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Fabrication and Optical Characterization of Palm Fiber Reinforced Acrylonitrile Butadiene Styrene Based Composites: Band Gap Studies

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Abstract

The composite materials are replacing the conventional materials, owing to their excellent properties. The developments of new materials are on the anvil and are thriving day by day. Natural fiber composites such as palm fiber (PF) polymer composites became more enchanting because of their high specific strength, low weight and biodegradability. Mixing of natural fiber like PF with acrylonitrile butadiene styrene (ABS) polymer is finding increased applications. In this work, PF reinforced ABS composites PF-ABS was fabricated by Injection Moulding Machine. The effect of UV-Visible radiation on PF-ABS composites was studied by means of ultraviolet-visible spectroscopy in the wavelength 200 - 1000 nm at room temperature. The present investigation shows that the addition of palm fiber modifies the absorption property of the materials. The absorption ability is maximal for 10% PF-ABS composites while minimal for 20% PF-ABS composites in the visible region of the spectrum. Optical constant like direct band gap energy, Urbach energy and Steepness parameter were determined using absorbance data. The values of direct energy band gap, Urbach energy as well as Steepness parameter were found to be in the range 2.6 - 3.9 eV, 0.40 - 0.85 eV and 0.03 - 0.06, respectively. It was observed that the value of direct band gap energy as well as Urbach energy is higher while the value of Steepness parameter is lower for PF-ABS composites with 10% palm fiber.

Keywords

Palm Fiber, UV-Visible Spectroscopy, Band Gap, Bio-Degradable

1. Introduction

Natural fiber (NF) as reinforcing agent in polymer composites has generated much attention in recent years for making low cost engineering materials. Manufacturing industries like automotive, construction and packaging company are searching new materials which can replace conventional non-renewable reinforcing materials such as glass fiber due to pressure of new environmental legislation and consumer demand [1] [2] [3] [4]. Good specific strengths and modulus, economical viability, low density, reduced tool wear, enhanced energy recovery, and reduced thermal and respiratory irritation and good biodegradability make natural plant fiber more reliable candidate over traditional glass fiber [5] [6] [7] [8] [9]. Due to excellent thermo-mechanical properties, biodegradability, low density and non-toxicity, composite materials reinforced with natural fiber are extensively used in many fields, namely civil, industrial, military, space craft, and biomedical sector [10] [11] [12] [13]. Natural fibers as like as jute, palm coir, sisal, pineapple, banana, kenaf, ramie, bamboo, and saw dust are used as reinforcement in different polymer, such as polypropylene, polyethylene, unsaturated polyester, acrylonitrile butadiene styrene, PVC, etc to prepare fiber composite [14]-[24]. Palm fiber is one of specific interest among these fibers since palm fiber (Palmyra Palm) is produced substantially all over Bangladesh. Acrylonitrile-butadiene-styrene (ABS) is an engineering thermoplastic terpolymer which is prepared by polymerizing styrene and acrylonitrile in the presence of poly butadiene. ABS has very good mechanical properties, especially high impact resistance and it is used between −20˚C and 80˚C as its mechanical properties vary with temperature [25] [26] [27]. The natural fiber's properties mainly depend on the chemical composition of the fiber. The optical behaviour of the composites can be altered by addition of natural fiber [28] [29]. Natural fiber reinforced polymer composites are also used in optical devices. The optical behaviour of polymer materials can be customized by the addition of some filler, which depends upon its reactivity with the host polymer matrix [30] [31]. A large number of experiments on optical properties of composites have been performed all over the world using Ultraviolet-Visible (UV-Vis) spectroscopy. K. Al-Ammar [32] investigated the optical properties of PMMA-$CrCl_2$ composites. They observed that the absorbance increased with the rise of the concentration of $CrCl_2$. The optical and mechanical properties for PVA-$AgCO_3$ composites were studied by B. H. Rabee [33]. They reported that the absorption coefficient increased while indirect allowed and forbidden energy gap decreased with increase of the weight percentage of silver carbonate content. S. Hadi *et al.* [34] analyzed the optical characteristics of polyvinyl alcohol and lithium fluoride composites and reported that the absorbance decreased while coefficient of absorption, extinction coefficient, and refractive index along with real and imaginary parts of dielectric constant increased with the addition lithium fluoride content. M. Ali *et al.* prepared and investigated the optical properties of polyvinyl alcohol- and poly-acrylic acid-fiber of wheat composites and obtained results indicated that the absorbance of the composites improved while energy band gap reduced with addition of the fiber of wheat concentrations [35]. Optical properties of polymer composites reinforced by natural materials were investigated by A. S. Jasim [36]. The absorbance was found to be decreased with the increasing of wavelength for all types of prepared composites, while increased with the increasing of palm fiber ratio. Keeping these facts in mind, the palm fiber was taken reinforcing agent in this study. This is because palm fiber is available in Bangladesh and is anticipated that it will offer composites having fascinating optical properties. Although citations on the preparation and characterizations of PF-ABS composites are carried out but the amount of studies are very limited and require more insightful analysis. As such this paper seeks a better understanding on the estimation of band-energy sharpness, Urbach-energy and steepness parameter of PF-ABS composites using the UV-Vis absorbance spectral distribution. The physical, structural, morphological, mechanical, electrical and thermal properties of these PF-ABS composites have been cited in our more recent study [25] [26] [27].

