UNIVERSITY TRANSPORTATION CENTER FOR RAILWAY SAFETY

Conductive Polymer Nano-Composites for Rail Suspension Applications

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Introduction

The steering pad of the AdapterPlus™, which bears the entire distributed load applied by the railcar on one railroad bearing, is composed of a thermoplastic polyurethane (TPU) polymer. The pad is positioned above the bearing on each axle and is designed to improve axle-to-rail wheelset alignment. The pad also improves curving and rolling resistance and reduces wear on the side frame pedestal roof and other adjacent components. Since TPU does not permit current flow, two copper studs are inserted mechanically into the pad to act as a pathway for conductivity. One very common industry application requires that a minimum of 240 mA of electrical current must flow from the rail through the adapter pad to the side frame in order to actuate air valves that operate automated cargo gates. Even though the copper studs work well triggering the valves, they deform over time under continuous cyclic loading causing loss of contact. Once contact is lost, electrical conductivity ceases and the automation systems fail. As a solution to this problem, the UTCRS research team has developed a conductive composite material by dispersing carbon nanofibers (CNFs) into a TPU matrix. This material is designed to replace the current system as a fully homogenous conductive composite which does not rely on copper studs for valve actuation.

Figure 1: (L to R) Pad with Conductive Additive, Pad with Conductive Puck Insert, Current AdapterPlus™

The composite CNF/TPU pad must meet Federal Railroad Administration (FRA) standards to be eligible for service. This research summarizes the design and optimization of a CNF/TPU composite material by studying CNF dispersion and distribution throughout a polymer matrix and its effects on conductivity and mechanical properties.

Research Methodology

Thermoplastic Polyurethane (Elastolan 195-A55) and Carbon Nanofibers (Pyrograf III PR-19-XT-LHT) were melt–mixed together in a HAAKE PolyLab machine to form the composite material. Various fiber concentrations were mixed in the TPU to establish key property/fiber content relationships. The composite material was used to transfer mold prototype pucks with dimensions of 2.5" in diameter and 0.55" in thickness for mechanical and electrical testing.

Figure 2: Carver Heat Press (Left); Transfer Mold (Top Right); 13% CNF/TPU Puck (Bottom Right)

