Carbon Nanotube, Carbon Fiber, and Wollastonite Filled Nylon 12 Polymers for Use in Fused Deposition Additive Manufacturing

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Introduction

Additive Manufacturing (AM) provides for rapid prototype and product development through a build-up process, layering materials to form the final part. Investigation of mixed material properties may lead to improved mechanical, electrical, and thermal properties. The goal of this research is to develop three filled Nylon 12 polymers for testing with the Fused Deposition Modeling (FDM) additive manufacturing process. The fillers selected were single walled carbon nanotubes (CNTs), 100 micron milled carbon fiber, and a fibrous mineral called wollastonite. Each polymer was evaluated for improved mechanical properties, and in the case of the carbon nanotube (CNT) filled material, may exhibit conductive properties.

Developing these materials for use in a FDM process will make these materials available to other research partners and Department of Defense agencies due to the low cost of fused deposition modeling machines. The work described in this report was completed as part of the Edgewood Chemical Biological Center's Innovative Projects for fiscal year 2014. The use of either trade or manufacturers' names does not constitute an official endorsement of any commercial products.

Approach

Three mixed materials were developed to be suitable for extrusion on the FDM process. The mixed materials consist of various concentrations by weight of the filler materials CNT, carbon fiber, and the mineral wollastonite. These materials were mixed with Nylon 12 thermoplastic and extruded into a filament suitable for use in 1.75 mm FDM processes. ASTM 638 tensile bars were fabricated on a Flashforge USA machine, and pull tested on an Instron tensile machine. Fill orientation and volume were characterized via microscopy. Electrical properties were evaluated with a megohmmeter. Mechanical and electrical properties of these filled materials are provided.

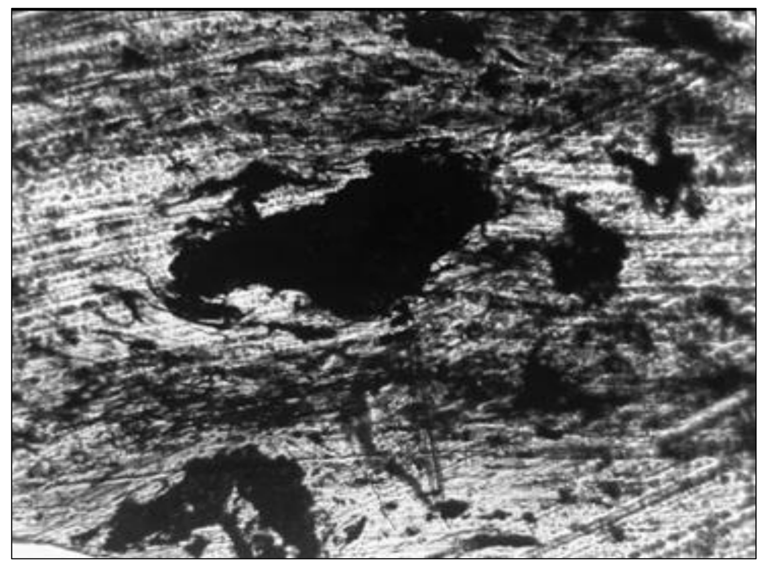
Filler concentration was determined separately for each material as polymer viscosity would increase dramatically based on the additive and could damage the filament extruder. The starting points of 2% CNT, 20% carbon fiber, and 6% wollastonite were determined to be safe for extrusion and initial testing.

Methodology

The fillers were pre mixed by hand or mechanically with the polymer powder and run through a filament extruder to process the filler and polymer into a filament. Once in filament form the filled polymer was run through a FDM machine to build an ASTM 638 standard tensile bar for Instron testing. Each of the three new materials had 10 tensile bars made. Tensile bars were also fabricated using an unfilled Nylon 12. Concentrations of fillers were determined for each batch of mixed polymer, and were measured by weight.

