Polymer 154 (2018) 42–47

Contents lists available at ScienceDirect

Polymer

journal homepage: www.elsevier.com/locate/polymer

Short communication

New insights into thermal conductivity of uniaxially stretched high density polyethylene films

Ri-Chao Zhang[a,*], Zhihuan Huang[a], Dan Sun[c,**], Dehui Ji[a], Meiling Zhong[a], Dongmian Zang[a], Jia-Zhuang Xu[d], Yizao Wan[a], Ai Lu[b,***]

[a] School of Materials Science and Engineering, East China Jiaotong University, Nanchang, 330013, China
[b] Institute of Chemical Materials, China Academy of Engineering Physics, Mianyang, 621900, Sichuan, China
[c] School of Mechanical and Aerospace Engineering, Queen's University Belfast, BT9 5AH, UK
[d] College of Polymer Science and Engineering, State Key Laboratory of Polymer Materials Engineering, Sichuan University, Chengdu, 610065, China

HIGHLIGHTS

- The higher stretch ratio contributes the higher thermal conductivity.
- Stretching can induce the formation of interlocking shish-kebab structure.
- Our work helps understand the process-structure-property relationship.

ARTICLE INFO

Keywords:
Thermal conductivity
Polyethylene
Stretch
Interlocking shish-kebab
Thermal conductive mechanism

ABSTRACT

Thermal conductivity of drawn polyethylene (PE) fibers has been extensively studied, while thermal conductivity for the stretched PE sheets still remains unknown. In addition, no consensus conclusions have been reached on the thermal conduction mechanisms for drawn PE. In this work, melt processed PE sheets are subjected to uniaxial stretching under different stretch ratios. The in-plane and out-of-plane thermal conductivity of stretched PE has been measured and the crystalline structure has been analyzed through 2-dimensional wide-angle X-ray diffraction (2D-WAXD) and scanning electron microscopy (SEM). Results show that both in-plane and out-of-plane thermal conductivities of stretched PE increase with increasing stretch ratios. The enhancement of thermal conductivity has been ascribed to the formation of interlocking shish-kebab superstructures induced by the stretching process. A new model is proposed to demonstrate the thermal conductivity improvement seen for the uniaxial-stretched PE. To the best of our knowledge, it is the first time that the mechanisms of thermal conductive enhancement were revealed for uniaxially stretched semi-crystalline PE sheet along with the understanding of the associated process-structure-property relationship. This work may provide key information towards design and manufacturing of polymer-based materials for thermal management applications.

1. Introduction

Thermally conductive yet electrically insulating polymer materials are of great interest for various applications such as heat exchangers [1], circuit boards in power electronics, and other microelectronic appliances [2] due to their attractive multi-functionalities in addition to other advantages such as lightweight, corrosion resistance and ease of large scale processing [3]. Unfortunately, bulk polymers normally have very low thermal conductivity, typically in the order of 0.1 $W\,m^{-1}\,K^{-1}$ [4]. The enhancement of polymer thermal conductivity has been mostly achieved through incorporation of thermally conductive fillers [5–9], to form a composite. However, most thermally conductive polymer composites contain high weight loading (> 50 w.t. %) of fillers. This would inevitably lead to complexity in manufacturing and increased cost. The high content fillers are likely to agglomerate, which will not only compromise the thermal conduction performance but also severely deteriorated the mechanical properties of the composites [7,8]. Despite the addition of highly thermally conductive filler materials, the best

* Corresponding author.
** Corresponding author.
*** Corresponding author.
E-mail addresses: zrcws@zju.edu.cn (R.-C. Zhang), d.sun@qub.ac.uk (D. Sun), ai_lu@tom.com (A. Lu).

https://doi.org/10.1016/j.polymer.2018.08.078
Received 4 May 2018; Received in revised form 16 August 2018; Accepted 31 August 2018
Available online 01 September 2018
0032-3861/ © 2018 Elsevier Ltd. All rights reserved.

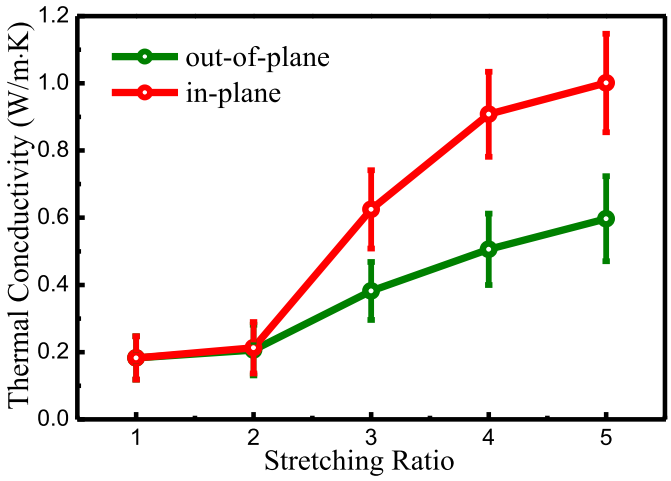

Fig. 1. In-plane and out-of-plane of PE sheets with various stretch ratio.

thermal conductivity achieved by polymer composites is still in the range of 1–10 $W\,m^{-1}\,K^{-1}$ [7,8], this is because the polymer matrix acts as a thermal barrier that limits the thermal transport efficiency of the composites. The conflicting requirements for high thermal conductivity and good mechanical properties make the design and manufacturing of thermally conductive polymer-based materials a long standing challenge. It is therefore of great interest to explore the approaches to enhance the thermal conductivity of neat polymers, as this would offer an effective solution to the existing challenges.

