University of Texas Rio Grande Valley
ScholarWorks @ UTRGV

Mechanical Engineering Faculty Publications and Presentations

College of Engineering and Computer Science

6-30-2022

Conductive Polymer Pad for Use in Freight Railcar Bearing Adapters

Jesse Aguilera

Constantine Tarawneh

Harry Siegel

Robert Jones

Santana Gutierrez

Follow this and additional works at: https://scholarworks.utrgv.edu/me_fac

Part of the Mechanical Engineering Commons

Proceedings of the 2022 Joint Rail Conference
JRC2022
April 20-21, 2022, Virtual, Online

JRC2022-78217

CONDUCTIVE POLYMER PAD FOR USE IN FREIGHT RAILCAR BEARING ADAPTERS

Jesse Aguilera
Mechanical Engineering Department
University of Texas Rio Grande Valley
University Transportation Center for
Railway Safety (UTCRS)
Edinburg, TX 78539, USA
jesse.aguilera01@utrgv.edu

Constantine Tarawneh, Ph.D.
Mechanical Engineering Department
University of Texas Rio Grande Valley
University Transportation Center for
Railway Safety (UTCRS)
Edinburg, TX 78539, USA
constantine.tarawneh@utrgv.edu

Harry Siegel
Mechanical Engineering Department
University of Texas Rio Grande Valley
University Transportation Center for
Railway Safety (UTCRS)
Edinburg, TX 78539, USA
harry.siegel01@utrgv.edu

Robert Jones, Ph.D.
Mechanical Engineering Department
University of Texas Rio Grande Valley
University Transportation Center for Railway Safety
Edinburg, TX 78539, USA
robert.jones@utrgv.edu

Santana Gutierrez
Mechanical Engineering Department
University of Texas Rio Grande Valley
University Transportation Center for Railway Safety
Edinburg, TX 78539, USA
santana.gutierrez01@utrgv.edu

ABSTRACT

Many freight railcars rest on polymer adapter pads made of injection-molded Thermoplastic Polyurethane (TPU) polymers which feature two copper studs to provide electrical conductivity through the pad. This design feature allows signal transmission from the track to the onboard systems, including cargo gates and pneumatic actuators. While in service, the polymer pads experience impact and cyclic loading that produce shear, resulting in the abrasive wear and plastic compression of the copper studs which leads to signal interruptions and loss of function requiring the periodic replacement of these polymer pads. This causes increased downtime due to maintenance and reduced reliability in the automated systems since pad failure is unpredictable. This limitation in current designs is the driving concern behind the effort to create an electrically conductive polymer adapter pad that would provide a durable conductive path between the rail and freight car side-frame.

To that end, the University Transportation Center for Railway Safety (UTCRS) has been working on developing a conductive composite blend of TPU and Carbon Nano Fibers (CNF) to create injection-molded polymer composite inserts that can provide the necessary conductivity without the need for the copper studs that are susceptible to wear. Previous work done on this project was successful in creating a TPU-CNF composite insert that provided the required electrical conductivity at full railcar loads but was inconsistent at empty railcar loads. Thus, current work presented here focused on studying the fiber orientation that would produce consistent conductivity at all railcar loads. Based on these findings, a new mold was fabricated to create injection-molded polymer composite inserts with the effective fiber orientation. Laboratory test results show that the newly created composite inserts provide approximately double the needed conductivity required for a 24-Volt railcar valve to actuate when tested under the minimum load conditions an adapter would experience in field service. This paper summarizes the work done on fiber alignment and the results of the testing performed on the UTCRS dynamic bearing test rigs.

Keywords: Thermoplastic Polyurethane (TPU), Carbon Nanofiber (CNF), conductive polymer pad, electrical conductivity, freight railcar suspension.

1. INTRODUCTION

The cyclic loading and harsh conditions experienced in rail service drive the need to replace the current design of the polymer adapter pads which features two copper studs to provide electrical conductivity needed to actuate gates on

Downloaded from http://asmedigitalcollection.asme.org/JRC/proceedings-pdf/JRC2022/85758/V001T02A002/6892715/v001t02a002-jrc2022-78217.pdf by Colorado State University user on 07 September 2022

Copyright © 2022 by ASME

freight railcars. The copper studs (seen in FIGURE 1C) are used to pass electric current to onboard systems on railcars to actuate valves that close and open gates. However, over time, the copper studs wear down or are plastically compressed by load excursions and the pad must be replaced with all the added cost and downtime that entails.

