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Effect of mold temperature on the structures and mechanical properties of micro-injection molded polypropylene

Jing Jiang [a], Shiwei Wang [a,*], Bo Sun [a], Shuaijiang Ma [a], Jianming Zhang [a], Qian Li [a,*], Guo-Hua Hu [b]

[a] National Center For International Joint Research of Micro-Nano Molding Technology, School of Mechanics & Engineering Science, Zhengzhou University, 450001 Zhengzhou, Henan, China
[b] Laboratory of Reactions and Process Engineering (LRGP), CNRS-University of Lorraine, 1 rue Grandville, BP 20451, 54001 Nancy, France

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ABSTRACT

The effects of the mold temperature of micro-injection molding on the microstructures and mechanical properties of isotactic polypropylene (PP) gears were studied. The micro-injection molded PP gears present a skin–core type of morphology. The core layer is much thicker than the core and shear layers. The generation of β polymorph in the test samples is easily promoted during the micro-molding process with high shear rate at low temperature, or low shear rate at high temperature. Nanoindentation tests show that the modulus decreases along the flow direction and increases with increasing mold temperature. The highly oriented shear layer has the highest nano-indentation modulus compared with the skin and core layers.

1. Introduction

Micro-injection molding (MIM) technology is expected to hold great potential in the mass production of good quality polymer micro-parts [1]. One of the main challenges associated with micro-molding resides in difficulties of controlling structures or mechanical properties of the parts [2–3]. MIM parts often exhibit a “skin–core” structure which is similar to that of conventional injection molding parts, expect that the oriented layer represents a large fraction [4]. A method was developed to explore the morphology evolution of micro-injection molded parts [5]. However, more detailed works remain to be done to explore the relationship between microstructure and mechanical properties of MIM parts. Nanoindentation could be a good mechanical test, especially for micro- or nano-composites [6–8]. Shokrieh found that the mechanical properties of polymers were improved significantly with the addition of low amounts of graphene nano-platelets [9]. During a nanoindentation test, mechanical properties are measured by the displacement that occurs when a small load is applied to the surface of the specimen using a diamond-tipped indenter. The region of the indenter tip during the test is typically less than 1 mm in diameter, allowing mechanical properties to be measured precisely in an extremely small area of the specimen. So nanoindentation test is a good means to measure the mechanical properties of different layers of MIM parts which cannot be measured easily otherwise [10].

The mold temperature is a critical factor in an injection molding process, and can have a notable effect on the morphology and properties of injection molded parts [11]. It is found that mechanical strength of semicrystalline polymers usually varies inversely with the crystallinity [12,13], which depends on mold temperature. A higher mold temperature, normally above T_g temperature for semicrystalline polymers, tends to decrease the thickness of the skin layer and increase the relative crystallinity [14,15]. For this reason, this work aims at investigating the effect of mold temperature on the micro-injection molded isotactic polypropylene (PP) by the nanoindentation test. PP micro-gears were molded at different mold temperatures. Their morphology was characterized by a polarization optical microscope. The mechanical properties of different layers and/or different positions of the micro-gears were measured by nanoindentation. The relationship between microstructure and mechanical properties provides new insights into MIM polymer parts.

2. Experimental

2.1. Materials

The polypropylene used in this study was isotactic PP (F401), a homopolymer of Lanzhou Petroleum Chemical Co, Ltd., PR China, with a melt flow rate of 2.3 g/10 min (ASTM D1238, 230 °C, and 2.16 kg) from Lanzhou Petrobleum Chemical Co., Ltd. (PR China).

* Corresponding authors.
E-mail addresses: shiweiwang@zzu.edu.cn (S. Wang), qianli@zzu.edu.cn (Q. Li).

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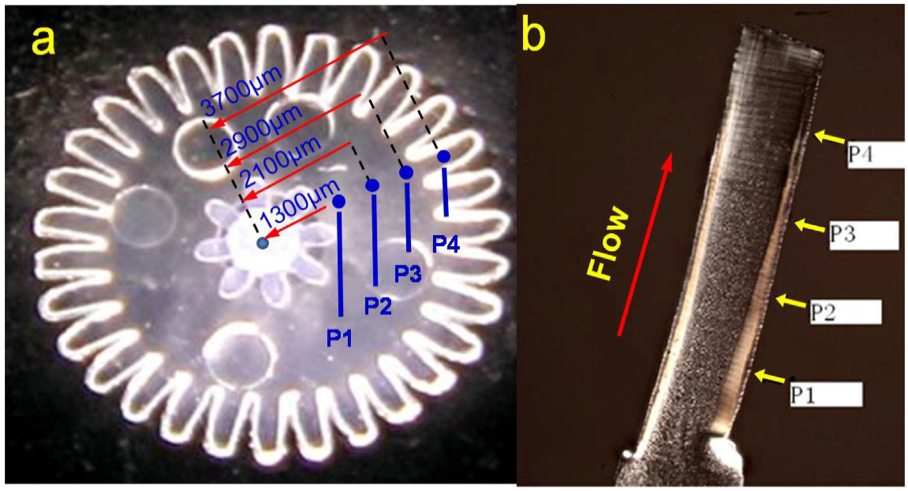

Fig. 1. An isotactic polypropylene microgear. (a) Geometry of a microgear; (b) positions for wide angle X-ray diffraction tests.

