CHAPTER VI
OPTICAL STUDY

6.1 Abstract

The polymer optical fiber is an optical waveguide. Total internal reflection is the principle to to keep the light in order to travel along the fiber. The optical fibers in this work are made from the polycarbonate (PC) core with PASE/PMMA cladding. The produced fibers were measured the optical properties. The attenuation was measure by cut back method. The attenuation of fibers is difference. It depends on the cladding thickness and quality of processing. The numerical aperture of all fibers is not so much different that is about 0.8. The maimum operating temperatures are higher than 100 $^{\circ}$C. It depends on core size and cladding thickness.

6.2 Introduction

Fiber optic transmission and communication are technologies that are constantly growing and becoming more modernized and increasingly being used in the modern day industries. The basic parameters of optical properties are fiber attenuation and numerical aperture. Dispersion, absorption, and scattering are the three properties of optical fibers that cause attenuation, or a maked decrease in transmitted power, and therefore, have limited progress in areas of high-speed transmission and signal efficiency over long distances. Numerical aperture (NA) determines the light gathering power of an optical fiber. A high numerical aperture increases the amount of dispersion as rays at different angles have different path lengths and therefore take different times to traverse the fiber. As the PC usually used at high service temperature application (Zubia, J. *et al.*, 2001 and Martijn, A.E. *et al.*, 2008) thus the maximum operating temperature is the properties that should be considered. Bending of optical fibers causes loss of optical power, and reduces its performance. So the exact modeling of bending loss is very important for designing communication systems and optical instruments. It is well-known that loss increases with bending (Zendeham A. *et al.*, 2010).

This chapter describes the study of optical properties of plastic optical fibers made of PC core and PASE/PMMA claddings.

6.3 Experiment

The fiber attenuation, numerical aperture (NA) , maximum operation temperature, and allowable bending radius were measured by 633 nm red light source.

Attenuation or optical loss was characterized by cut-back method; the experimental set-up is shown below. The 80 cm length fiber was measured the power output (P_0) first. Then the fiber was cut to 50 cm and measured the power output (P_I). Since power was measured as a voltage so the attenuation was obtained from the following equation;

$$Attenuation\ coefficient = \frac{20}{L-x} \cdot \log \frac{V_o}{V_I} \qquad \text{dB/m}$$

The numerical aperture was estimated from the width of light shone on the background. The red light shone through a 50 cm length fiber. A distance between the detector and the end of fiber is 1 cm. then changing the detector position on a left and a right side until the voltage output is zero and determining the distance from the left to the right. The calculation of NA is shown as follow;

$$NA = \sin\left(\arctan\left(\frac{d/2}{D}\right)\right)$$

Bending loss was determined the power loss while fibers were bended at difference radius. A 30 cm length fiber was measured power output ($P_{straight}$) first. Then the fiber was bended beginning from the biggest radius to the smallest; 10, 7.7 and 5.8 cm. The power output (P_{bend}) in each diameter was reported and calculated as below equation.

$$Optical\ loss = 10 \cdot \log \frac{V_{bend}^2}{V_{straight}^2}$$

The operating temperature was evaluated by the maximum temperature at which the intensity of the emitted light is reduced by 10% from that at room temperature (25 ^{0} C). A 20 cm fiber length was used, the 10 cm heating tube was place in the middle to the end of fiber. The temperature when the power reduced by 10% from that at room temperature was then reported.

6.4 Results and Discussion

6.4.1 Attenuation

The attenuation of fibers was characterized by cut-back method. The 80 cm length fiber was measured frist. Then the fiber was cut to 50 cm. These length is far enough to avoid the cladding mode effect which occured at the near light source region having high power of light. The attenuation of fibers is difference as show in the Table 6.1. The qualitity of processing and cladding thickness are effect to the optical loss of the fiber. The 10% PASE/PMMA-cladding type fiber at 20 rpm draw ratio and 24.5 mm/min of piston speed has the lowest attenuation—2.606 dB/m because it's shape is very good either concentric shape and good interface between core and cladding as same as 25% PASE/PMMA cladding (attenuation = 3.766) at the same processing parameter and 20% PASE/PMMA-cladding (attenuation = 2.930) (see the fiber's dimension in the figure 6.1). 20% PASE/PMMA-cladding type fiber has the attenuation equal to 14.653. This optical loss might come from nonclearly boundary of core and cladding, therfore total internal reflection is not perfectly. For 20 mm/min fibers; 25% PASE/PMMA of free falling and 20% PASE/PMMA of 20 rpm draw ratio, they have high optical loss (attenuation; 14.783 and 9.851, respectively) because they have bubble at the interface of core and cladding as the research of Ma H. and cowerker (2002). They reported that the bubble is the cause of scattering effectively which is the main cuase of lossing of light. Furthermore, if it is greater than 1 μm in diameter, in which case the scattering intensity is largely wavelength independent. For a waveguide, a loss of 0.03 dB/cm can be achived by reducing the roughness of the cladding and core interfaces to 0.04 μm. In this work, the results indicate that the quality of fiber shape has the influence on the attenuation more than the composition of PASE in the cladding. However, PMMA-cladding type fiber which was used to be the reference of cladding type has the attenuation higher than all of PASE/PMMA-cladding type fiber. It cannot measure the attenuation at the same length as another claddings which were measure at 80 cm and then cuting to 50 cm. The experiment of PMMA-cladding fiber was set up at 50 cm first, then it was cut to 30 cm because at 80 cm, the detector cannot detect the through light at the end of the fiber. However, the fibers in this work have the attenuation higher than other research. Thus the attenuation is able to reduce by the manufacturing process which should make fiber well in shape without bubble inside (Cai *et. al*, 2003 and Zubia J. *et. al*, 2001). In other words, the uniform coating thickness of the cladding material enhances the attenuation and this effect becomes very important for our case due to the thin cladding thickness.

