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Light Transmission and the Fine Structure of Poly(methyl methacrylate) Nanofibers and Films

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Abstract: In this paper, the structure and optical properties of poly(methyl methacrylate) (PMMA) nanofibers and films were investigated. Differential scanning calorimetery (DSC) and Wide-Angle X-ray scattering (WAXS) results confirmed the amorphous structure of both nanofibers and films. Low angle X-ray diffraction (LA-XRD) revealed the presence of voids and/or particles with the spacing of 128.4 Å within the nanofibers. From the Porod plots, a three-dimensional surface fractal for the nanofibers and a mass fractal structure for the films were derived. By the interpretation of Small Angle X-ray scattering (SAXS), the shape and size of the particles in the samples were assessed. It was concluded that the particles shape within the nanofibers and the films were globular, with the radius of gyration of 8.5 nm for the nanofibers and 16.5 nm for the films. The nanofiber mat showed less light transparency when compared with the film. This phenomenon could be attributed to the difference in the physical shape, as well as scattering of the light by the voids or particles within the nanofibers.

Keywords: PMMA, Fine structure, Nanofibers, Light transmission, WAXS, LA-XRD, SAXS

Introduction

Poly(methyl methacrylate) (PMMA) is known as an important transparent commercial polymer with excellent transparency and an amorphous structure [1]. It has a wide range of optical applications, such as glass substitutes, dielectric films [2], transparent nanocompsites [3-5], optical sensors [6,7], daylighting systems [8], and polymer optical fibers [9,10]. Nowadays, PMMA finds applications not only in optical systems, but also in areas such as dentistry [11], scaffolds [12], acrylic paints [13], and biomedical tools [14, 15]. In the last two decades, nanofibers have been fabricated from natural or synthetic polymers mainly by the electrospinning method; this fiber-spinning technology is a highly versatile and effective process that can be utilized to produce fibers with diameters that are in the range of a few microns to a few nanometers. One principle of nanotechnology is that the reduction of the dimensions of a material leads to new properties [16-18]. When the diameters of polymer fibers are shrunk to nanometers, there appear several characteristics such as a very big specific surface area, flexibility for chemical/physical functionalization, pore sizes within the nano range, and superior mechanical performance, in comparison with other forms of materials [19]. Also, the high specific surface area makes electrospun micro and nano structures great candidates for a variety of sensing applications involving high sensitivity [20].

Until now, a large number of PMMA nanofibers with a smooth and cylindrical morphology features and without any junctions have been made [21,22]. The average light transmission of PMMA panel or sheet has been reported to be 92 % in the visible light range [23], as mentioned in lots of studied [24,25]. In this regard, there is the possibility of changing the optical properties by increasing or decreasing the components present in PMMA polymer panels [26,27]; as an example, there has been an investigation on the optical properties of nanofibers or composites of PMMA polymer blends [28], but there is not yet enough research on the nanofibers of the pure PMMA. In order to improve the morphology of nanofibers, many parameters have been proposed; these include various solution properties (intrinsic parameters) and processing parameters (extrinsic parameters) [29,30]. To probe the overall morphology of nanofibers, it is necessary to use the electron microscopy technique that provides the direct structure of them [31]. Recently, several techniques such as X-ray (WAXS, SAXS, LA-XRD), differential scanning calorimetery (DSC), etc. have been utilized in an indirect way to infer the characteristics of the interphase in the nanofibers, polymer films and composites [32-34]. The DSC heat scan of the nanofibers could represent the structural variation of the nanofibers at elevated temperatures, showing the subtler physical changes [34,35]. X-ray Reflectometry based on total reflection has become the other technique for the assessment of nanofibers and polymer film issues [36,37]. In this way, the Small angle X-ray scattering (SAXS) technique has been used to investigate the nanostructures and morphology of both ordered and disordered systems [38]. The advancement of the theoretical modeling and the techniques for analyzing the experimental SAXS data is important. This has been accelerated and aided by the rapid evolution of computers [36]. Furthermore, the interpretation of SAXS can be complicated as it may contain several contributions including the microfibrillar structure, the surface reflection/scattering of nanofibers, and the void morphology [30]. Therefore, in order to do SAXS data interpretation, the Hamburg BioSAXS group presented ATSAS software, which is the most popular and suitable one [39,40].

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