The low thermal conductivity of polymer is usually caused by the scattering of phonons due to the entangled molecular chains, presence of grain boundaries and defects etc [3,10]. Even for polymers with the highest degree of crystallinity, there is ~40% of amorphous phase present in between the crystalline lamellae. Although single crystalline lamella possesses very high thermal conductivity (> 100 $W\,m^{-1}\,K^{-1}$) [10,11], the thermal transportation process is inevitably interrupted by the interfaces that present between the crystalline and amorphous phases, and crystallizable polymers normally exhibit thermal conductivity similar to that of its amorphous phases.

It is well accepted that thermal conductivity of polymer can be enhanced by improving the crystallites alignment and macromolecular chain orientation. Recent reports showed that ultra-drawn highly crystalline polyethylene fibres exhibit metal-like thermal conductivity (> 100 $W\,m^{-1}\,K^{-1}$), due to the formation of an 'ideal' single crystalline fibre [11]. A high thermal conductivity (up to 4.4 $W\,m^{-1}\,K^{-1}$) for amorphous polythiophene nanofibers has also been achieved with molecular chain orientation along the fibre axis [12]. Moreover, a number of molecular dynamics simulation studies suggest that a single extended polymer chain could achieve thermal conductivity as high as ~350 $W\,m^{-1}\,K^{-1}$ [13,14]. Although past experimental and simulation results show that very high thermal conductivity can be achieved for neat polymers, the effort has been mostly focused on the ultra-drawn polymeric fibres, which have limited practical applications. Furthermore, no consensus conclusions have been drawn so far on thermal conduction mechanism for the polymers after being subjected to the external stretching force.

Here we report the enhanced thermal conductivity of bulk polyethylene (PE) sheet achieved by uniaxially stretching. The enhancement of thermal conductivity can be attributed to the combination of lamellae and chain alignments in a semi-crystallizable material induced by the stretching force. A new model has been proposed elucidating the mechanisms of thermal conductivity enhancement for uniaxially stretched bulk semi-crystalline PE through the analysis of the process-structure-property relationship. The new model may be generalized for a greater range of polymer-based materials and hence may provide key information towards design and manufacturing of high thermally conductive polymers and polymer-based composite materials.

1.1. Fabrication of uniaxially stretching PE sheets

Uniaxial drawing was carried out using an Instron 5564 Universal Tensile Tester fitted with an environmental chamber to enable uniaxial drawing of PE sheets at elevated temperatures to obtain tailored lamellar alignments and macromolecular orientation. Bulk PE sheet (76 mm × 76 mm × 1 mm) (S1) was first heated to 160 °C and hold for 3 min to erase any materials processing history. The sample was then cooled down to 110 °C at a cooling rate of 80 °C/min, followed by uniaxial drawing in a nitrogen atmosphere (S2). Four different stretch ratios (Λ = 1, 2, 3, 4, and 5, where Λ is the ratio between the final length l and the initial length L of the material, $\Lambda = l/L$. Λ = 1, denotes unstretched material) have been deployed. The in-plane and out-of-plane thermal conductivities (S3) as a function of stretch ratio has been measured using a laser flash method (LFA-447, Netzsch, Germany) based on xenon flash lamp source at room temperature. In order to understand the effect of structural change on the thermal conductivity of the bulk PE sheet during the uniaxial drawing process, a synchrotron 2-dimensional wide-angle X-ray diffraction (2D-WAXD) apparatus in

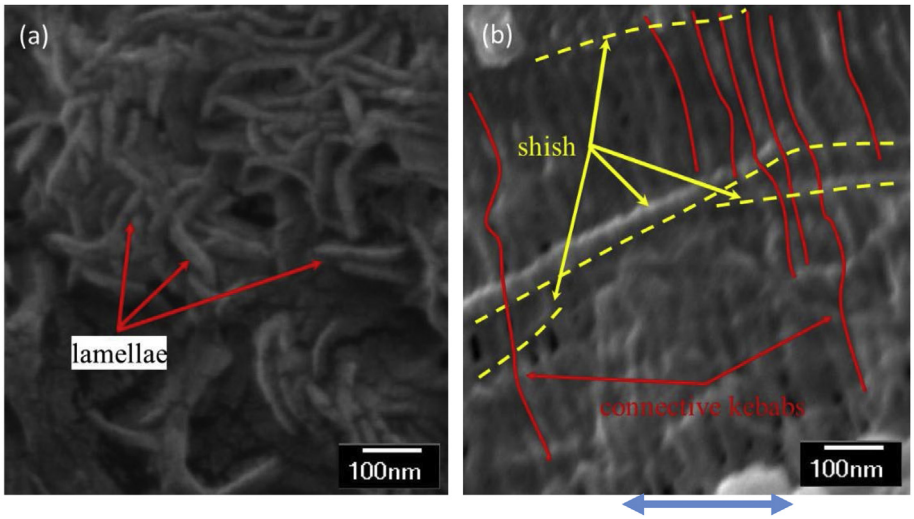

Fig. 2. SEM images of (a) unstretched PE sheets and (b) stretched PE sheets, blue arrow denotes stretching direction. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Download English Version:

https://daneshyari.com/en/article/8961366

Download Persian Version:

https://daneshyari.com/article/8961366

Daneshyari.com