Motivated by this challenge, researchers at the University Transportation Center for Railway Safety (UTCRS) have been working on a solution which will make the polymer pad electrically conductive without compromising its structural integrity and functionality. Initial work focused on fabricating a prototype polymer pad made completely out of a TPU-Carbon Black blend [1], as shown in FIGURE 1A. Unfortunately, this design did not pass the abrasion and surface shear tests and the structural integrity of the pad was thoroughly compromised. The second attempt at a solution involved creating TPU-CNF circular puck inserts to be placed in the middle of the polymer pad [2], as pictured in FIGURE 1B. Although this design produced acceptable conductivity at full railcar loads where the polymer pad was completely in contact with the side frame of the railcar, the pad was not conductive at empty railcar loads since the side frame did not engage the pad firmly over the entire top surface, and contact was especially light at the center of pad where the conductive component was located.

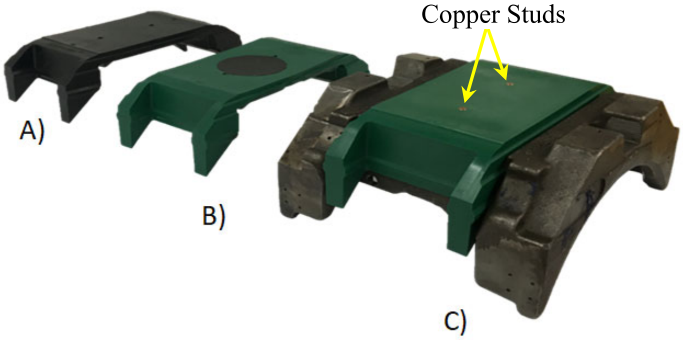

FIGURE 1: (A) CNF PROTOTYPE PAD, (B) INITIAL PROTOTYPE WITH CNF INSERT, AND (C) ADAPTERPLUS^{TM} STEERING PAD WITH COPPER STUD DESIGN ON A STEEL BEARING ADAPTER.

A third attempt at this problem involved a redesign of the TPU-CNF inserts to locate them at the two interlocks of the polymer pad so they are always engaged by the side frame regardless of whether the railcar was fully loaded or empty [3]. These "interlocks" are two triangular protrusions on the underside of the pad which engage appropriately shaped grooves in the top of the bearing adapter and provide resistance to shear displacement by the pad in the rolling direction. A picture of this design can be seen in FIGURE 2. This design produced consistent conductivity at full railcar loads but inconsistent results at empty railcar loads. The mold for the design was gated for ease of manufacture and no effort was made to optimize flow orientation of nanofibers. The failure of this design revealed that fiber alignment had to be controlled and optimized if function over the full range of operating loads was to be achieved.

Current work on this project involved redesigning the injection mold based on numerous mold flow simulations to create TPU-CNF inserts with favorable carbon nanofiber alignment that will allow the pad to be electrically conductive at all operating conditions [4]. This paper summarizes the results of testing of the new injection-molded flow optimized thermoplastic polyurethane-carbon nanofiber (TPU-CNF) composite inserts which were fabricated using the redesigned mold. The newest insert design is identical to the one shown in FIGURE 2 but the gating of the mold results in the carbon nanofibers aligning vertically in the insert, in the direction in which current needs to be carried.

FIGURE 2: POLYMER PAD WITH PROTOTYPE TPU-CNF INSERTS AT THE TWO INTERLOCKS OF THE PAD FOR ENHANCED CONTACT

2. METHODOLOGY AND EXPIREMENTAL SETUP

The modified adapter pad was first subjected to static compressive loading on a servo hydraulic material testing system (MTS 810, see FIGURE 3) and then was statically loaded on a bearing test rig at different ambient temperatures while bearing life tests were underway, exposing the pad to the vibration environment and thermal fluctuation of an operating bearing. The four-bearing tester pictured in FIGURE 4 mimics rail service operating conditions of speed, temperature, and bearing driven vibration but not external dynamic load variability due to rail conditions, wheel impacts, or other random loads.