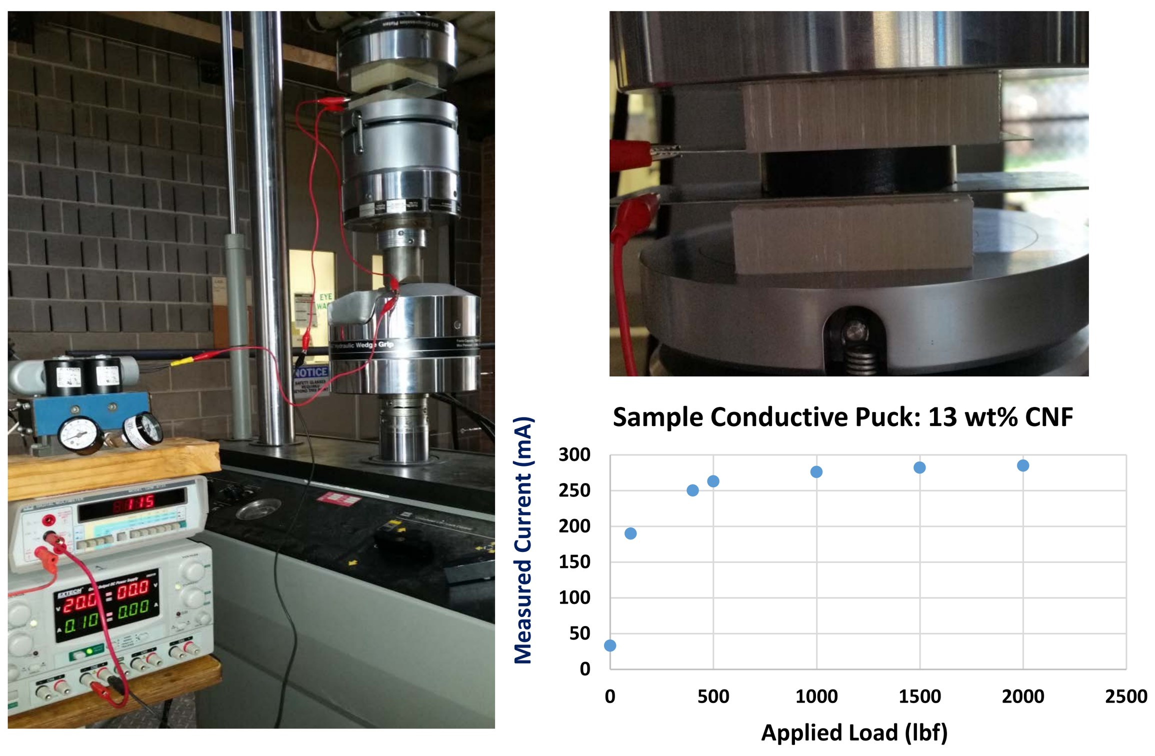

Figure 3: Electrical Conductivity Test Setup Showing Air Valve (Blue)

The pucks were molded in a transfer molding process on a Carver Heat Press as shown in **Figure 2**. Characterization of the resulting materials included: thermal gravimetric analysis (TGA), differential scanning calorimetry (DSC), shore hardness, creep relaxation, complex modulus by dynamic mechanical analysis (DMA), compressive stress-strain, and electrical and thermal conductivity. The conductivity tests involved measurement of a puck's conductivity under increasing applied loads while the puck was in series with a voltage source and the air valve. Lastly, CNF distribution and dispersion were examined using fractured parts in a scanning electron microscope (SEM).

Results and Discussion

Nanofiber addition increases the hardness of the TPU. Because the pad compliance is critical for the proper functionality of the suspension system, the original TPU could not be used. A softer material was chosen and the effect of fiber addition was quantified to determine the allowable limits for the fiber content.

