Continuous Processing of High Thermal Conductivity Polyethylene Fibers and Sheets

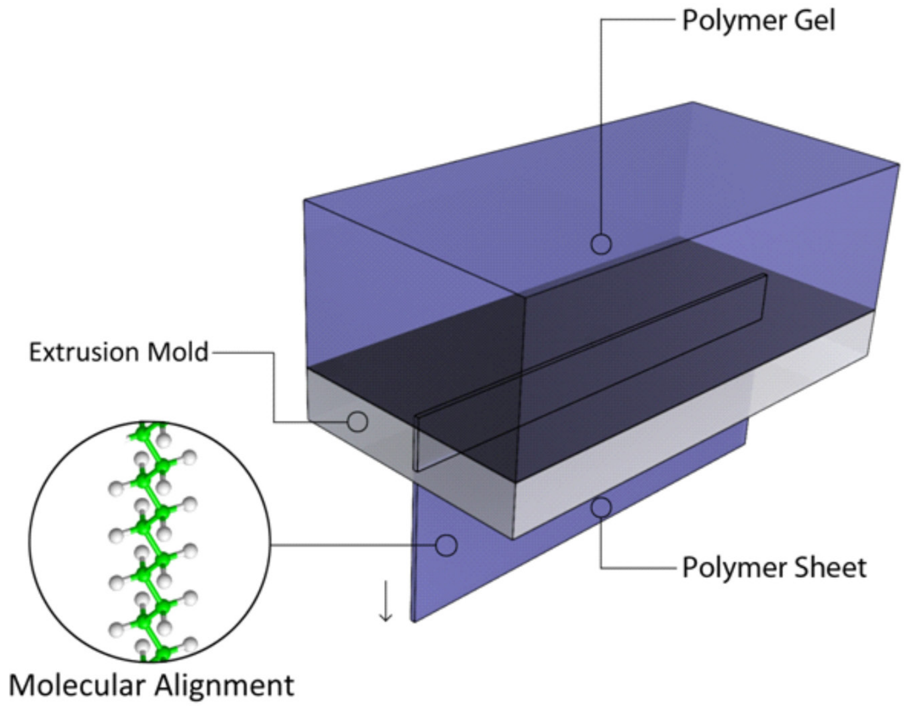

Illustration of continuous processing of UHMW-PE sheets (or fibers) with highly aligned molecule chains. UHMW-PE nanofibers are extruded through a template to form a continuous sheet (or fiber) and are stretched (not shown) further to align the molecules. *Graphic courtesy of MIT.*

A Lightweight Material for Heat Exchange Applications

Introduction

Thermal conductivity is an important consideration in choosing materials for different manufacturing applications. For example, materials used in heat exchangers require high thermal conductivity because heat must be transferred between substances located at a distance from one another. Historically, heat exchangers have been manufactured from metal because metals are effective in conducting thermal energy. Plastics, although cheaper, lighter, and less energy intensive to make than metals, are much less efficient in conducting heat than metals. This project will combine the valuable performance characteristics of both metals and plastics by developing a continuous production process for ultra-high molecular weight polyethylene (UHMW-PE) fiber and sheet production that will result in a thermally conductive plastic material.

A number of lab-scale studies have shown that thermal conductivity is improved when polymer fibers are stretched mechanically. This increase is believed to be a direct result of the higher molecular chain alignment achieved by stretching. The aim of this work is to transform these early laboratory results into a scalable production process.

The proposed production process will involve using a spinneret specially designed for sheet formation to extrude an UHMW-PE gel at a chosen temperature and shear rate. The resultant gel then will be exposed to a controlled temperature environment to partially evaporate the solvent and solidify the gel sheet.

The sheet will then be reheated and stretched to enhance the molecular chain orientation and create high thermal conductivity. A combination of process modeling and experimental trials will be used to identify conditions that yield plastic sheets with high thermal conductivity.

The thermal conductivity of the fibers and sheets is expected to be about two orders of magnitude higher than bulk polymers and at least twice that of currently available fibers.

Benefits for Our Industry and Our Nation

Benefits are expected to be realized in both fabrication and end use. Energy intensity will be significantly lowered during material synthesis and processing because lower process heating temperatures will be used. The result will be that production plants for these materials will generate less pollution compared to metal processing plants. These polymers could be a game changer for many heat exchangers, especially in fins that require directionally high thermal conductivity values. They also could be used in thermal management systems in microelectronics, where an electrical insulating material is preferred. High thermal conductivity sheets could significantly expand the potential application for plastics and could help the U.S. plastics industry to expand its competitive position internationally. From an end use perspective, polyethylene is 35% less dense than aluminum, making the material lighter per unit volume. For example, using these polyethylene sheets in automotive applications would reduce vehicle weight and improve fuel economy.

Applications in Our Nation's Industry

This process could provide the plastics industry a low-energy, cost-effective method of producing high thermal conductivity polyethylene material for further use as a lighter and less expensive alternative to metals in various heat transfer applications. Process integration is simplified by existing knowledge and widespread use of the primary material input (polyethylene).

Project Description

Project tasks will focus on manufacturing platform design and fabrication, process modeling and optimization, materials characterization, and property characterization and modeling. The project objective is to develop and validate a continuous manufacturing process for polyethylene fibers and sheets yielding a thermal conductivity value greater than 60 Watts per meter-Kelvin (W/m.K).

Barriers

- Lack of scalable processes for manufacturing high thermal conductivity polyethylene sheets.
- Uncertainties associated with molecular-scale chain manipulation and modeling.
- Understanding of the optimum conditions for proper polymer flow through the spinneret to limit or eliminate clogging.

Pathways

The primary task involves manufacturing platform design and fabrication. The concept is based on the gel-extrusion process and hot drawing. Efforts will focus on fabricating and assembling the processing apparatus as well as the spinneret. Process modeling and optimization will be conducted to guide the manufacturing process considering four key variables: mechanical strength of the spinneret, flow of the polymer through the spinneret, polymer drying, and the optimal stretch ratio.

Researchers will characterize the molecular orientation of the polymer chains within the finished product using techniques such as X-ray diffraction, polarized microscope, scanning electron microscope, and transmission electron microscopy.

Researchers will also undertake property modeling to determine the thermal conductivity of the polymer sheets, specifically focusing on discovering the heat transfer characteristics between the polyethylene chains. These models will also provide guidance for structure and process optimization.

Milestones

This project began in 2012.

- Achieve the capability to fabricate 1x5 square centimeter (cm^2) polymer sheets by means of the proposed gel-extrusion and hot drawing process (2013).
- Reach a thermal conductivity greater than 30 W/m.K for the 1x5 cm^2 sheets (2014).
- Reach a thermal conductivity greater than 60 W/m.K for the 1x10 cm^2 sheets (2015).

Commercialization

There is strong interest from major chemical and polymer producers regarding this high thermal conductivity polyethylene material. The Massachusetts Institute of Technology (MIT) intends to secure intellectual property for this technology, then determine whether to license it directly to other companies or pursue another commercialization option. As has been the case for numerous MIT technology developments, there is also a strong possibility that a start-up company could be formed by project participants to further advance the technology.

Project Partners

Massachusetts Institute of Technology
Cambridge, MA
Principal Investigator: Gang Chen
Email: gchen2@mit.edu

For additional information, please contact

Bob Gemmer
Technology Manager
U.S. Department of Energy
Advanced Manufacturing Office
Phone: (202) 586-5885
Email: Bob.Gemmer@ee.doe.gov

DOE/EE-0869 • Updated September 2014