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CRITICAL ANGLE ESTIMATION OF LIGHT IN PLANTAIN FIBRES

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ABSTRACT

Whenever light passes from one medium to another, a small portion is always reflected back into the first material. Also, fibres in plantain pseudo-stems are natural fibres, which suffer from thinning, non-uniformity of fibre circumference, knots and other imperfections along their lengths. These are in addition to the plantain fibre characteristics of dispersion, bandwidth, attenuation, equilibrium mode distribution and numerical aperture. Using Snell's law, refractive index and velocity of light, the critical angle of light in plantain fibres was estimated. The results showed that the critical angle was approximately 35.26^{o} and Fresnel reflection was approximately 0.072. It is also known that if the rays of light propagated in the plantain fibres are less than the critical angle of the plantain fibre core, the rays of light are confined to the core. It is this property of light rays confinement in fibre core that lend themselves to applications in optical communication systems. Consequently, the optical properties derivable from plantain fibre critical angle determination, and with proper modifications and manufacture, could find applications in pulse propagation, optical interconnections in microelectronics, optical computing, photonic switching, analogue optical computing, artificial intelligence and associated memory operations in neural networks. It is, strongly recommended that further research be carried out on the optical properties of plantain pseudo-stems fibres that would enable us derive more benefits in their application, than is currently the case.

Keywords: Critical angle, fresnel reflection, light, plantain fibres.

INTRODUCTION

Although light could be used to transmit data, voice and video, many parts of the electromagnetic (EM) spectrum are used for communication (Leven, 1998). Similarly, both the visible and infrared portions of spectrum are used for optical fibre transmission. Furthermore, light as a wave is known to exhibit reflection and refraction phenomena at the surfaces of differing materials with different optical densities (Morton, 1971). Invoking Snell's law and using the results of Asemota (2010), for the velocity of light and refractive index of plantain, it is, therefore, simple to obtain the critical angle. In general, for optical communication, particle physics is involved in optical transmitters and receivers, while wave physics is considered inside the fibre. Consequently, these concepts are better understood using the principle of wave-particle duality (Gatreau and Savin, 1978; Leven, 1998).

Natural fibres are defined as bio-based or fibres from vegetable and animal origin. This definition involves all natural cellulosic fibres like cotton, jute, flax, hemp, abaca (plantain or banana) and protein based fibres like wool and silk. Synthetic fibres like viscose-rayon and cellulose acetate are produced from pulped wood or other sources using chemical procedures. Similarly, polymer fibres like bio-polyester, PHA, PLA and chitosan are semi-synthetic products developed from renewable sources (Van Dam, 2008). The issues of escalating costs and the need to drive down operational costs for profitability, growth and operational efficiency in the transportation industry has made the reinforced plastics and other composites produced from fibres to become increasingly used. Therefore, the characteristics of light weight composite fibre structures reduce fuel consumption and also increase payload. The shape and fibre consistency of fibre glass for example, have been known to bring about the advantages of dry winding, which uses a higher winding speed that is not limited by centripetal forces on the wet resin required for firm fibre binding (Van Rijswijk *et al*., 2003).

Further, natural fibres are usually elongated substances produced by plants and animals, which can be spun into filaments, threads and ropes. They can also be woven, knitted, matted and bonded to form fabrics and other materials, which are useful to society (FAO, 2009). While fabrics manufacturing methods have changed significantly since antiquity, their functions have changed, very slightly. This is so because most natural fibres are still used for clothing, containers, insulation, soften and decorate our living spaces. However, traditional textiles are being used in industrial purposes as well as in components of composite materials, medical implants and for geo- and agro-textiles (FAO, 2009). Furthermore, studies on the use of natural fibres as replacement to

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synthetic fibres in reinforced composites have increased and opened up a flood-gate of industrial possibilities. The advantages of natural fibres in composites are low density, low cost and biodegradability, while the disadvantages are poor compatibility between fibre and matrix coupled with the relatively high moisture sorption (Xue *et al*., 2007). Therefore, chemical treatment of fibre improves the adhesion capacity between fibre surface and polymer matrix, modifies fibre surface and increases its strength (Xue *et al*., 2007).