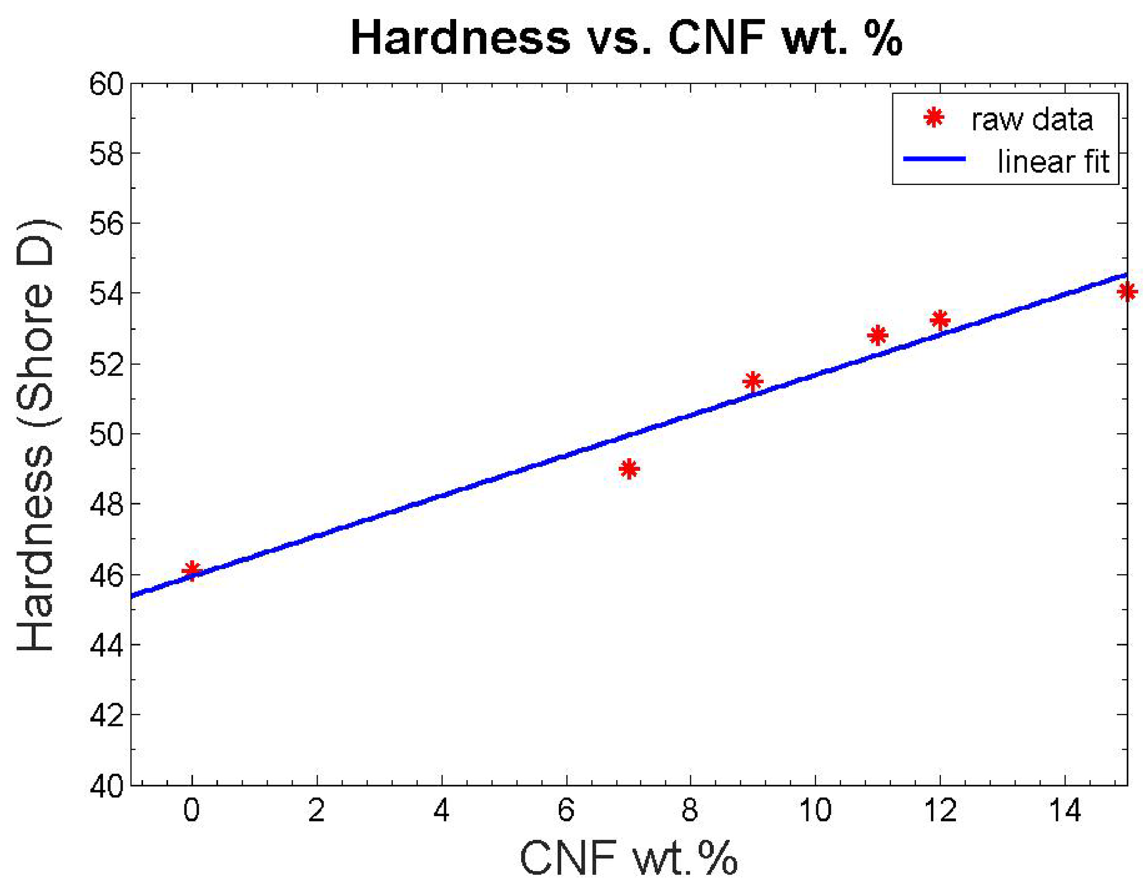

Figure 4: Effect of CNF Addition on Polymer Hardness (Durometer)

The resulting composite has improved thermal conductivity, which would likely result in lower bearing operating temperatures, and reduced creep rate when compared to that of unmodified TPU.