Observations

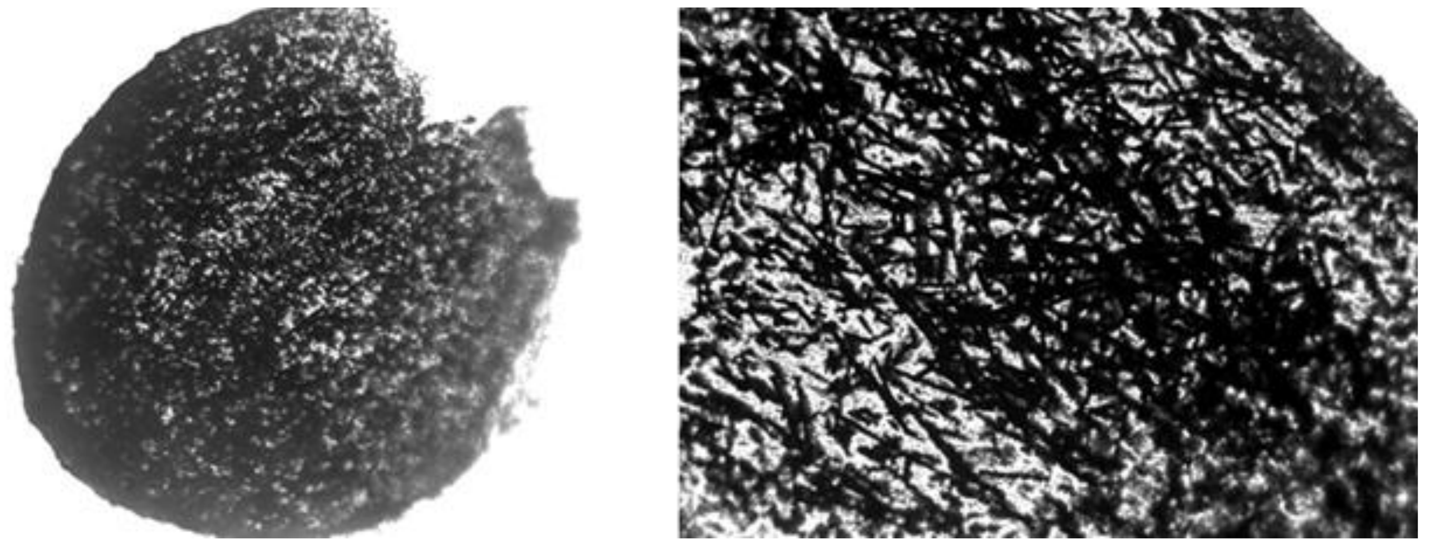
Filling Nylon 12 with single walled CNTs proved to be difficult in achieving a homogenous nanotube dispersion through the polymer.



Spectroscopy of the first batch of partially manufactured tensile bars using 2% CNT filament which clogged the 0.4 mm open diameter nozzle of the FDM machine. This clogging made manufacture of complete tensile bars impossible. Photo courtesy of Nanocomp.

Spectroscopy of the 0.4 mm strands of partially dispersed carbon nanotubes in a Nylon 12 polymer show that the CNTs appear to be orienting in the direction of nozzle travel. Photo courtesy of Nanocomp.

Carbon fiber filled nylon was found to have no limitations in producing a usable filament. Carbon fiber can achieve proper dispersion very easily with hand mixing of the Nylon powder and filler prior to extrusion. The 6% Wollastonite material can also be extruded into a filament with no issues after a manual hand mixing of the polymer and filler. Increased concentration may yield similar results to the carbon fiber material.



Spectroscopy of the first batch of 20% Carbon Fiiber filled Nylon 12. Photo courtesy of Nanocomp.