Natural fibres have significant advantages over glass as an alternative fibre reinforcement material. They are environmentally more user friendly, healthier, safer and cause less wear on processing equipment. Nevertheless, their mechanical properties show a large scatter and at best equivalent to glass, coupled with their moisture sensitivity that predisposes them to swelling and rotting, which make them to smell (de Bruijn, 2000). Furthermore, experiments with natural fibre mat thermosplastics (NMT) to automotive products have yielded several new research themes regarding property limits and exactly where to optimise so as to obtain a broad spectrum of application areas (de Bruijn, 2000). Knots are inherent in natural fibres and tend to weaken and break just before or outside the “entrance” to the knot. Knots also affect the mechanical properties of polymers and are highly probable in any long polymer strand. Fragments of DNA have also been observed to contain knots, which weaken the strand significantly, and that, like a knotted rope, breaks under tension at the entrance to the knot (Saitta *et al*., 1999). Whenever a knot is tied, the fibres become bent, stretched, squeezed and broken. This procedure ultimately weakens the strength of the rope. Knots are rated by percentages of how much havoc they cause on the overall strength of the rope. Some knots weaken a rope by 20% and some, 50% (Machovec.com, 2010).

Recent developments in the use of natural fibre composites for technical applications were driven by: (a) price, (b) weight reduction and (c) marketing (processing of renewable resources) rather than technical demands (Brouwer, 2004). As a result, (a) low specific weight, (b) renewable sources, (c) production with low investment at low cost, (d) friendly processing- no tooling wear or skin irritation, (e) thermal recycling possibility and (f) good thermal and acoustic insulating properties, are the strong points for natural fibres (Brouwer, 2004). Conversely, lower impact strength, variable quality that is dependent on weather, moisture absorption (swelling), restricted maximum processing temperature, lower durability, poor fire resistance and price fluctuation that depends on harvest results or purely based on agricultural politics, remain the natural fibres use, weaknesses (Brouwer, 2004).

Equilibrium mode distribution (EMD), is a condition in which a multimode fibre after propagation for a certain distance called the equilibrium length, the relative power distribution among modes becomes statistically constant and remains so for the course of its further propagation down the fibre (FS-0137C, 1996). In practice, the equilibrium length may vary from a fraction of a kilometre to more than a kilometre. In addition, after the equilibrium length has been traversed, the numerical aperture of the fibre’s output is independent of the numerical aperture of the optical source. This is so because both the mode coupling and stripping are caused primarily by small perturbations in the fibre geometry, which result from manufacturing and cabling processes (FS-0137C, 1996). Analogously, the EMD can be thought of as a condition in which the “outermost” rays in the fibre core are stripped off by microbends and only the “inner most” rays continue to propagate (FS-0137C, 1996).

Other problems associated with natural fibres like those of plantains are dispersion, attenuation and bandwidth. Dispersion can be defined as the scattering or the spreading out of light rays due to different refrangibility or non-uniformity of refractive indices displayed by that material.

Quartz, halogen or xenon arc lamps with interference filters were once popular broadband sources. The filters were supposed to have a bandpass, which approximates the output of the source to be used in the proposed system to better account for wavelength-dependent fibre characteristics like numerical aperture, attenuation and dispersion (Fiber-Optics.info, 2010). Today, the information revolution is fuelled by bandwidth (or online accommodation), just as the industrial revolution was fuelled by oil and other alternative energy sources. Since all kinds of businesses presently depend on one form of connectivity or another for their very existence, they cannot, therefore, afford to either abandon the internet or stop using phones as their prices rise. This is especially so because online access has become an everyday utility that the modern man uses for everything from shopping, entertainment and transportation to banking (Marshall, 2008) and even, governance. Most importantly, Marshall (2008) surmises, that all our online connections are under the control of a small number of producers, whose aim is to maximise profits. Moreover, the above behaviour is mostly often incompatible with the public good.

Multimode optical fibre is usually sold with a bandwidth specification in MHz*km, which is a frequency measurement normalised against the measured length. While manufacturing measurements are made on fibre lengths up to 17.6 km, the fibre is most often used in network link lengths shorter than 300 m (Bell *et al*., 2005). Three bandwidth measuring techniques were considered to ensure bandwidth-length uniformity, which is increasingly vital for today's ultra-high performance multimode fibres designed for bit rates of up to 10 Gb/s. The techniques are: (a) overfilled launch bandwidth (OFL BW) for legacy LED-based systems, (b) restricted mode launch bandwidth (RML BW) for intermediate performance VCSEL-based systems, and (c) minimum calculated effective modal bandwidth (minEMBc) for high-performance VCSEL-based systems (Bell *et al*., 2005).

