

Mechanical Characterization of Nickel Nanoparticles Elastomer Composites

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ABSTRACT

Polymer composites exhibiting magnetic properties are becoming increasingly important for a variety of applications. This work presents fabrication and mechanical characterization of magnetic polymer nanocomposites based on polydimethylsiloxane (PDMS) with nickel nanoparticles as fillers. Allyltrimethoxysilane (ATS) was used as surfactant to enhance nanoparticle dispersion in the polymer matrix. Composites with nanoparticles concentrations of 5, 10 and 15 vol. % respectively as well as pure PDMS specimens were fabricated and their mechanical properties were tested. Up to 70% increase in the elastic modulus is reported for composites with particle concentration of 15 vol. % and cured at 100°C.

Keywords: polydimethylsiloxane, nickel nanoparticles, nanocomposites

1. INTRODUCTION

Magnetic polymer composites consisting of polymer matrix and magnetic fillers are emerging as a new class of multi-functional materials. They have tunable elastic modulus (via application of an external magnetic field), tunable electromagnetic properties (such as index of refraction and RF absorption), may be heat-activated to self heal (via hysteresis or magnetic relaxation losses in alternating external magnetic field) and can be used for selective, remote thermal and magnetic actuation. Potential applications include low-loss cores in power transformers [1], electromagnetic shielding [2,3] adjustable vibration dampers [4] as well as microelectromechanical systems (MEMS) magnetic sensors or actuators [5-10] and medical devices [11]. Polydimethylsiloxane (PDMS) polymer is of particular interest to the microsystems and medical field, being employed in a wide range of applications in the areas of microfluidics and biotechnology [12,13]. In this context, this work presents fabrication and mechanical property characterization of PDMS composites with 100 nm

diameter nickel nanoparticles as filler. Studies on particle dispersion in the polymer matrix are carried out via scanning electron microscopy, while mechanical properties are measured through standard tensile test.

2. FABRICATION

Nickel nanoparticles, 100 nm in diameter were procured from Argonide Corporation (Sanford, FL). Prior to mixing with PDMS, the nanoparticles were coated with allyltrimethoxysilane surfactant. The ATS solution was prepared by adding 2 wt. % ATS to a mix of 95% ethanol and 5% deionized water. After the pH of the solution was adjusted to 5 by the addition of acetic acid, it was stirred with a magnetic stir bar for 5 minutes. Then it was added to the nickel nanoparticles in a ratio of 100 mL per 25 grams of nickel. The nickel was ultrasonicated for 3 minutes and then was rinsed twice in ethanol to remove the ATS excess. The nanoparticles were then left for 24 hours at 60°C to cure the ATS coating and to evaporate any residual ethanol.

PDMS polymer (Sylgrad 184) was acquired from Dow Corning Corporation (Midland, MI). It consists of a siloxane base and a cross-linking agent, which must be mixed in 10:1 volumetric ratio. The ATS coated nickel nanoparticles were first dispersed in PDMS base elastomer by utilizing an ultrasonicator for 4 hours. Next, a Hauschild, FlackTek Speed Mixer was used for 30 minutes to enhance nanoparticle dispersion. During the last 3 minutes in the Speed Mixer, the curing agent was added to the base. A vacuum oven was then used to degas the sample for 30 minutes to remove the air bubbles. Finally the samples were poured into a mold and heated to 100°C for 2 hours to cure. This process was followed to fabricate composites with different concentrations of nickel nanoparticles of 5, 10 and 15 vol. % respectively. In addition, similar procedure was followed to prepare pure PDMS samples for comparison of mechanical properties.