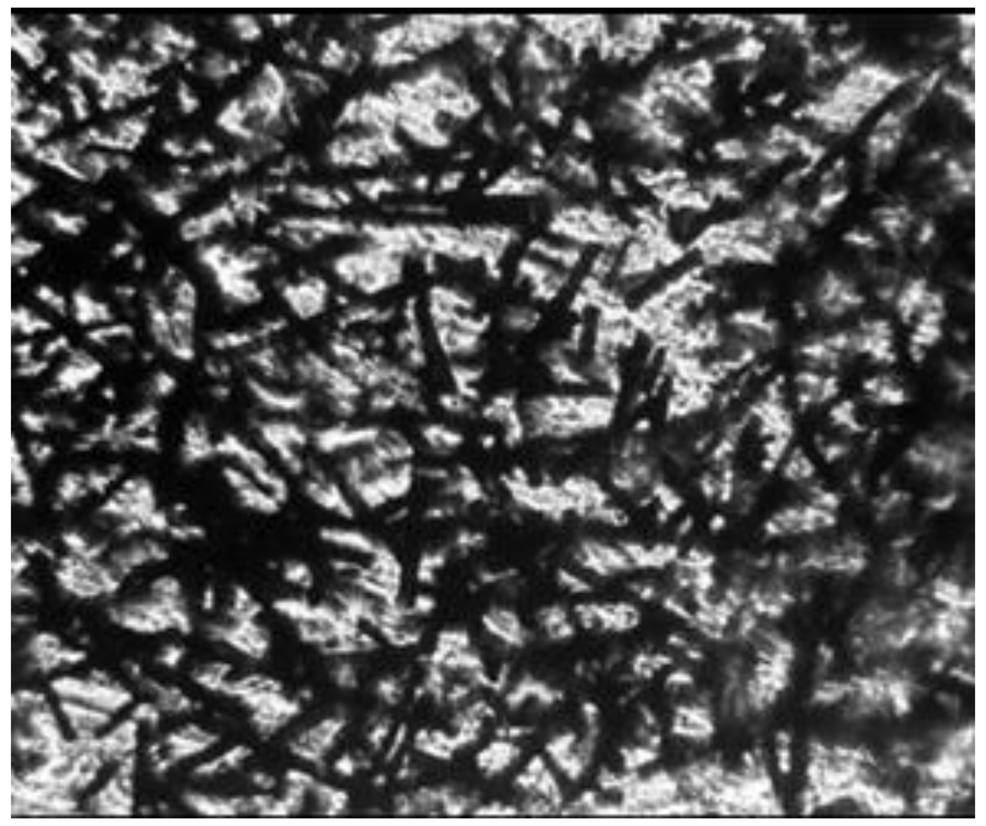
Results

The filled materials exhibited increased mechanical properties over the unfilled Nylon 12 samples. Each test sample was pulled to the ASTM 638 standard using a stock Instron tensile machine. The most striking increase in mechanical properties was the 20% filled carbon fiber Nylon 12, with a 50% increase in tensile strength. The CNT showed limited conductivity with average resistance of 7.325 Mega-Ohms based on tests of five samples of 1.75 mm diameter filled filament cut to 50 mm lengths at 1000 volts.

Material	*Max load (lbf)*	*Modululs of Elasticity (psi)*	*Tensile Strength (psi)*
Nylon 12	232.05	82,776.05	4,375.59
Carbon Fiber	433.77	206,818.26	7,336.09
Carbon Nanotube	292.59	107,585.03	5,131.79
Wollastonite	305.02	111,351.35	5,206.58

Potential Applications

The carbon fiber material has been singled out by the Aviation and Missile Research, Development and Engineering Center (AMRDEC) for possible use in Unmanned Aircraft System airframes. The University of Delaware has been working on additive manufactured Ankle/Foot Orthotics (AFO) for the last 8 years, and is interested in the carbon fiber filled material as a possible solution to premature failures of their current poly-carbonate material.



Spectroscopy of the first batch of 20% Carbon Fiiber filled Nylon 12. Photo courtesy of Nanocomp.

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