Optics and Laser Technology 94 (2017) 208–216

Contents lists available at ScienceDirect

Optics and Laser Technology

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

Full length article

Optical birefringence and molecular orientation of crazed fibres utilizing the phase shifting interferometric technique

T.Z.N. Sokkar, K.A. El-Farahaty *, M.A. El-Bakary, E.Z. Omar, A.A. Hamza

Physics Department, Faculty of Science, Mansoura University, Mansoura, Egypt

ARTICLE INFO

Article history:
Received 7 November 2016
Received in revised form 15 March 2017
Accepted 25 March 2017

Keywords:
Fracture
Crazing
Molecular orientation
Spatial carrier frequency technique
Four-shot phase shifting technique

ABSTRACT

In this article, the features of the phase shifting interferometric technique were utilized to investigate the effect of the presence of crazes in both outer and inner layers on optical birefringence and molecular orientation of polypropylene fibres. The Pluta polarizing interference microscope was used as a phase shifting technique. This method includes adding a stepper motor with a control unit to the micrometer screw of the Pluta microscope. This optical system was calibrated to be used as a phase shifting interferometric technique. The advantage of this technique is that it can detect the crazes in both inner and outer layers of the sample under test. Via this method, the relation between the presence of the crazes (in both inner and outer layers) and the optical molecular orientation of polypropylene (PP) fibres was demonstrated. To clarify the role of this method, the spatial carrier frequency technique was used to show the effect of the presence of the crazes only in the outer layers on the phase distribution values and hence the structural properties of PP fibres.

1. Introduction

In the present decade, the majority of industrial applications are based on using polymeric fibres as structural components [1,2]. Despite the extensive applications for the polymeric fibre, they are restricted by the tendency of their materials to undergo macroscopic fracture. Generally, the fracture process refers to the degradation of the given material into two or more pieces having undergone the action of an applied stress. Usually, the occurrence of the fracture process is related to the structural properties of the given fibre and the ability of its chains to resist the applied load [3]. The birefringence and the optical molecular orientation are used to characterize the fibres on the molecular level [4,5]. These properties provides us with quantitative information about the relation between the structural properties of the tested fibres and the different physical properties [6,7]. So, measuring these parameters for the polymeric fibres becomes a fundamental mission to control the catastrophic fracture and increase the safe operation of fibrous products [8]. In the fibre science, the fracture process is preceded by the crazes formation or in other words, the formation of the crazes in the drawn fibres act as a strong indicator for the fracture process [9].

The crazing phenomenon was observed by Kambour [10]. The molecular structure of the craze contains microviods, like defects, bridged by super-drawn microfibrils in nanometer scale [11]. This phenomenon is classified into three stages as follow; the craze creation stage [11,12], the craze propagation stage and the craze failure. In this stage, the majority of crazes were turned into cracks and this lead to the final fracture [12]. The experimental investigation of craze morphology of polymeric fibres using computed tomography (CT) showed that, crazes are not just surface phenomena but also extend to the bulk material [13]. In-depth study of the crazing in polymeric fibres showed that, crazes are created at the inner layers of the fibre and then the drawn microfibrils start to tear gradually from the core (inner layers) to the surface (outer layers) [13]. The percentage of the craze density, especially at the surface layers, is considered the strongest indicator to the fracture process. Sokkar et al. [9] reported that, the occurrence of the fracture in the drawn fibre is mainly related to the value of the craze density. As the craze density increases, the opportunities of a fracture happening increase. This mean that, to control the catastrophic fracture of the fibrous products, we urgently needed to investigate the effect of the presence of the crazes, whether on the inner layers or the surface layers and their densities, on the birefringence and the optical molecular orientation values. The craze densities of the crazed patterns were calculated using the modified microscopic image analysis system (MIAS) [9].

There are many experimental techniques that are used to observe and detect the crazes [11,14,15]. But few of them are able to correlate between the structure properties of the drawn fibres

* Corresponding author.
E-mail address: emam88@mans.edu.eg (K.A. El-Farahaty).

http://dx.doi.org/10.1016/j.optlastec.2017.03.037
0030-3992/

and the presence of crazes. Interference techniques are one of the most accurate experimental techniques to perform this task [9]. These techniques are based on splitting the light that emitted from a light source into two or more beams. These beams are propagated into two different paths and then superposed in the surface of a digital recording medium like CCD camera [16]. In the interference techniques, the optical and structural properties mainly depend on the values of the optical phase that are extracted from the interference pattern. To retrieve the phase distribution of the tested fibre from the interference pattern, there are two algorithms; the spatial carrier frequency [17,18] and the phase shifting interferometry (PSI) [18,19].

The phase shifting interferometry (PSI) technique [18,19] is a spatial algorithm to retrieve the phase distribution of the tested object. This technique calculates the phase of a pixel in the interference pattern relying on the values of that pixel in several interference patterns. So, the phase shifting interferometry needs, at least, three interference patterns to retrieve the phase distribution. The four-shot algorithm is the most common phase shifting interferometric technique. This algorithm uses a four-shot interference patterns with precisely phase shift ($\pi/2$) radians between the recorded patterns [19]. The main disadvantage of this technique is extra technical efforts that need to do the phase shift and cannot be used to perform in-situ investigation of a dynamic object. On the other hand, this technique is characterized by high accuracy and good results even with low contrast interference patterns [20].