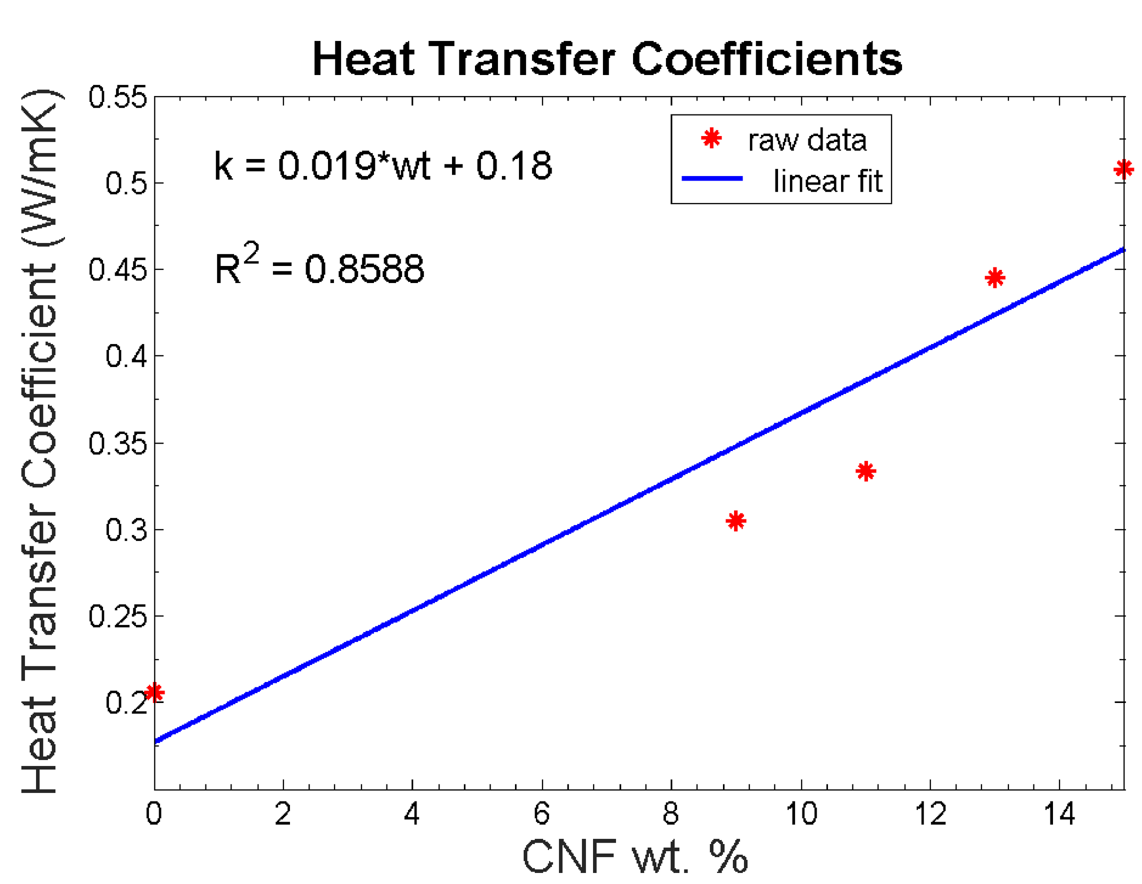

Figure 5: Effect of CNF Addition on Polymer Thermal Conductivity

A quantity of TPU blended with 18% CNF was prepared by a commercial provider for mold testing at UTRGV. Transfer molded pucks of this commercially prepared material were tested and were found to have the desired conductivity.

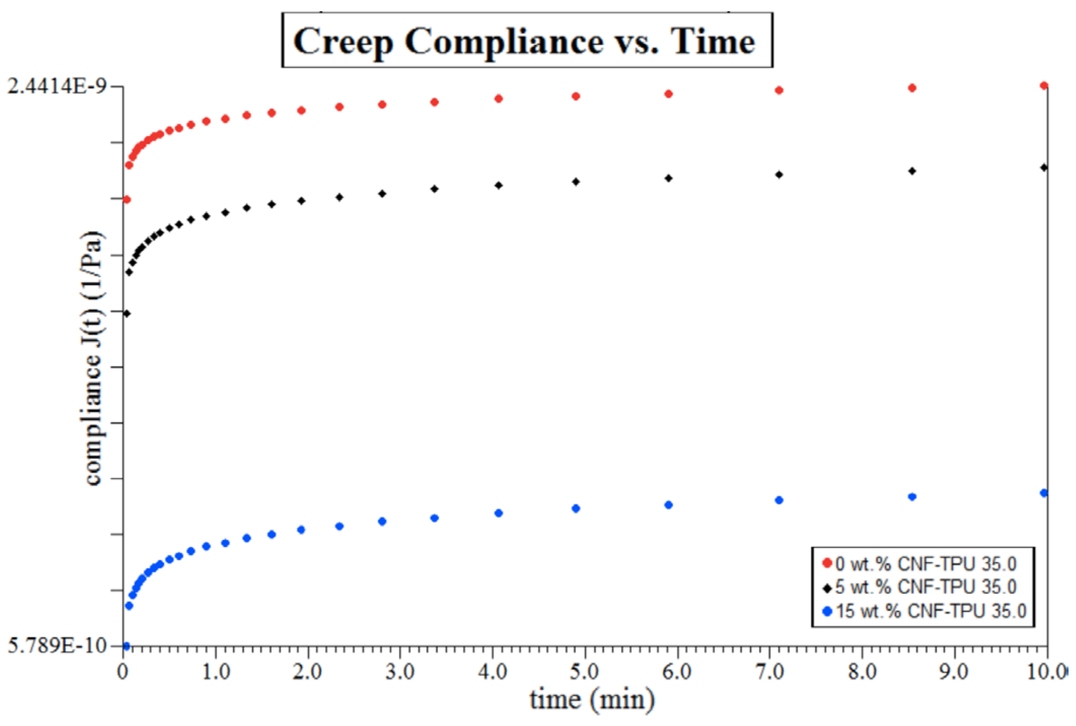

Figure 6: Reduction in Creep Compliance with CNF Addition

When test production was moved to a standard injection molding machine similar to that used in commercial production, the resulting components showed no conductivity. The loss of conductivity has since been the focus of the research. Fiber orientation has been eliminated as the cause. Fractured specimens evaluated in the SEM do not show strong flow orientation for any pucks, and flow modeling (AutoCad MoldFlow) of the transfer molded and injection molded pucks showed that neither should develop significant fiber orientation through their thickness.

