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Carbon Nanotubes with Temperature Invariant Viscoelasticity from -196°C to 1000°C

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Viscoelasticity describes the ability of a material to possess both elasticity and viscosity. Viscoelastic materials, such as rubbers, possess a limited operational temperature range, (e.g., for silicone rubber: -55 to 300°C) above which the material breaks down and below which the material undergoes a glass transition and hardens. This is because molecular motion that is the origin of viscoelasticity is a thermally activated process. We created a viscoelastic material composed from a random network of long interconnected carbon nanotubes that exhibited an operational temperature range from -196°C to 1000°C [1]. The viscoelastic properties (storage modulus, loss modulus, and damping ratio) measured by DMA in N_2 ambient were nearly constant over an exceptionally wide temperature range (-140°C$\sim$600°C). As exemplified by the vibration isolator demonstration, the CNT material showed viscoelasticity beyond the DMA limitation at -190°C (immersed in liquid nitrogen) and at >900°C (exposed to butane torch). And we implemented impact tests at -196°C, 25°C and 1000°C using a steel ball and analyzed the ball tracks. The ball tracks were identical for all cases as observed by SEM and 3-D mapping that suggested unvarying viscoelastic properties across this 1200°C temperature range. We interpret that the thermal stability stems from energy dissipation through the zipping and unzipping of carbon nanotubes at contacts. Quantitatively, the viscoelastic properties by DMA showed that the CNT material possessed similar stiffness (storage modulus 1MPa), higher dissipation ability (loss modulus (0.3MPa) and damping ratio (0.3) than silicone rubber at room temperature. Further DMA characterization from -140°C to 600°C demonstrated temperature invariant frequency stability (0.1-100Hz), the same level of reversible deformation (critical strain 5%) and fatigue resistance (1,000,000 cycles, 100Hz).

[1] Xu, M.; Futaba, D. N.; Yamada, T.; Yumura, M.; Hata, K. *Science* (Accepted)