were aged at 25 °C for 12 hours. The aged alcolgels were dried supercritically in an autoclave. The details of autoclave drying conditions were given in this publication [13-14].

In this work, we have calculated the elongation ‘l’, by holographic method by calculating the deformation of the silica aerogel sample after application of the load. Hence by using the holographic method the equation (1) can be modified as follows,

$$Y = \frac{MgL}{\pi r^2 a} \tag{2}$$

Where, ‘a’ = surface displacement of the sample. The surface displacement of sample can be calculated by the following geometry.

3.1) Geometry for in- plane displacement of a rigid object:

To view the object from a distance R, in the following figure,

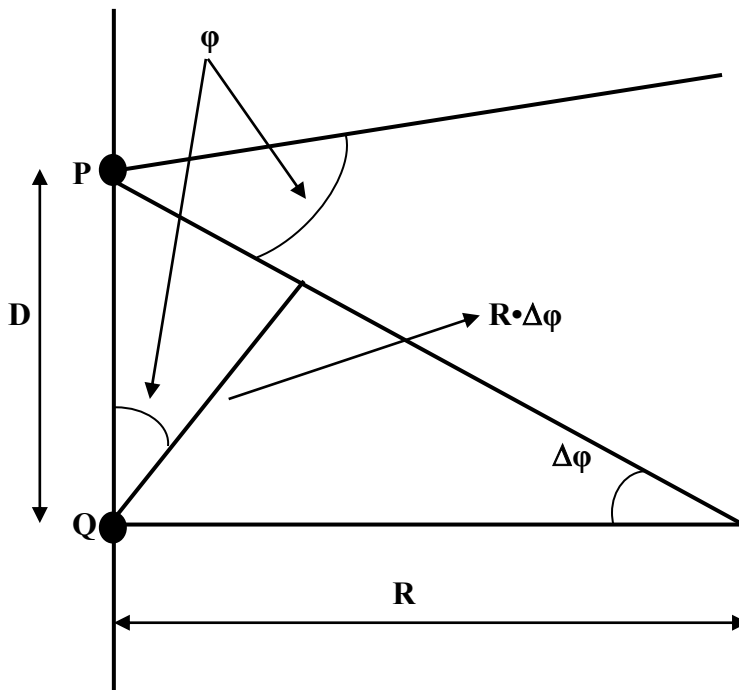


Figure 1: Geometry for in- plane displacement of a rigid object

Where, R = distance of object, phi = viewing angle.

The separation of fringes on the object is given by,

$$D = \frac{R\Delta\phi}{\cos\phi} = \frac{R\lambda}{a \cos(\phi) \sin(\phi - \delta)} \tag{3}$$

For the silica aerogel samples, the movement after the application of load is parallel to surface, hence in above equation (3), delta = pi/2. Hence equation (3) becomes,

$$D = \frac{R\lambda}{a \cos^2 \phi} \tag{4}$$

Where, ‘a’ = surface displacement of the sample

$$\therefore a = \frac{R\lambda}{D\cos^2 \varphi} \quad (5)$$

Here, D = Fringe separation, λ = wavelength of the source, φ = viewing angle, R = Distance of object. Using equation (2) the values of the 'Y' of the silica aerogel samples can be calculated.

4. Results:

4.1. Fourier Transform Infrared Spectroscopy (FTIR):

FTIR study of the silica aerogel was carried out.