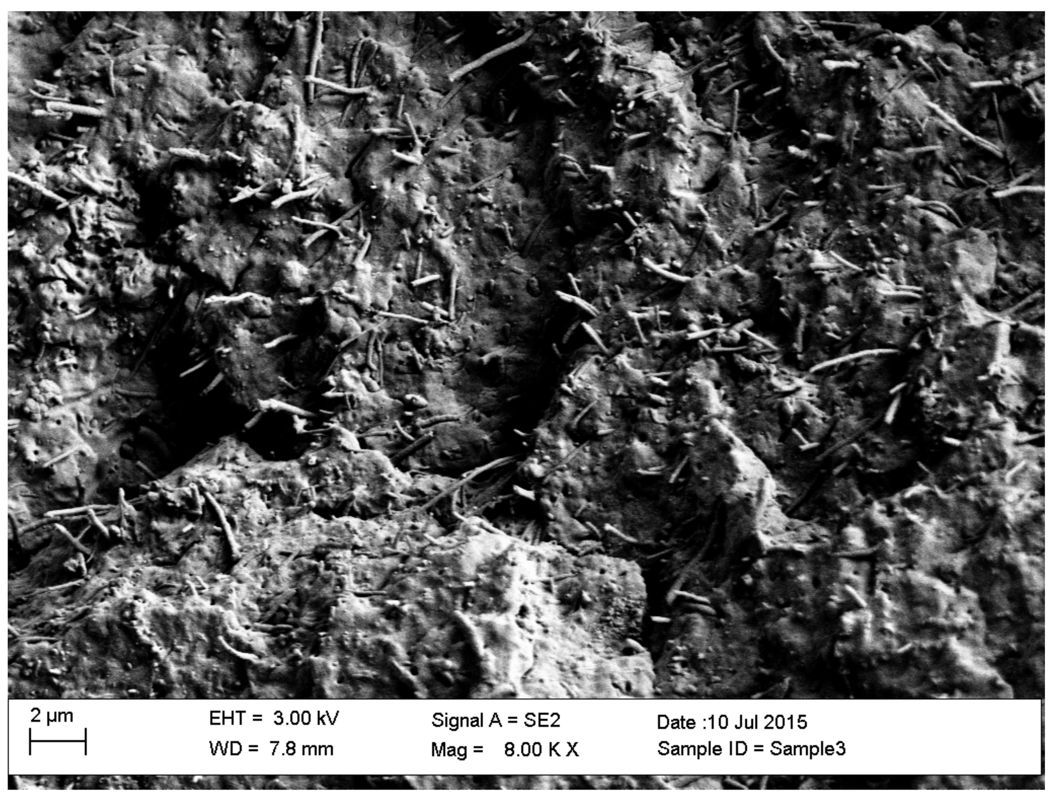

Figure 7: Fractured Puck Surface Showing Poor Fiber Orientation. (Magnification 8000x)

Damage to the fibers by the injection molding process has also been eliminated as the cause since injection molded parts were reground and then transfer molded into conductive parts. The biggest difference found between the transfer molded and injection molded pucks is in the level of crystallinity as measured by the DSC. Since the transfer mold is operated near 300°F while the injection mold operates at ambient temperature, the lower cooling rate of the transfer mold produces a more crystalline product. X-ray diffraction of the samples shows that, in the conductive samples, the nanofibers are dispersed while in non-conductive samples, they are aggregated into pockets surrounded by non-conductive regions. Apparently, rapid formation of crystallites locks the nanofibers into a dispersed arrangement while lower levels of crystallization permit fiber aggregation.

Conclusion and Future Work

A conductive polymer can be made with CNF reinforcements while maintaining the required stiffness. Molding must be at temperatures near 300°F to maintain conductivity. Current work is focused on reducing this temperature closer to normal molding conditions. To that end, industry partners are compounding CNF's with an experimental, rapidly crystallizing version of the TPU, which will be evaluated at UTRGV.

Acknowledgments

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