Data are the products and also the byproducts of the information age. They are being generated, processed and stored at exponential rates. Storage area networks (SANs) have become the infrastructure of choice for networking, transporting and storing data traffic. As a result, network congestions and input/output bottlenecks will be and will continue to be the challenges confronting many Information Technology managers, both today and in the future. Therefore, leveraging the capabilities of 8 Gb/s or higher Fibre Channel technologies, can alleviate congestion and increase network band to enterprises that require the needed support to accommodate their expected increases in data traffic. Furthermore, technological innovations, regulatory frameworks, transformations in digital entertainment data retention technologies and compliance requirements, coupled with data retention needs have all become the demand drivers for network and bandwidth performance, today (Gamara, 2008).

The purpose of this work is to study the critical angle and Fresnel characteristics of plantains fibres, using the simple theoretical method of critical angle measurements, which depend on the already determined refractive index of plantains pseudostems (Asemota, 2010), as shown in figure 1.

However, plantain fibres (abaca), which was once a favoured source of ropes, now shows promise as an energy-saving replacement for glass fibres in automobiles (FAO, 2009) and other applications to be discussed in this work.

MATERIALS AND METHODS

In this paper, plantain pseudostems were used as the materials for the study of critical angle estimation of light in plantain fibres. Extensive literature search and review, coupled with elementary wave equations, Snell's law, refractive index and velocity of light in plantains as determined by Asemota (2010), were also used to estimate the critical angle in plantains pseduostem fibres.

The simple theoretical critical angle method was employed for estimating plantains fibre critical angle in this study mainly because incident beam of light collects to form a common beam illuminating the internal surface of the plantains fibre unit. At small angles of incidence, diffraction orders can be observed. But, whenever the angle of incidence reaches the critical angle of the plantain fibre, the diffraction pattern disappears (Kasarova *et al*., 2009).

It is therefore, hypothesised that the critical angle for plantains fibres is close to that of thin polymer films (Kasarova *et al*., 2009), glasses (Zhao *et al*., 2008), gemstones (Anthony, 2010) and organic-inorganic hybrid materials (Su and Chen, 2008).

Wave Model

The relationship between the wavelength (λ) and frequency (υ) of electromagnetic radiation is based on the following formulae, where *c* is the speed of light in vacuum, n_p and u_p are the refractive index and velocity of light in plantains, respectively (Morton, 1971; Gatreau and Savin, 1978; Saleh and Teich, 1991; Leven, 1998; Asemota, 2010):

$$c = \lambda \nu \quad (1)$$

$$\nu = \frac{c}{\lambda} \quad (2)$$

$$n_p = \frac{c}{u_p} \quad (3)$$

Both the reflection and refraction relationships of light at the different interfaces of air and plantains pseudostems are explored in the subsequent section.

Reflection and Refraction

The refractive index for plantains fibres is given by equation (3), where n_p and u_p, are the refractive index and velocity of light in plantain, respectively (Morton, 1971; Gatreau and Savin, 1978; Saleh and Teich, 1991; Leven, 1998; Asemota, 2010).

From Snell's law,

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \quad (4)$$

where n_1 and n_2 are the refractive indices of two different light transmitting materials, while $\theta_1$and θ_2 are angles of reflection and refraction, respectively.

The critical angle at which total internal reflection occurs is given by,

$$\theta_c = \arcsin\frac{n_2}{n_1} \quad (5)$$

If n_2 is the refractive index of air, then the critical angle expression becomes,

$$\theta_c = arcSin\frac{1}{n_p} \quad (6)$$

Also, whenever light passes from one index to another, a small portion is always reflected back into the first material. These reflections are known as Fresnel reflections. A greater difference in the indices in the materials results in greater portions of the light reflecting. Consequently, the Fresnel reflection is given by Saleh and Teich (1991),

$$P = \left(\frac{n-1}{n+1}\right)^2 \tag{7}$$

Upon substituting values as estimated by Asemota (2010), $n_p = 1.732122502$, then the critical angle for plantain fibres become,

$$\Theta_{cp} = \sin^{-1}(1.0/1.732122502) = 35.26^0 \tag{8}$$

Similarly, the Fresnel reflection for plantain fibres becomes (by substituting value of n_p)

$$P = ((1.732122502 - 1)/(1.732122502 + 1))^2 = 0.072 \tag{9}$$

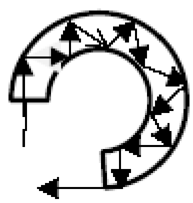

Fig. 1. Critical angle illustration and total internal reflection in plantain pseudostem fibre.

