SOUTHERN PLAINS TRANSPORTATION CENTER

SPTC Brief

Highlighting Developments at Southern Plains Transportation Center
September 2016

Nano-Modified Polymer Concrete for Highway Repairs and Bridge Deck Overlays

OVERVIEW: Highways and bridges are key infrastructure that require regular maintenance. According to Federal Highway Administration estimates, there are over 600,000 bridges and 4 million miles of highway across the United States. Regular maintenance of these key infrastructures have significant economic impacts. This SPTC-funded project, through The University of New Mexico (UNM), has been researching polymer concrete modified with nanoparticles as an alternative material for repair and overlay. Polymer Concrete (PC) is a type of concrete that replaces cementitious binders with polymer. It can serve under severe weather conditions, has rapid curing, and can develop a strong bond with steel or concrete. The findings show that incorporating small weight fractions of nanoparticles into the PC matrix improves the mechanical properties and prolongs its service life. Alumina nanoparticles (ANPs) and multi-walled carbon nanotubes (MWCNTs) modified PC are found to improvement tensile strength, ductility, and fracture toughness. Further, structural health monitoring (SHM) can be enabled using pristine MWCNTs (P-MWCNTs).

BACKGROUND: Nanoparticles are materials with characteristic dimensions that lie in the nanoscale. ANPs are Aluminum oxide particles with maximum nominal dimension of 50 nm. MWCNTs are cylindrical nanostructures made of carbon molecules whose diameter is in the nanoscale and are tens of microns long. The MWCNTs used here were of 20-30 nm outer diameter, 5-10 nm inner diameter, and 10-30 µm length. Transmission electron microscope (TEM) images of both nanoparticles are shown in Figure 1.

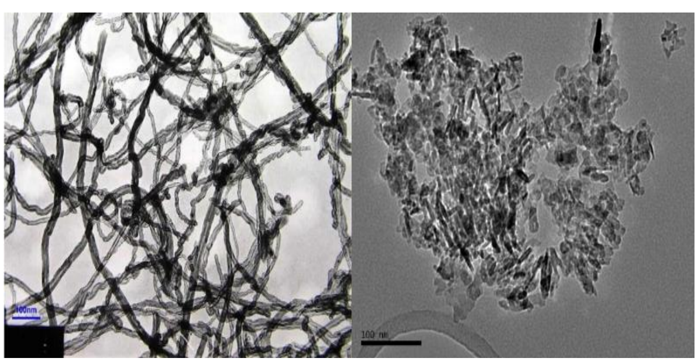

Figure 1: TEM images of MWCNTs (left) and ANPs (right).
MWCNTs photo credit: Cheap Tubes, Inc.

The key properties investigated include:

1. Tensile strength - the material's ability to resist breaking under tension.
2. Ductility - the material's ability to deform to failure often represented as strain at failure in tension.
3. Fracture toughness: the material's resistance to crack propagation.

By improving these properties, maintenance frequencies are reduced and degradation is mitigated.

ANPs MODIFIED PC: The results show that the use of ANPs in PC provides improved ductility with negligible loss of tensile strength. PC and ANPs modified PC both show high tensile strength in the range of 9.5-11.3 MPa, while normal concrete is often limited to 2-3 MPa. More importantly, ANPs modified PC reached a strain at failure up to 5%, whereas ordinary concrete usually fails at a tension strain lower than 0.1%. Therefore, an order of magnitude improvement in ductility can be achieved using ANPs of up to 3% by weight, as shown in Figure 2. These improvements are reflected in fracture toughness results as well, where ANPs modified PC have up to 131% increase in fracture toughness, as shown in Figure 3.

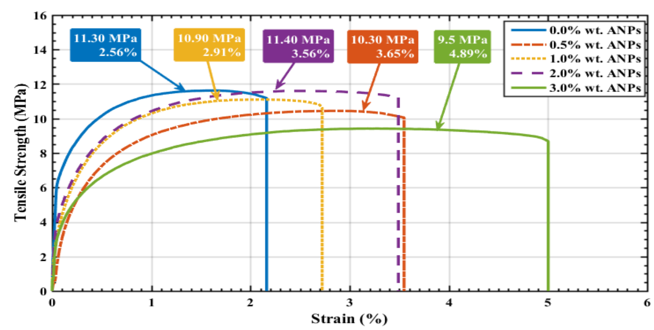

Figure 2: Tensile stress-strain curves for ANP modified PC.

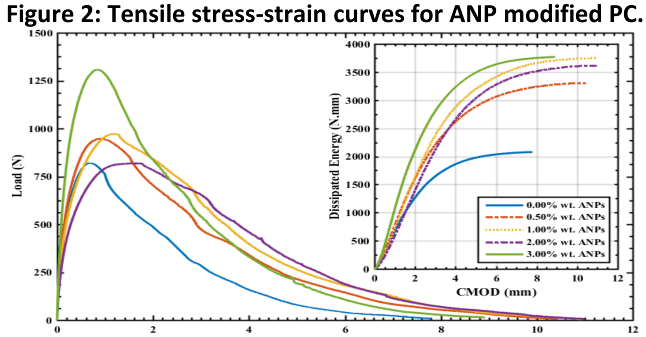

Figure 3: Crack mouth opening displacement (CMOD) vs load and energy for ANP modified PC.