In the static test, the bearing adapter on which the pad was placed was supported by half of the outer ring (cup) of a class F bearing which was welded to a steel plate for loading between standard compression platens. A piece of sheet steel was then placed on the top face of the pad to permit the application of the desired triggering voltage to the system. Two 1.27 cm (0.5") thick sheets of acrylic were used to electrically isolate the top and bottom surfaces of the test stack from the loading frame (see FIGURE 3). The load was applied to the top surface of the stack through an I-beam to ensure uniform load distribution [3].

Downloaded from http://asmedigitalcollection.asme.org/JRC/proceedings-pdf/JRC2022/85758/V001T02A002/6892715/v001t02a002-jrc2022-78217.pdf by Colorado State University user on 07 September 2022

Copyright © 2022 by ASME

FIGURE 3: MTS 810 MATERIALS TESTER SETUP FOR VALIDATION TESTING OF THE ADAPTER PAD WITH THE PROTOTYPE TPU-CNF INSERTS.

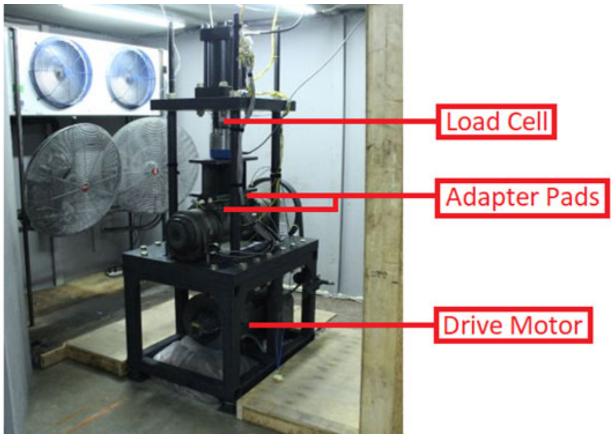

FIGURE 4: DYNAMIC FOUR-BEARING TESTER HOUSED IN AN ENVIRONMENTAL CHAMBER THAT CAN SIMULATE AMBIENT CONDITIONS OF -40°C to 65°C. THIS TESTER WAS USED TO PERFORM SIMULTANEOUS VALIDATION TESTING ON TWO ADAPTER PADS WITH PROTOTYPE TPU-CNF INSERTS TO ENSURE THAT THEY REMAIN ELECTRICALLY CONDUCTIVE AT ALL AMBIENT CONDITIONS.

All static testing was performed at an ambient temperature of 22°C (72°F). In the static tests, a load of 26 kN (5.85 kips) was applied to simulate the load of an empty freight railcar. Because conductivity usually improves at higher loads in these types of materials, an empty car represents the worst case loading from the perspective of conductive performance. The remaining runs on the four-bearing tester used a load of 153 kN (34.4 kips) which is the force carried by a bearing under a freight car loaded to capacity. Testing on the four-bearing dynamic test rig was conducted at speeds ranging from typical railcar operating speeds (40 to 97 km/h) to maximum tester speed (137 km/h) for highest heat generation within the bearings. The four-bearing test rig is housed in an environmental chamber equipped with an industrial refrigeration unit which allows the chamber temperature to be controlled to simulate various freight service conditions.

For each test, a solenoid driven air valve was added to the circuit applying voltage through the pad so that actuation of a valve could be demonstrated under each condition rather than just inferred from measurement of resistivity. For valve actuation tests, a driving voltage of 24 volts was supplied by an adjustable power supply. For long term measurement of pad resistivity, the solenoid was removed from the circuit and the pad alone was subjected to a driving voltage which was varied from 5 to 10 volts. This represents the net voltage available to drive current through the pad in field applications after losses due to impedance of a solenoid air valve which would normally be installed in series in the circuit [3].

National Instruments LabVIEW, a data acquisition software, was used to continuously record the voltage across the pad from which the pad resistivity was plotted in MATLAB®.

