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Optical properties of ultra-high molecular weight polyethylene (UHMWPE): A material of choice for total joint applications

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HIGHLIGHTS

- Feasibility of using high power lasers for polymer modifications.
- Optical characterization of biomaterials.
- Anisotropic nature of UHMWPE.

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ABSTRACT

In this study optical spectroscopic investigation (from 360 nm to 850 nm) of UHMWPE has been performed using double integrating sphere (DIS) setup. The results revealed that ~9.6% of reference light signal transmitted without interaction i.e. collimated transmitted light was found ~10%. Major portion of reference signal was found to be absorbed, while ~4% of light at each wavelength reflected back from UHMWPE surface. However, de-convolution of absorbance curve having goodness of fit value >98% showed five main absorption peaks at 390 nm, 460 nm, 500 nm, 532 nm and 632 nm, respectively. The absorption peaks at 390 nm and 460 nm belonged to the strong absorption at surface of UHMWPE due to lower penetration depth at these wavelengths, and the peaks at 532 nm and 650 nm might be due to Raman active bands of PE. In addition, maximum collimated transmittance and almost negligible diffuse transmittance of reference signal showed that scattering was total forward directed which revealed the anisotropic nature of UHMWPE.

1. Introduction

Ultra-High Molecular Weight Polyethylene (UHMWPE), articulating against metal/ceramic head has been the most acceptable and reliable bearing couple in total hip replacement for over five decades. The efforts are still going over to enhance the mechanical properties of UHMWPE either by chemical means or by using high energy radiations to have long lasting implants with longer service life (Mehmood et al., 2013a, 2013b; Shafiq et al., 2013).

Although surface and depth modification of UHMWPE can be made using high energy radiations such as γ-rays, e-beam, etc. (Mehmood et al. 2014; Shafiq et al., 2013) but using the high power laser or broad band light sources (for aforementioned purpose) can never be ruled out (Ullah et al., 2010). The dependance of penetration depth on wavelength of incident light is an important fact and can be used for UHMWPE modifications up to certain depth. However, reported literature on the optical properties (absorption coefficient, scattering coefficient, anisotropic factor, refractive index, and penetration depth) of UHMWPE is quiet limited, according to our knowledge, and need to be explored further.

The current study aims at investigating the light distribution in UHMWPE which includes finding out absorption, scattering and total attenuation of light over the spectral range of 400–800 nm using Double integrating sphere (DIS) setup. The penetration depth as a function of wavelength, and anisotropic nature of UHMWPE over the aforementioned wavelength range has been discussed on the basis of experimental results.

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2. Material s and methods

A commercially available medical grade of UHMWPE (GUR 1020 provided by Ticona) was in used in compression molded sheets of micron size thickness. The molding was done using hot press available at PIEAS (Islamabad, Pakistan). All samples were stored at room temperature, and washed with acetone to remove impurities from surfaces before measurements. For holding each sample of micron size thickness in DIS, an aluminum sample holder was manufactured at mechanical workshop of PIEAS with a hole of 0.09 m diameter at center.

Fig. 1 illustrates the experimental setup used in this study. Briefly, DIS setup consists of two spheres (incident and measurement spheres) of 300 mm internally coated with barium sulfate ($BaSO_4$) to integrate maximum light. For light, halogen source is directly coupled to incident sphere through single mode optical fiber (core diameter 200 μm fiber; length 2 m). Integrated light from incident sphere falls on the micron size sheet placed at sample holder. Detection of collimated transmitted, diffused transmittance was carried out from second sphere (also called as detection sphere) and diffused reflectance was measured from incident sphere (see Fig. 1). For detection, storage and further analysis, optical fiber coupled spectrometer (Avantus Inc. with 600 lines/mm grating and CCD array camera) was used to record experimental data. For each experimental measurement following steps was followed:

- Dark data was measured from port B (see Fig. 1) with port C and D of DIS closed. Note that during this measurement efforts has been made to minimize the contribution from all possible sources of light in lab.
- Reference data was taken by switching the source light on and keeping the sample holder empty.
- Collimated transmitted light (T_c) (intensity of light that passes through the sample without interaction) was measured from port B with sample in holder and closing other ports i.e. C and D.
- To optimize the reference signal integration time of spectrometer was set at 10,000 ms with running average of 10.