2. Experimental

2.1. Raw Materials Collection

Palm leaves were collected from ten different aged trees from Burura, Comilla, Bangladesh. Hammering was done at the dividing ends of the middle rigid part of the palm leaves. Rigid part of the leaves was kept in underwater for 20 days to rotten. Rotten materials were cleaned and fiber were then separated, dried under sun light and kept at around 100˚C for one day for removal of moisture. ABS polymer was purchased from scientific shop old Dhaka, Bangladesh.

2.2. Preparation of Composite

Palm fiber was sliced into 1 - 2 mm in sized. ABS and small palm fiber were dried for 1 day at 50˚C using a dryer. Fined palm fiber and ABS polymer placed into the injection moulding machine. The mixture of palm fiber and ABS polymer was heated at around 150˚C inside the injection molded machine (IMM). The molten mixture became composite and came out of the IMM. This composite was transferred into different shape of die for different test. Composites samples (with 5%, 10% and 20% palm fiber content) were prepared along with pure ABS polymer (0% palm fiber) to accomplish this research.

2.3. Characterization and Properties

UV-visible spectroscopy of ABS and composites (containing 1 - 2 mm long fibers as filler) were performed in absorption mode using Shimadzu UV-1601 spectrometer (Shimadzu Corporation, Tokyo, Japan) in the wavelength range 200 to 1000 nm at room temperature. The composite sample which is a rectangular bar was in the dimension of 105.5 mm × 10.5 mm. Before performing test, the samples were kept in the incubator (Memmart, Model: ICP400) at 50˚C for one day, then removed and cooled in the desiccator. The optical absorption was measured with reference to air.

3. Result and Discussion

The UV-visible spectroscopy is an important powerful experimental technique for identification of various optical transitions in the materials. The optical energy gaps, the allowed direct and indirect transitions and forbidden transitions of optically active substances can be determined from the UV-visible spectroscopy studied for the potential applications such as light guide materials, optical fibers, optical coating to inhibit corrosion, etc.

3.1. Fiber Loading Effect on Absorbance of PF-ABS Composites

The effect of palm fiber loading on the absorbance with respect to wavelength is shown in Figure 1. It is found from Figure 1 that the absorbance of pure ABS rises with the increase of wavelength and becomes higher in the visible region (400 - 700 nm). This indicates that the low energy light absorbs by the pure ABS polymer. It is also observed that the absorption of pure ABS is comparatively lower than that of the PF-ABS composites. The maximum absorbance within PF-ABS composites is found with 10% PF. The increase of absorbance with the rise of fiber content in composites is also found by K. Al-Ammar *et al.* [32].