3. RESULTS AND DISCUSSION

For the solenoid driven pneumatic valve to function when the activating voltage is applied, the pad resistivity must be below **750 ohm-cm**. To ensure a significant margin for operation as solenoids age or other operational factors intrude, **600 ohm-cm** was set as a ***target resistivity***. Both levels are shown in FIGURE 5 and FIGURE 6 as dashed lines. A successful prototype must always exhibit a resistivity below these lines.

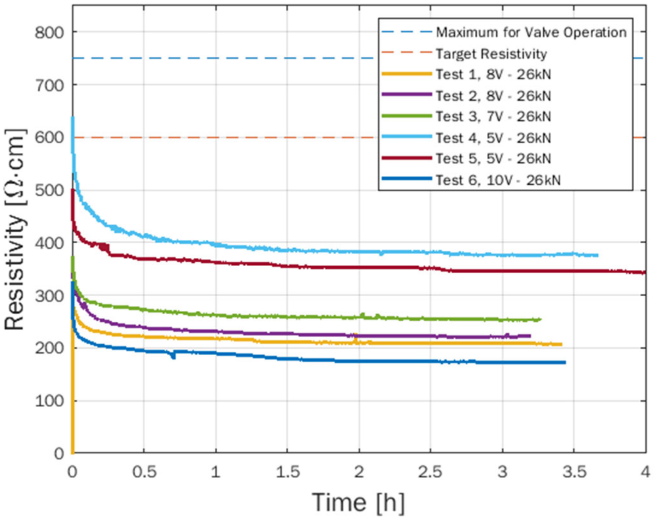

FIGURE 5: RESISTIVITY OF PAD WITH ONE CONDUCTIVE INTERLOCK INSERT UNDER STATIC EMPTY RAILCAR LOAD

Static testing of a pad with only one conductive insert yielded resistivities well below the maximum allowable level at all tested voltages, as shown in FIGURE 5. In all cases, the resistivity rapidly dropped upon load application and approached a steady-state resistivity in about 30 minutes. Note that resistivity continues to decline very slowly after this, reaching a steady state value in about 2 hours. The initial rapid drop in resistivity is probably due to a reduction in the contact resistance between the metal components and the polymer pad.

Downloaded from http://asmedigitalcollection.asme.org/JRC/proceedings-pdf/JRC2022/85758/V001T02A002/6892715/v001t02a002-jrc2022-78217.pdf by Colorado State University user on 07 September 2022

As the polymer in the pad conforms to the metal surfaces due to creep under the applied load, the improved contact causes a rapid reduction in this resistance. The continued slow decline in resistivity is probably due to low levels of creep by the polymer matrix of the pad which will reduce the gaps between conductive fibers. This ability to conform to less-than-ideal surfaces suggests the system will adapt to some level of surface roughness in the side-frame which will rest on the pad.

The resistivity of the pad also showed a marked voltage dependence with higher applied voltage resulting in a lower overall resistivity. This is consistent with mechanism of conduction where the conductive filler is not continuous. Higher voltages allow current to be carried over larger gaps between conductive fibers, thus opening new paths for current and reducing the overall resistivity. The fact that acceptable resistivities were obtained with as little as five volts applied to the pad indicates a robust conductivity which should permit valve functionality even when system voltages drop below normal. In all test cases, a solenoid valve installed in the circuit functioned fully when the test voltage of 24 volts was applied to the full circuit.

The excellent results obtained from the pad with a single conductive insert at unloaded railcar weights provided the impetus to mold additional oriented fiber inserts and construct a pad with both interlocking elements replaced with these conductive inserts (see picture of FIGURE 2). The resulting pad was subjected to long term testing on the UTCRS Four-Bearing Tester. This allowed for testing to be carried out at different ambient temperatures, simulated axle speeds, and full bearing loads. The test load was set to 153 kN (34.4 kips) simulating a fully loaded railcar, with speeds ranging between 72 and 137 km/h (45 and 85 mph) and ambient temperatures between 4 and 29°C (40 and 85°F).