RESULTS AND DISCUSSION

The critical angle of light in plantains was estimated to be about 35.26° and the Fresnel reflections was about 0.072. The critical angle occurs at the point of total internal reflection, where the angle between the refracted and the normal in the less dense medium is 90°. Therefore, whenever the rays of light propagated in the plantains fibre are less than the critical angle of the plantains fibre core, the rays are confined to the core. It is this property of light rays confinement in plantains fibre core that lend themselves to applications in optical communication systems. Although there are three fibre types, namely: (a) Multimode step-index fibre, (b) Multimode graded-index fibre and, (c) Single-mode step-index fibre, fibres generally, exhibit dispersion, bandwidth, attenuation, equilibrium mode distribution and numerical aperture (Morton, 1971; Saleh and Teich, 1991; Norman *et al*., 1996; Leven, 1998; Lerner, 2004).

It should be realised that the refractive index of plantains fibres, which was determined as 1.732 by Asemota (2010), makes its properties and application areas similar to other materials. Unlike for plantain fibres, the refractive index of the eye cornea of Cybister (Dytiscidae: Coleoptera) decrease from the central layer from 1.724 to about 1.561 at the periphery. For the typical dark-adapted position, the field of view was 38^0 wide and only 18^0 wide in the light-adapted position of the distal pigment (Meyer-Rochow and Horridge, 1973). These values could reduce due to the crystalline tract through which the light must pass (Meyer-Rochow and Horridge, 1973). The refractive indices of five thin films deposited from polymers, for which different thicknesses were measured in (Kasarova *et al*., 2009). The polycarbonate refractive index varied between 1.595 and 1.599, while those for Copolyester B also varied between 1.562 and 1.649. Similarly, the refractive indices for Polyarylate varied between 1.603 and 1.656, while those for Polyester varied between 1.492 and 1.508. In addition, Copolyester A's refractive index varied between 1.510 and 1.538. Interestingly, the above five thin films have their respective critical angles (Kasarova *et al*., 2009), larger than that obtained for plantain pseudostem fibres in this study.

A group of rather uncommon gemstones: the Epidote group-Epidote, Allanite (Orthite), Clinizoisite. Hankockite and Piedmontite (Anthony, 2010), had their refractive indices between 1.718 and 1.830. Specifically, Epidote has double refractive indices of between 1.733 and 1.768, with a varying birefringence of 0.015 to 0.049. Allanite (Orthite), on the other hand has a wide birefringence of between 0.013 and 0.036, caused by a spread of the refractive indices of the biaxial substance from between 1.640 and 1.828 (Anthony, 2010). Biaxial Clinozoisite possesses the lowest birefringence of between 0.005 and 0.015 and a refractive index range of between 1.670 and 1.734. While Hankockite exhibits birefringence of 0.042 and refractive index range of between 1.788 and 1.830, Piedmontite on the other hand exhibits the greatest birefringence of between 0.025 and 0.073, with a refractive index range of between 1.732 and 1.829 (Anthony, 2010). It can be seen that Epidote group of gemstones exhibit critical angles close to that of plantain fibres determined in this study.

Su and Chen (2008), prepared a photosensitive high-refractive-index poly(acrylic acid)-graft-poly(ethylene glycol methacrylate) nanocrystalline Titania hybrid films with patternability attributes. The refractive indices of the prepared hybrid films were in the range from 1.528 to 1.803 as the titania content increased from 5.6 to 61.9 wt.-%. Also, the titania domain size must be well controlled to less than 40 nm to avoid scattering loss and retain their optical transparency (Su and Chen, 2008). This condition of controlling a specified factor in plantain pseudostems fibres being a natural fibre so as to avoid scattering and to consequently, retain their optical transparency, is either presently unknown or a project for further research. In addition, we may apply other chemical treatments natural fibres like plantain fibres, are presently exposed to in order to retain their fresh and natural optical characteristics.

High-order Bragg reflectors were used in optical fibres to mask image projection with a single pulse exposure excimer laser. While the effective refractive index was 1.4588 ± 0.019, the peak Fresnel reflectivity was approximately 72 % (Mihailov and Gower, 1994). Fortunately, the Fresnel reflectivity determined in this study for plantains pseudostems fibres was about 7.2 %. It therefore, follows that the near field interference (Fresnel diffraction) for plantains pseudostems fibres reflectivity, determined in this work is at least ten (10) times smaller than those of glass optical fibres.