In the case of PF-ABS composites, at around 200 nm absorbance was around 2.8 unit (for 10% PF-ABS composites). After 190 nm absorbance decrease up to 400 nm (initial point of visible region). After 400 nm, absorbance of PF-ABS composites exponentially increased up to 700 nm. Absorbance is highest at 700 nm for all PF-ABS composites. This reveals that in the UV region with the decrease of energy (with increase of wave length) absorption decreased which means PF-ABS composites transmit UV-ray rapidly. But in visible region with

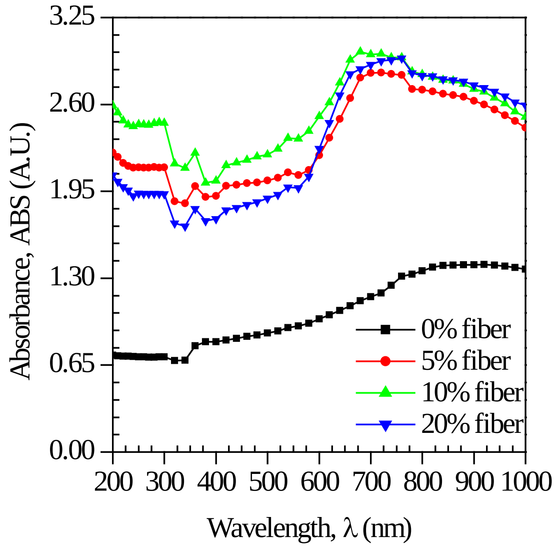

Figure 1. Variation of absorbance with wavelength at different fiber contents.

the decrease of energy (wave length increased) absorbance increased meaning that low amount of visible light is transmitted. However, after visible region (after 700 nm), with decreasing energy absorption decreases while transmittance increases. The average absorbance of pure ABS and PF-ABS composites with respect to wt (%) of palm fiber in composites is summarized in Table 1.

3.2. Effect of Fiber Loading on Optical Band Gap in Composites

Coefficient of absorption (α) is defined as the ability of a material to absorb the light of given wavelength and can be calculated by the Equation (1),

$$\alpha = 2.303\frac{A}{t} \quad (1)$$

where A and t are absorption and thickness of the material respectively.

The absorption coefficient at various photon energies for pure ABS and PF-ABS composites is plotted in Figure 2. The absorption coefficient for pure ABS is lower than that of PF-ABS composites. Palm fiber addition in PF-ABS composite increases absorption coefficient of all composites. Among the three different composites, the absorption coefficient for 10% PF-ABS composites is greater than that of 5% as well as 20% PF-ABS composites. Similar result was found by S. Hadi *et al.* experiment [34].

Table 1. Average absorbance of pure ABS, PF-ABS composites.

Fiber content in composites (%)	Average absorbance
0%	1.157
5%	2.393
10%	2.552
20%	2.447

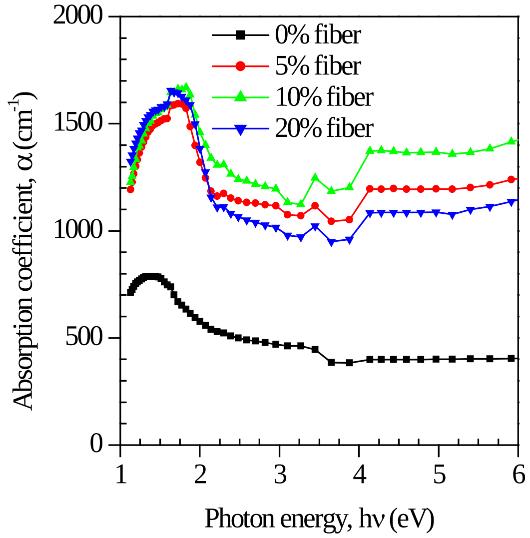

Figure 2. Effect of absorption coefficient on fiber contents of PF-ABS composite at different photon energy.