2.2. Sample preparation

Fig. 1a shows an MIM PP gear with a thickness of 450 μm, a gear teeth length of 1000 μm, a half gear tooth width of 350 μm, and a gear tooth length of 1000 μm. Four positions with 800 μm gaps were selected along flow direction for testing. The micro-gear was molded using an MIM machine (Cornoplast, Babyplast 6/10P), with a temperature profile of 190 to 200 °C from the hopper to the

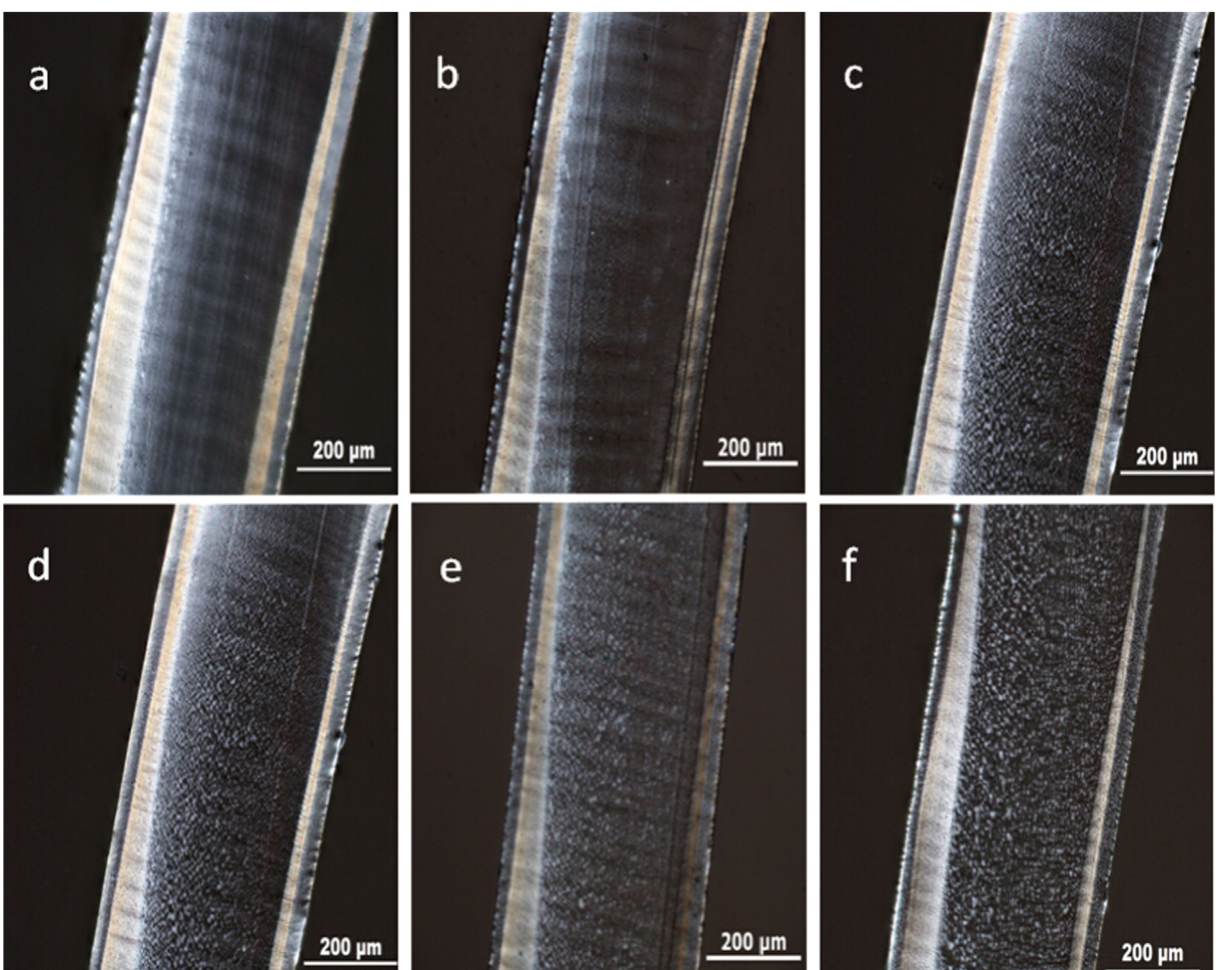

Fig. 2. Images observed by the polarized optical microscope of the micro-injection molded isotactic polypropylene gear slices at different mold temperatures (a) 30 (b) 40 (c) 50 (d) 60 (e) 70 and (f) 80 °C.