However, in many applications it is desirable to have the flexibility of curing the composite at room temperature. Hence, for comparison, samples with similar nanoparticle concentrations were prepared curing the composite at

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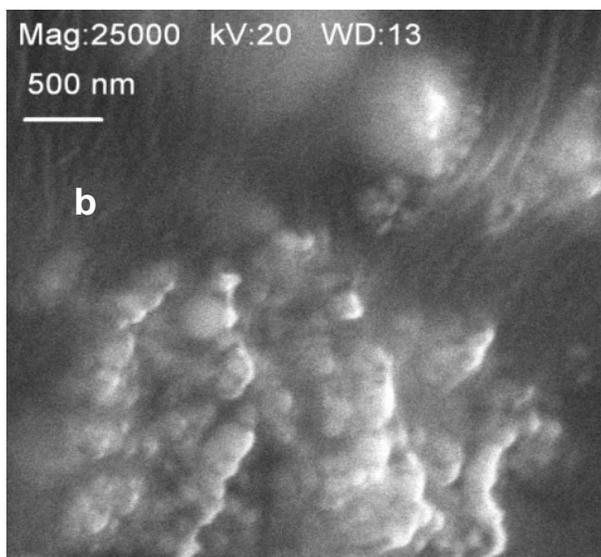
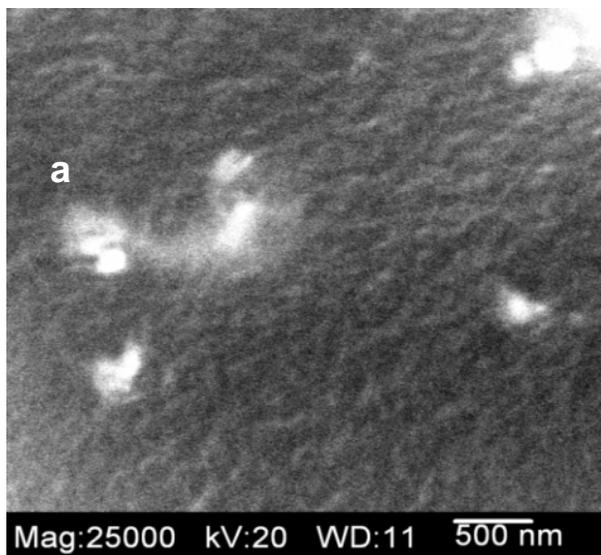


Figure 1: SEM of composites with 1 vol. % nickel nanoparticle: a) ATS coated and b) bare nanoparticles.

ambient temperature for 24 hours. To synthesize these specimens, the same steps were followed as for the samples cured at 100°C, except for vacuum degassing.

2. MECHANICAL PROPERTIES TESTING

The tensile test specimens had a gage length of 1 inch and a width of 0.25 inches. The mold was made from aluminum to prevent interactions between the ligands in the polymer. Tests were carried out with an Instron 5480 employing the ASTM (E8-04) Standard Test Method. After the sample was loaded into the testing apparatus, the video strain gage was activated, all variables were cleared and the speed of the grips was set to 10 mm/minute. Each

specimen was pulled until failure while data was collected by a computer acquisition system for further analysis.

3. RESULTS AND DISCUSSION

3.1 Structural Characterization

The quality of the dispersion was evaluated in the preliminary stage of the fabrication process in order to ensure that particle uniformity is acceptable. Figure 1a) is a scanning electron micrograph (SEM) of a sample with 1 vol. % nickel nanoparticles coated with ATS. This sample showed uniform particle dispersion without noticeable agglomeration. In contrast, PDMS composites with bare nickel nanoparticles filler of same concentration were observed to present significant particle agglomeration, as shown in Fig. 1b. It was concluded that addition of ATS is critical for ensuring uniform nanoparticle dispersion.

3.2 Mechanical Properties

Figure 2 shows the measured tensile stress as function of the applied strain for samples with different concentrations of ATS coated nickel fillers that were cured at 100°C. As seen from this figure, at higher nanoparticle concentration the slope of the stress curve increases which indicates an increase in the elastic modulus. Figure 3 shows the measured elastic modulus as function of nanoparticle concentration for the composite samples with ATS coated nanoparticles that were cured at 100°C and room temperature respectively. The measured elastic modulus of plain PDMS, 2.57 MPa and 1.73 MPa respectively, are comparable with literature values (1.7-3.7MPa) [13,14]. The variation observed is may be due to the difference in curing temperature[14] and possible voids in the sample cured at room temperature which was not degassed. The elastic modulus of the specimens cured at 100°C increases with particle concentration. For example, the elastic modulus of 15 vol. % nickel nanoparticle- PDMS is