The optical absorption coefficient was used to determine the band gap energy of the solid polymer composites, using the Tauc relation in the following form [37]:

$$\alpha h\vartheta = R\left(h\vartheta - E_g\right)^S \quad (2)$$

where, R is a constant not connected to the energy, E_g the optical energy band gap and S is parameter that describes the nature of band transition. The value of S = 1/2 and 2 correspond to direct and indirect allowed transitions, respectively while that of 3/2 and 3 indicate direct and indirect forbidden transitions, respectively. The E_g can be estimated from extrapolation of the straight-line part of the $(\alpha h\nu)^{1/S}$ against $h\nu$ graph to $h\nu = 0$. The direct band gap energy (E_{dg}) and indirect band gap (E_{ig}) was computed from the plots $(\alpha h\nu)^2$ against $h\nu$ and $(\alpha h\nu)^{1/2}$ against $h\nu$, respectively which are shown in **Figure 3** and **Figure 4**. From **Figure 4**, it can be found that the investigated samples have no indirect band gap. The

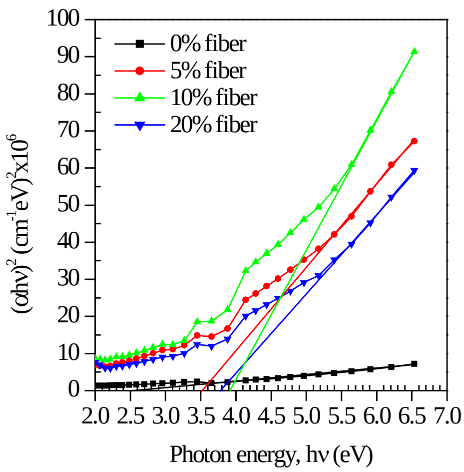

Figure 3. The plot of $(\alpha h\nu)^2$ vs $h\nu$ for different fiber contents of PF-ABS composite at various photon energy.

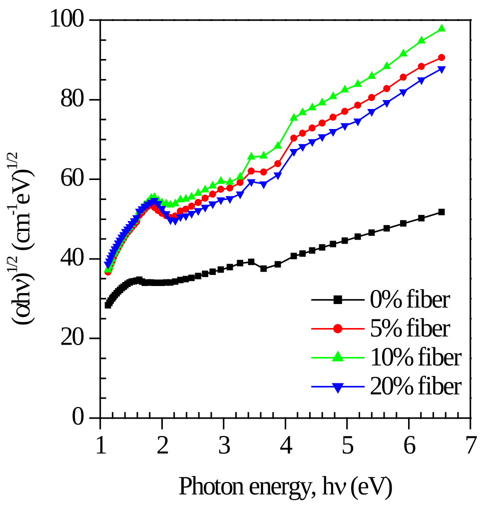

Figure 4. The plot of $(\alpha h\nu)^{1/2}$ vs $h\nu$ for different fiber contents of PF-ABS composite at various photon energy.

obtained values of E_{dg}, are noted in **Table 2**. The direct band gap energy values for pure ABS, PF-ABS composites are in the range of 2.6 - 3.9 eV. It is observed that direct band gap energy is maximum for 10% PF-ABS composites while minimum for pure ABS.

3.3. Urbach Energy and Steepness Parameters of PF-ABS Composite

Generally, the spectral reliance of α is investigated in the region of the photon energies under energy gap of the materials. This region is termed as Urbach spectral tail which indicates the gradient of the exponential edge. The relation between α and photon energy (E) in the Urbach spectral tail region can be expressed as [38],

$$\alpha = \alpha_0 \exp\left(\frac{E}{E_u}\right) \tag{3}$$

where a_0, E_u are a constant and Urbach energy respectively. The E_u can be worked out as the tail of the exponential absorption edge or as the breadth of the tails of localized states. The graph obtained by plotting lnα against $h\nu$ should be linear whose gradient gives the value of E_u. The lnα vs $h\nu$ plots for pure ABS and PF-ABS composites are represented in **Figure 5** and the estimated values of E_u are recorded in **Table 3**. It is observed that the value of E_u, is maximum for 10%

Table 2. Direct band gap energy of pure ABS, PF-ABS composites.