3. Results and discussion

Fig. 2(a) shows the experimental curves of dark data, reference data and collimated transmittance data (from UHMWPE sheet), respectively. As it can be seen, dark data is almost negligible because no light enters the sphere, therefore; the detection is almost zero. Reference signal with peak intensity value of 11500 a.u., at 700 nm is found and used as reference for the calculation % collimated transmittance (T_c) as follows:

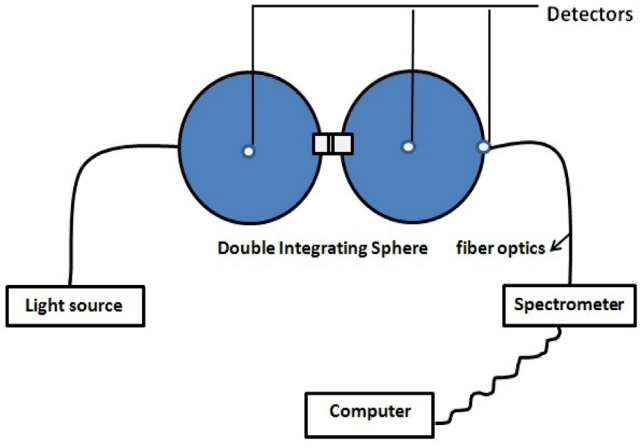

Fig. 1. Double integrating sphere (DIS) for measurements.

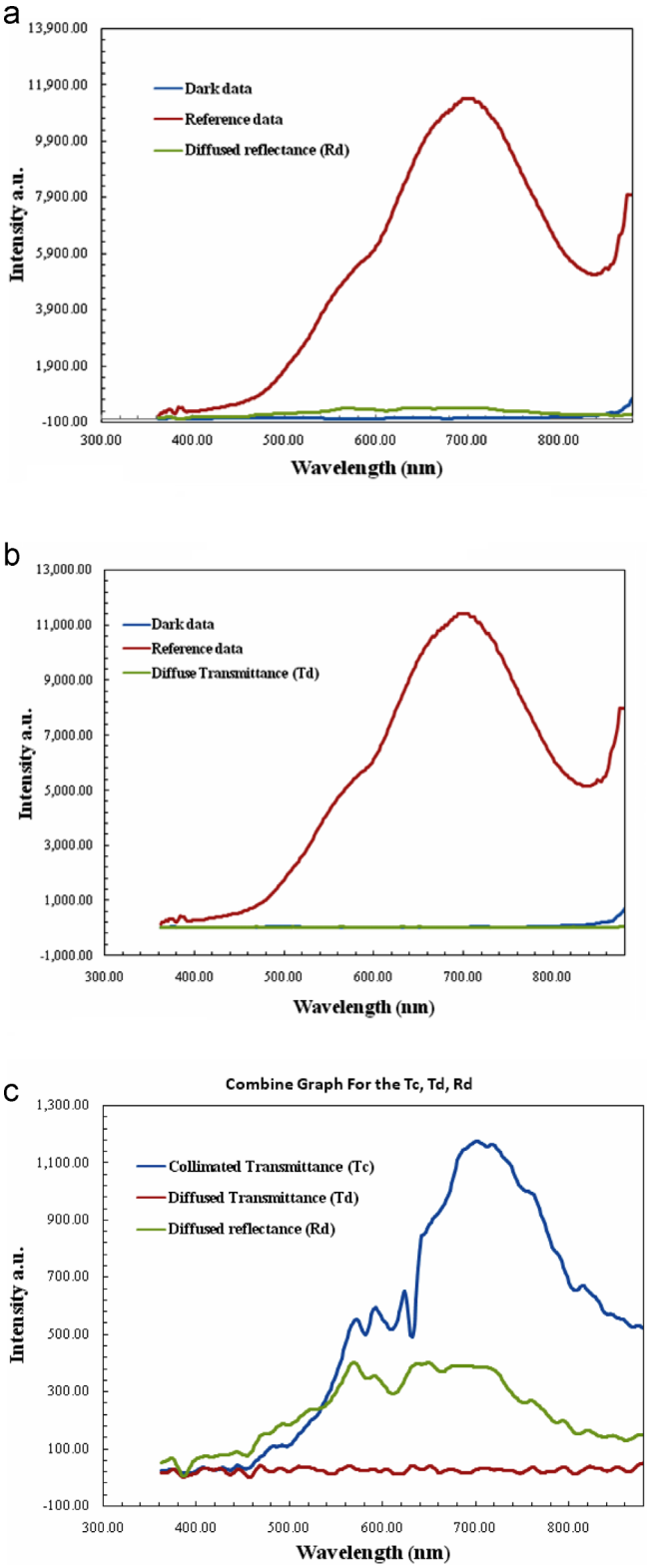

Fig. 2. Measured values of diffuse transmittance (a) and diffuse reflectance (b). All three measurable (c).