Ambient pressure drying of silica aerogel: spring-back or lack thereof, density and thermal conductivity

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Industrial silica aerogel production employs both supercritical drying (SCD) and ambient pressure drying (APD) processes. SCD offers more flexibility in terms of gel chemistry and properties, but the high-pressure requirements add complexity and cost. Evaporative drying at ambient pressure, is potentially more cost-effective, but is limited in terms of materials chemistry and, in practice, only suitable for silica aerogel production. Even for silica aerogel, for which APD is routine, the process window to produce high quality materials is narrower for APD than SCD. In this presentation, we summarize our recent studies on how silica concentration and gel mechanics affect spring-back during APD and how controlled pore collapse during APD enables the production of dense and strong, yet superinsulating silica aerogel.

Hydrophobization is a necessary, but not sufficient, condition to produce high-quality silica aerogels with APD [1]. Spring-back, i.e. the recovery of most of the original gel volume, also requires the necessary mechanical strength for an elastic response as capillary stresses are relieved towards the end of the drying cycle. For example, we recently observed the importance of aging to produce low-density silica aerogels by APD [2]. In a follow-up study, we systematically quantify the degree of irreversible deformation after uniaxial compression of silica aerogels prepared by SCD with different silica concentrations and aging times. The strain recovery of the SCD aerogels correlates with the density of the corresponding APD aerogels. Silica aerogels display poor strain recovery and high APD shrinkage and density for low silica concentrations, irrespective of the aging time. At intermediate silica concentrations, near complete strain recovery and low APD shrinkage and density are feasible, but only after sufficient aging. At high silica concentrations, the aerogels are too brittle to determine strain recovery, but APD shrinkage is low, even at low aging times. In summary, strain recovery after uniaxial compression of SCD aerogels is a good predictor of spring-back during APD.

The thermal conductivity (λ) of silica aerogels displays a U-shaped density dependence with a minimum around 0.120 g/cm^3 [3, 4]. Because of the strong, power-law dependence of the E modulus on density, this rather low density inevitably leads to low E moduli [3, 4]. The dense (up to 0.29 g/cm^3), but superinsulating (λ~15 mW·m^{-1}·K^{-1}) silica aerogels presented here challenge this paradigm. Short aging times reduce the cross-section of, and heat transport through, inter-particle necks, leading to a decrease in skeletal conduction (λ_s). In addition, the gels undergo a partial pore collapse during ambient pressure drying due to less aged, hence weaker network structures, which creates additional point contacts that increase stiffness (10x increase) but limit heat transport in the final aerogels. The resulting strong and superinsulating particles are ideal fillers for aerogel composites, concrete and renders, and may help aerogels to break into new high-strength, superinsulating structural applications.

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