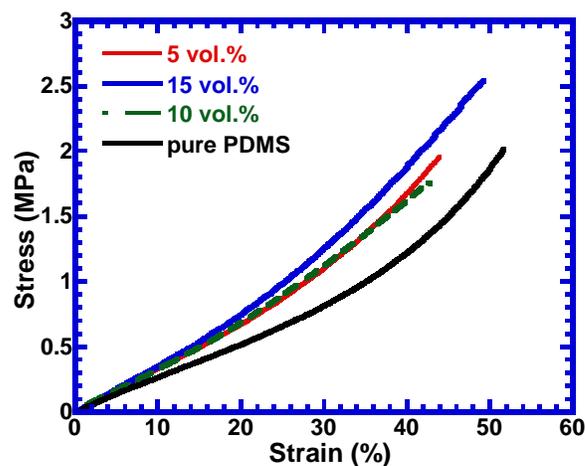


Figure 2: Stress versus strain obtained from tensile experiments carried out on pure PDMS and Ni nanoparticle PDMS composites cured at 100°C.

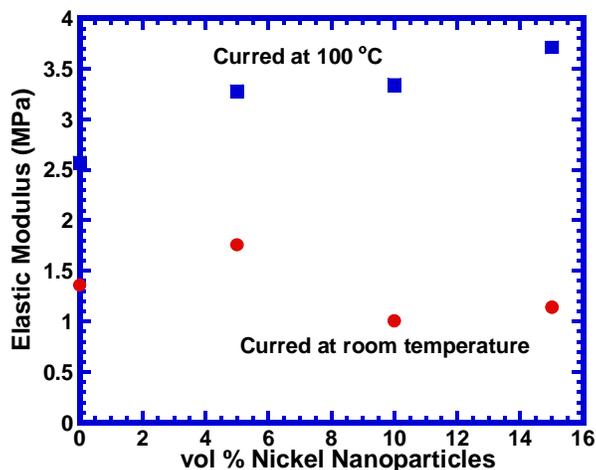


Figure 3: Elastic modulus as function of nanoparticle concentration for specimens cured at 100°C (squares) and room temperature (circles).

3.71 MPa, which represent ~ 70% increase over that of pure PDMS cured at the same temperature. Although predicting mechanical properties of polymer nanocomposites often requires extensive modeling that needs to take into account inclusion/matrix interfacial characteristics [15], the elastic modulus of the PDMS nickel composite is expected to increase with an increase in nanoparticle concentration, since nickel has a much higher Young's modulus of 200 GPa. However, samples cured at room temperature show an inconsistent trend of elastic modulus, which apparently decreases as particle concentration increases. Since samples cured at room temperature were not degassed during preparation, the decrease in elastic modulus may be partially due to presence of the air bubbles within the specimens. In addition, differential scanning calorimetry studies were carried out on specimens with similar compositions. These studies revealed that for temperatures below 60°C the cross-linking process is not consistent (the peak in heat flow when this was plotted as function of time varied from sample to sample), suggesting possible problems in sample curing. These indicate that both, degassing and higher curing temperature, are critical in order to produce composites with good mechanical properties.

In addition to mechanical characterization, simple qualitative tests where samples were subjected to the magnetic field from a strong permanent magnet, indicated that these samples have acquired magnetic properties. Quantitative magnetic characterization of the composites is currently under way.

4. SUMMARY

This work presents fabrication and mechanical property characterization of magnetic polymer composites based on PDMS and nickel nanoparticle as fillers. It is found that ATS addition to nickel nanoparticles greatly

enhances their dispersions in the polymer matrix. Mechanical property characterization shows that composites with 15 vol. % of nickel particles have an elastic modulus 70% higher than pure polymer samples when samples are cured at 100°C.

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