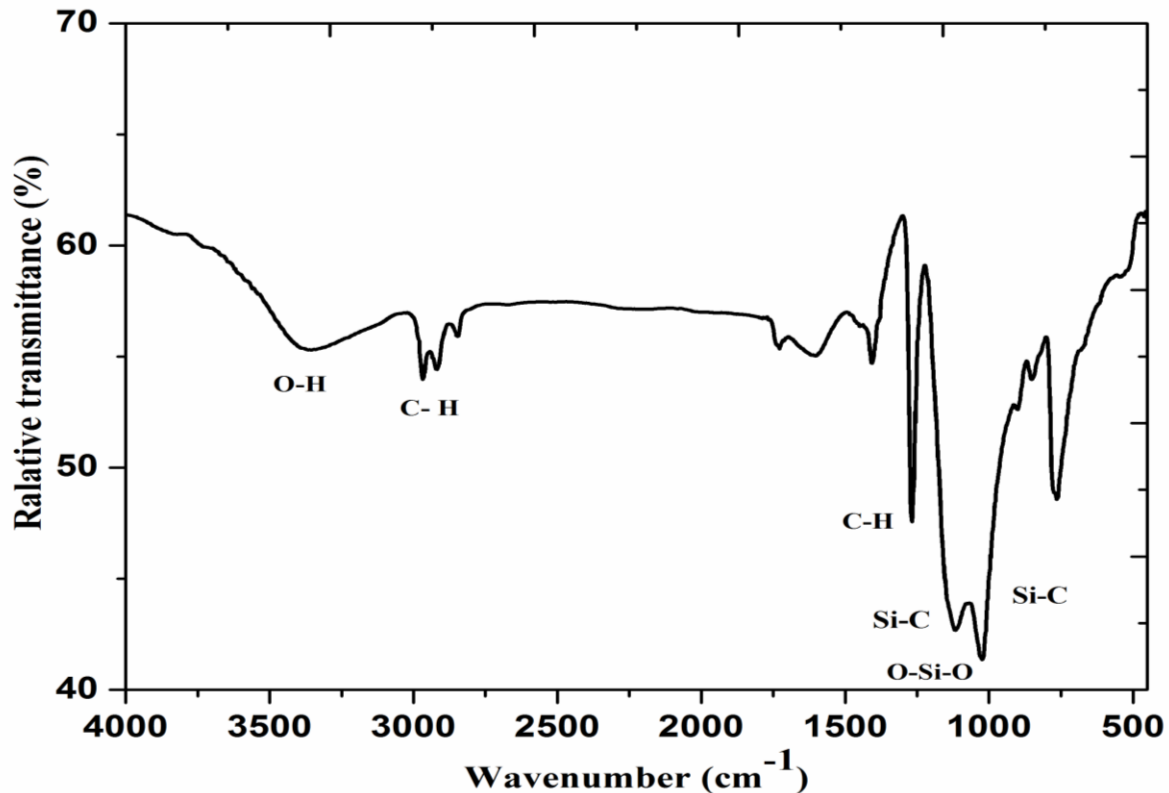


Figure 2: FTIR Study of the silica aerogel

Several characteristic absorption bands were observed in the range of 450 cm⁻¹ to 4000 cm⁻¹ indicating the presence of methyl groups [16]. The broad absorption band observed at 1080 cm⁻¹ is a characteristic of the Si-O-Si bond present in samples. The absorption bands were observed at 2950 and 1400 cm⁻¹ due to stretching and bending modes of C-H bond and the deeps observed at 765 & 1265 cm⁻¹ due to the Si-C bonds. The 1265 cm⁻¹ peak indicates the presence of the Si-C bonding [17]. The absorption deeps at 1600 and 3400 cm⁻¹ corresponding to the polar -OH bonds.

4.2. Determination of Young's modulus of silica Aerogel:

We have determined the 'Y' of the silica aerogel samples having different bulk densities and thermal conductivities of the silica aerogel monoliths. These values are reported in the table no. 1. We have used the silica aerogels having the five different densities. First the values of the surface deformations were calculated. Values of surface deformations of all

the samples were also reported in table no. 1. All the results have shown that as load on the sample increases, surface deformation also increases. All the values of the 'Y' calculated are reported in table no.1 and all the values are in consistent with the standard values. The photographs of some of the silica aerogel samples are shown here.



Figure 2: Photographs of synthesized silica aerogel monoliths,

[A] Flexible silica aerogel showing bending behaviour.

[B] Silica aerogels in 25 ml test tubes.

Sample	Density 'ρ' (g/cm ³)	Thermal conductivity 'k' (W/mK)	Applied load in 'g'	No of fringes.	Deformation (x 10 ⁻³ cm)	Youngs modulus 'Y' (x10 ⁵ dyne/cm ²)
M 1	0.1613	0.0023	2	5	3.953	1.38
			4	11	4.646	4.84
			6	13	7.7518	12.54
			8	13	19.243	6.57
M 9	0.1725	0.0029	2	3	2.270	3.434
			4	11	7.356	2.087
			6	19	12.452	5.787
			8	22	14.337	6.2376
			10	34	16.532	10.529
M 14	0.1366	0.0019	0.5	5	21.201	4.946
			1	33	47.194	5.404
M 21	0.1280	0.0019	1	3	16.190	3.253
			2	7	19.273	3.775
			3	11	44.950	2.367
M 29	0.1124	0.0016	0.5	3	16.869	2.364
			1	7	34.387	4.841
			2	21	76.897	5.810

Table No:1. Physical and elastic properties of monolithic silica aerogels.

5. Conclusions:

DEHI technique, for determination of 'Y' of sol-gel derived porous silica aerogel monoliths was successfully used. The prepared monoliths revealed very low thermal conductivity. These properties were achieved by quantifying the sol-gel chemistry and parameters during the supercritical drying of the silica aerogels. Usually, the derived porous materials are stiff in nature but this work demonstrated the a kind of new measurements in the synthesis of porous, elastic and insulating silica aerogel monoliths.

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