The spatial carrier frequency technique [17,18] is another technique to extract the optical phase distribution of the tested object from the recorded interference pattern with high degree of accuracy. Only a single interference pattern is required to retrieve the phase values by this algorithm. The major advantages of this algorithm are not sensitive for the vibration which allows studying the dynamic objects. Also, this algorithm has high resistance against the unwanted information (noises). On the other hand, the bad selection for the applied band pass filter (that lead to increase the error in the phase calculation) is the main disadvantage of this technique [17]. This technique was used by Sokkar et al. [9] to relate the structure properties of (PP) drawn fibres with craze density. They found that, this algorithm considered the crazes of the surface layers as unwanted noises and removed them. Subsequently, the effect of the presence of the craze in the outer layers is not taken into calculations. So, they reported only the effect of the craze density in the inner layers on the structural properties at relative high draw ratio.

This article aims to report the role of crazes in the fracture process using the non-duplicated position of the Pluta polarizing interference microscope. For this purpose, the Pluta microscope was modified to be suitable for working with (PSI) technique. As this technique was utilized to show the effect of the occurrence of crazes in both surface and inner layers on the birefringence and the molecular orientation chains of polypropylene fibres compared with the spatial carrier frequency technique which measure

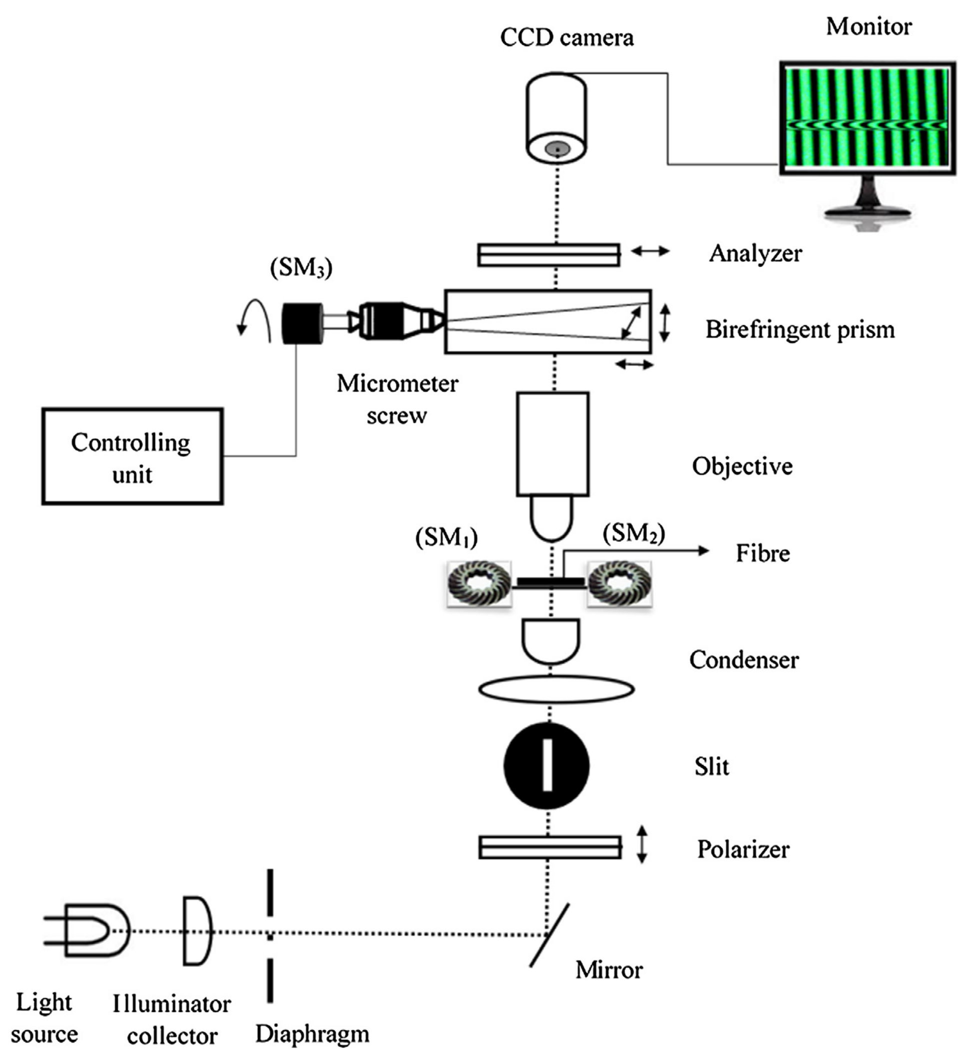

Fig. 1. Experimental set-up of the modified Pluta polarizing interference microscope.