PF-ABS composites (% of palm fiber)	Direct Band Gap (eV)
Pure ABS (0% fiber)	2.6
PF-ABS composites with 5% fiber	3.5
PF-ABS composites with 10% fiber	3.9
PF-ABS composites with 20% fiber	3.8

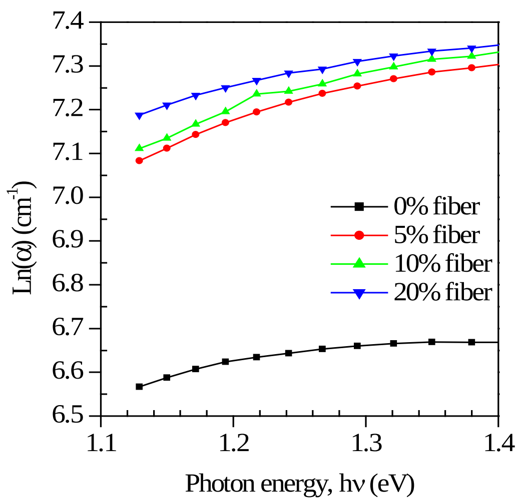

Figure 5. The plot of Ln(α) vs $h\nu$ for different fiber contents of PF-ABS composite at various photon energy.

PF-ABS composites and minimum for pure ABS. The steepness parameter (σ) that represents the expansion of the optical absorption end because of interaction of electron phonon or exciton-phonon [39], could be computed with the following relation,

$$\sigma = \frac{kT}{E_u} \tag{4}$$

where k and T are Boltzmann constant and absolute temperature, respectively. In calculation of σ in this study, the value of T was 300 K. The calculated values of σ are tabulated in Table 3. It can be noticed that the value of steepness parameter is maximal for pure ABS while minimum for 5% as well as 10% PF-ABS composites.

3.4. Extinction Co-Efficient of PF-ABS Composite

The value of α as well as λ can be used to find the values of extinction coefficient, K by using the simple equation [39],

$$K = \frac{\alpha\lambda}{4\pi} \tag{3}$$

The variation of K for pure ABS and PF-ABS composites with respect to wavelength of the UV-visible light spectrum is shown in Figure 6. In each case of

Table 3. Urbach energy and Steepness parameter for pure ABS, PF-ABS composites.

Wt (%) of palm fiber in composites	Urbach energy, E_u (eV)	Steepness parameter, σ
Pure ABS (0% fiber)	0.40	0.06
PF-ABS composites with 5% fiber	0.84	0.03
PF-ABS composites with 10% fiber	0.85	0.03
PF-ABS composites with 20% fiber	0.61	0.05

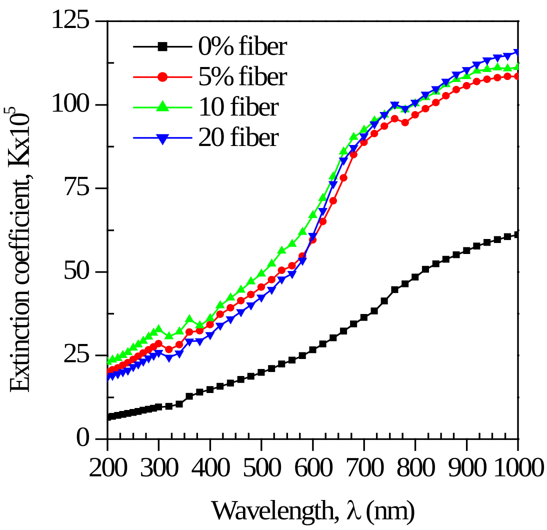

Figure 6. Variation of extinction coefficient with wavelength for pure ABS and PF-ABS composites.

5%, 10% and 20% PF-ABS composite samples, total ten samples from two age groups were taken for extinction co-efficient calculation. The extinction co-efficient of PF-ABS composites is much higher than the pure ABS. The extinction co-efficient increased slightly with the addition of palm fiber in PF-ABS composite. Similar result was found in PVA-LiF composite by S. Hadi *et al.* [34].

4. Conclusion

The UV-visible properties of pure ABS as well as PF-ABS composites were investigated using UV-visible spectrometer. The result indicates that addition of palm fiber modifies absorption property of composite materials. The absorption ability is enhanced for 10% PF-ABS composites. The direct band gap energy varies at 2.6 - 3.9 eV. The highest direct band gap energy is obtained for 10% PF-ABS composites. The values of Urbach energy and Steepness parameter vary at 0.40 - 0.85 eV and 0.03 - 0.06 eV, respectively. Maximum Urbach energy is observed while minimum Steepness parameter is for 10% PF-ABS composites. The extinction coefficient of PF-ABS composites is greater than that of pure ABS polymer matrix.

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