MWCNTs MODIFIED PC FINDINGS: Two types of MWCNTs were used in this study, namely pristine (PCNP) and carboxyl functionalized (PCNC) MWCNTs. The use of functionalized MWCNTs resulted in increased tensile strength with a small reduction in ductility, whereas pristine samples improved ductility with minimal loss in strength. The results are shown in Figure 4. Fracture toughness of PC incorporating pristine and carboxyl functionalized MWCNTs also improved by 130%. Importantly, great improvements in the mechanical properties were observed at very low MWCNTs contents (0.5 wt.%). It is apparent that ductility, tensile strength, and fracture toughness of PC can be controlled through the functionalization of MWCNTs. The results for fracture toughness are shown in Figure 5.

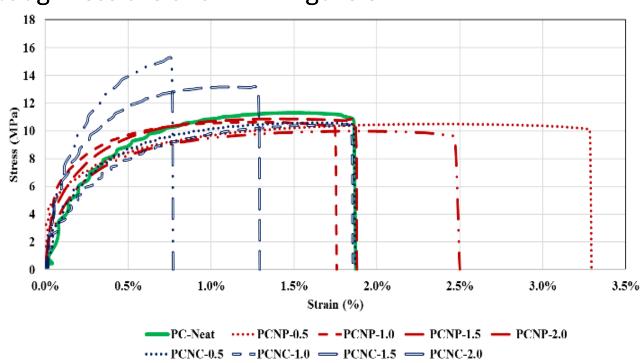

Figure 4: Tensile stress-strain curves for MWCNTs modified PC.

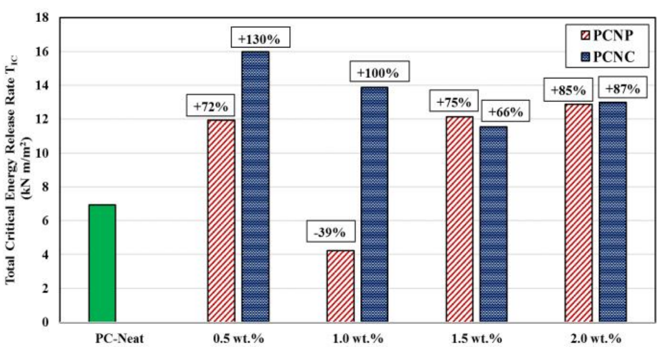

Figure 5: Energy release rate for MWCNTs modified PC in fracture investigation.

Because of their specific dimension and high electrical conductivity, pristine MWCNTs at 2% weight content are able to provide an electrical network whose resistivity changes with the material's mechanical damage. Such change enables damage propagation by monitoring electrical conductivity of PC. Figure 6 depicts how such property is capable of capturing mechanical damage in the four-point bending test.

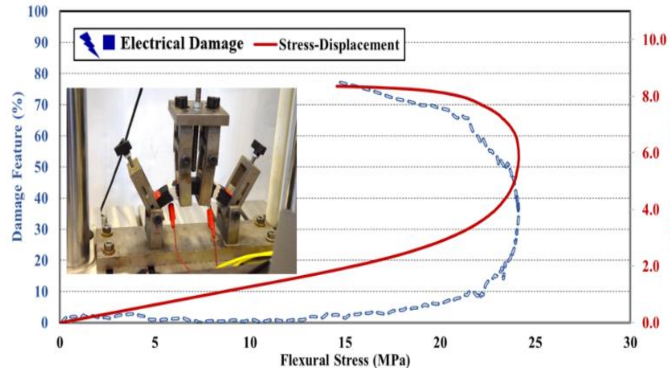

Figure 6: Structural health monitoring of PC using MWCNTs in four-point flexural bending test.

IMPACT: Incorporating nanoparticles at low weight content enables making a significant improvement in the properties of PC. High ductility, fracture toughness and tensile strength of PC are achievable using ANPs and MWCNTs, as shown in this brief. Pristine MWCNTs also enable structural health monitoring of PC. PC modified with nanoparticles provides a promising material for bridge deck overlays and highway repair. Such material would require minimal maintenance and would improve the service life of highways.

ABOUT THE RESEARCHERS: Dr. Mahmoud Reda Taha is the principal investigator of this project. He is a Professor and Chair of Civil Engineering Department at The University of New Mexico (UNM). Dr. Rafiqul Tarefder is a Professor in the Department of Civil Engineering at UNM and is an Associate Director of SPTC.