There are three kinds of fibre insertion loss: (a) fibre-related loss, (b) connector-related loss and systems factors that contribute to loss. Therefore, the ideal interconnection should be for two fibres that are optically and physically identical, which are held together by a connector or splice that squarely aligns them on their central axes (Fiber-Optics.info, 2010). But Fresnel reflection loss occurs whenever some connectors hold two fibres slightly apart so as to prevent the fibres from rubbing against each other and damaging their end polishes. Fresnel reflection loss or end separation loss is caused by the differences in the refractive indices of the two fibres in contact and the air that fills the gap between these two fibres. While Fresnel reflection can be as much as -11 dB in a single mode interconnection with a flat end finish, this loss can be reduced by rounding the fibre end of one fibre during polishing (PC or physical contact finish) (Fiber-Optics.info, 2010). In addition, the -11 dB loss is sufficient to disrupt the operations of most lasers. So, with a rounded finish, fibres always touch on the high point near the light-carrying fibre core.

CONCLUSION

The fibres in plantain pseudostem are natural fibres, which equally suffer from thinning, non-uniformity of fibre circumference, knots and other imperfections along their lengths. These are in addition to the fibre characteristics of dispersion, bandwidth, attenuation, equilibrium mode distribution and numerical aperture (Morton, 1971; Leven, 1998; Saleh and Teich, 1991; Norman *et al.*, 1996; Leven, 1998; Lerner, 2004).

Be that as it may, the uses to which optical fibres can be put; are simply enormous and new application areas are constantly unfolding. Arguably, the energy-saving advantages of plantain fibres (abaca) over glass as optical fibres alternative (FAO, 2009), demonstrates great promise.

Increased demands and the need for more bandwidth for telephone calls which were essentially carried as electrical signals along copper wire cables, necessitated optical fibre networks systems being brought to the rescue of carrying the volume of information (data, voice and video) required to be transmitted over large distances.

As a result, more signal regenerators coupled with their complicated and expensive electronic circuitry were needed, which also had difficulties of being able to service these astronomically increased demands for bandwidth for billions of people on the Earth's surface.

Therefore, optical fibres offered an extensive communications capacity, because a single optical fibre can carry the conversations of every human being on the planet, twice over at the same time (Harte and Eckard, 2006; FAO, 2009; Tinkquest.com, 2010). The advantages of optical fibres over copper cables are: (a) ability to carry much more information, (b) fewer boosters, (c) no electrical interference, (d) can be used in explosive environments, (e) cheaper and thinner for equal capacity, (f) easier to install and maintain (Harte and Eckard, 2006; FAO, 2009; Tinkquest.com, 2010).

Low loss and high bandwidth make optical fibres useful as submarine communications links. Keyhole surgery has developed as a new branch in medical technology by being able to illuminate internal body organs for microsurgical procedures (Laparascopic surgery) (Harte and Eckard, 2006; FAO, 2009; Tinkquest.com, 2010). Interior and outdoor lighting can also be carried out using optical fibre technologies. They are also used as sensors and in telemetry systems. Distributed sensors are especially useful because data measurements can be conducted at different points along the fibre length and also, able to determine those different measurements to which each relates (Harte and Eckard, 2006; FAO, 2009; Tinkquest.com, 2010).

In addition, fibres provide flexible and safe methods for distributing high power lasers around installations so that robots and machine tools can be equipped with laser machining capabilities. They can also be used as simple light guides and for operations of optical systems like synchronous optical network (SONET), Synchronous digital hierarchy (SDH), fibre distributed data interface (FDDI), passive optical networks (PON) and dense wave division multiplexing (DWDM) (Harte and Eckard, 2006; FAO, 2009; Tinkquest.com, 2010).

Consequently, the optical properties derivable from plantain pseudostems critical angle determination, and with proper modifications and manufacture can find applications in pulse propagation, optical interconnections in microelectronics, optical computing, photonic switching, analogue optical computing, broadband signal processing, radar signal processing, image processing and machine vision, artificial intelligence and associated memory operations in neural networks, parallel computing, optical transmitters, modulation, multiplexing and coupling, and coherent and incoherent optical communications.

It is, however, strongly recommended that further research be carried out on the optical properties of plantain pseudostems fibres that would enable us derive more benefits in their application, than is currently the case.

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