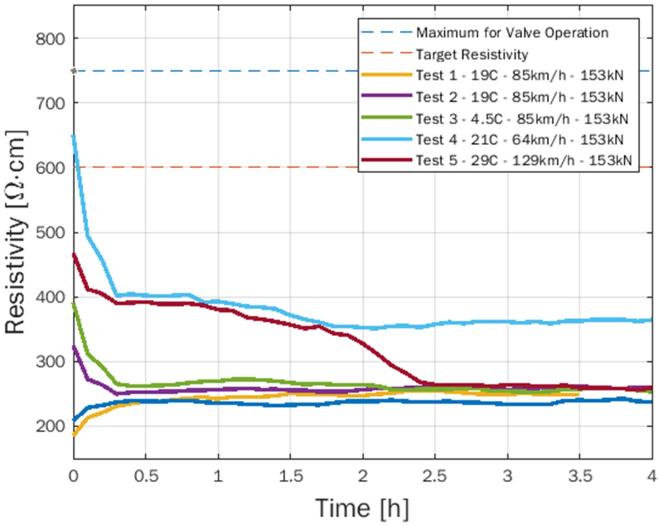

FIGURE 6: RESISTIVITY OF DUAL INSERT PAD ON FOUR-BEARING TESTER UNDER SIMULATED SERVICE CONDITIONS

Figure 6 plots the resistivity measured for the two-element pad in five long term tests. Throughout these tests, the solenoid driven air valve was randomly actuated. It never failed to fully actuate. As in the earlier static tests, the pad shows a rapid decline in resistivity and largely levels out at 30 minutes under load. Since the pads in service are only fully unloaded when removed from a railcar, this transient response is not an operational concern. Baseline resistivity at all temperatures and vibration levels is well below the target value and appears to be mostly independent of temperature over the range tested.

4. SCANNING ELECTRON MICROSCOPE

The other priority in this work was to determine whether commercial mold flow software could provide guidance for mold and gate design. For commercial deployment of this technology a larger, probably multi-cavity, mold would likely be required. Prediction of fiber alignment during mold filling using standard mold flow software would greatly facilitate the design process. Commercial software generally does not include flow data for nanofiber systems so modeling and mold design was done using data for standard short fibers. The models which guided the mold redesign provided an overall map of fiber alignment and predicted high levels of alignment in certain regions. One of the molded inserts was sectioned and a number of these regions exposed by fracturing the parts after cooling in liquid nitrogen. Scanning electron microscopy of these key sections indicates that the alignment obtained is consistent with the model predictions. Sample SEM images showing the high levels of fiber alignment are provided in FIGURE 7 and FIGURE 8.

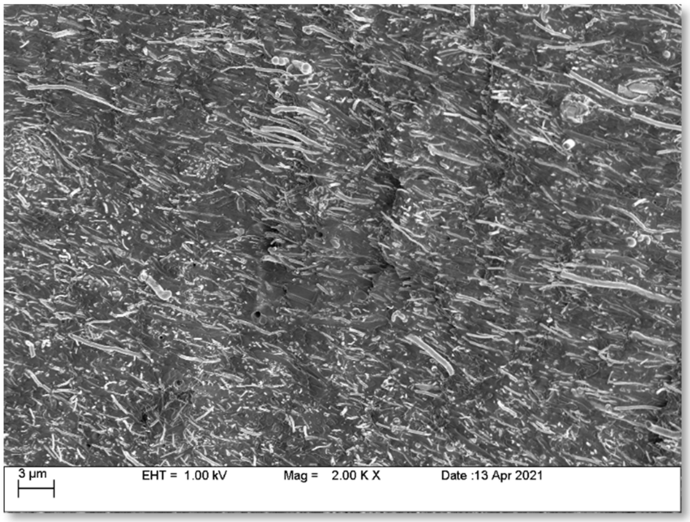

FIGURE 7: SCANNING ELECTRON MICROGRAPH OF SECTION FROM CONDUCTIVE INSERT (MAGNIFICATION 2000x)

Downloaded from http://asmedigitalcollection.asme.org/JRC/proceedings-pdf/JRC2022/85758/V001T02A002/6892715/v001t02a002-jrc2022-78217.pdf by Colorado State University user on 07 September 2022

Copyright © 2022 by ASME

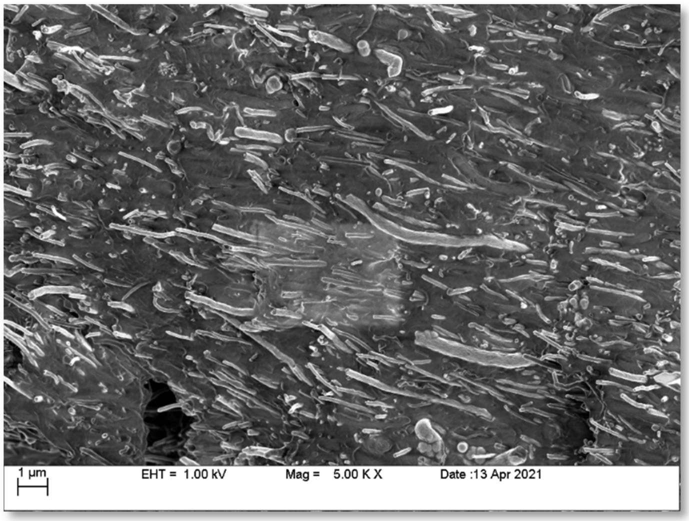

FIGURE 8: SCANNING ELECTRON MICROGRAPH OF SECTION FROM CONDUCTIVE INSERT (MAGNIFICATION 5000x)

5. CONCLUSION

The results of this work suggest that TPU-CNF inserts with controlled fiber orientation can be manufactured using ordinary injection molding and will provide the required level of conductivity for functioning of automatic devices requiring a conductive path for signaling between the rail and railcar. The level of conductivity obtained provides a large margin of safety for successful functioning of systems. This conductivity is largely insensitive to ambient temperature over the range 4 to 30ºC and bearing operating conditions and load levels associated with the full range of rail operations. The observed behavior indicates that the pad will adapt to some variability in surface quality in the neighboring suspension components through creep of the polymer which results in reduced contact resistivity between the pad and components. Furthermore, the mold redesign successfully applied existing commercial mold flow analysis software without adjustment for the use of nanofibers which will ease fabrication of a commercial mold to be used for producing injection-molded TPU-CNF inserts.

Additional testing is ongoing to assess performance at temperatures well below 0ºC and above 30ºC. Additional mechanical testing to establish the long-term durability under a broad range of shear and impact load conditions is also being pursued.

ACKNOWLEDGEMENTS

This study is made possible by funding provided by the Dwight David Eisenhower Transportation Fellowship Program (DDETFP) through a USDOT Grant No. 693JJ32145214 and by guidance from faculty affiliated with the University Transportation Center for Railway Safety (UTCRS) at the University of Texas Rio Grande Valley (UTRGV). The help of Dr. Victoria Padilla who provided the SEM micrographs presented in this paper is greatly appreciated.

REFERENCES

[1] Suarez, R. “Design and Optimization of a Railroad Conductive Suspension Element Pad Composed of Thermoplastic Polyurethane and Carbon Black.” Master’s Thesis, Mechanical Engineering Department, University of Texas Pan-American, August 2013.

[2] Basaldua, D. “Effects of Vapor Grown Carbon Nanofibers on Electrical and Mechanical Properties of a Thermoplastic Elastomer.” Master’s Thesis, Mechanical Engineering Department, University of Texas Pan-American, December 2014.

[3] Villareal, A. “Microstructural Influences on the Mechanical and Electrical Properties of Carbon Nanofiber Thermoplastic Polyurethane Composites.” Master’s Thesis, Mechanical Engineering Department, University of Texas Rio Grande Valley, August 2019.

[4] Siegel, H. “Fiber Orientation Analysis and Implementation in TPU-CNF Composite for Railway Use,” *Dwight D. Eisenhauer Transportation Fellowship Program*, Final Report, 2019.

Downloaded from http://asmedigitalcollection.asme.org/JRC/proceedings-pdf/JRC2022/85758/V001T02A002/6892715/v001t02a002-jrc2022-78217.pdf by Colorado State University user on 07 September 2022

Copyright © 2022 by ASME