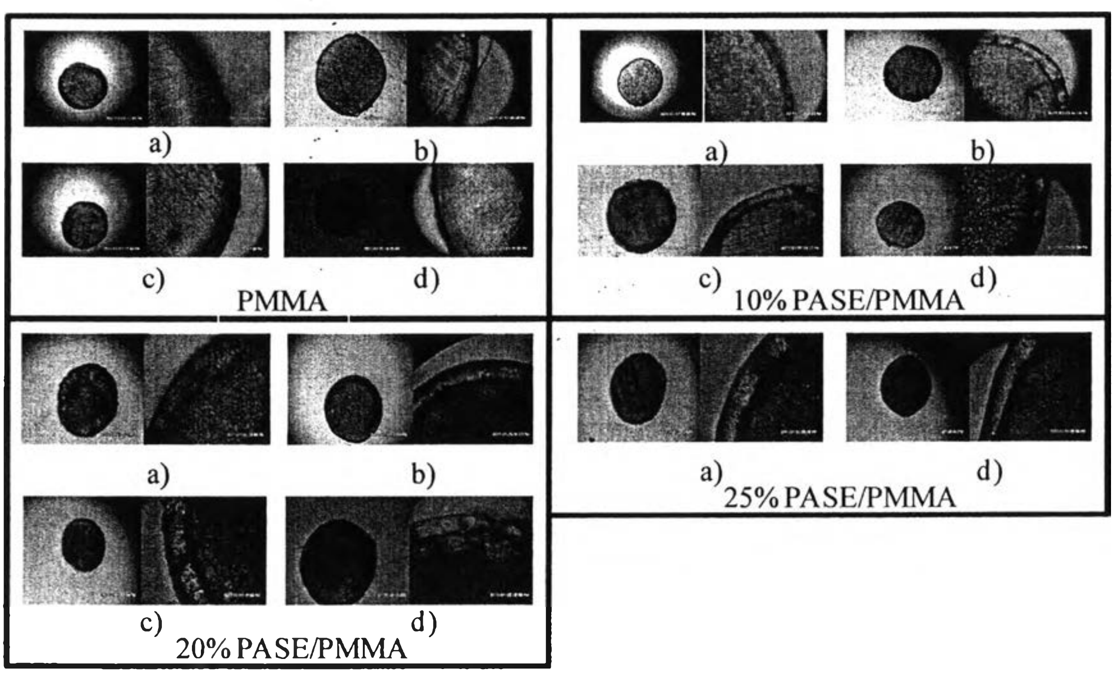

Figure 6.1 Optical microscope of fibers at various processing parameter— free falling; a) 20 min/mm and b) 24.5 mm/min of piston speed, 20 rpm odraw ratio; c) 20 min/mm and b) 24.5 mm/min of piston speed.

Table 6.1 Summary of numerical aperture and attenuation of fibers

Cladding type	**Piston speed (mm./min)**			
	20		24.5	
	attenuation (dB/m)	**NA**	**attenuation (dB/m)**	**NA**
Free falling				
PMMA*	60.089 ± 3.036	0.867 ± 0.007	67.858 ± 4.093	0.788 ± 0.018
10% PASE/PMMA	20.007 ± 1.164	0.838 ± 0.020	8.825 ± 0.790	0.811 ± 0.009
20% PASE/PMMA	14.653 ± 2.387	0.824 ± 0.017	2.930 ± 0.608	0.779 ± 0.015
25% PASE/PMMA	14.783 ± 0.527	0.813 ± 0.042	–	
20 rpm draw ratio				
PMMA*	78.773 ± 0.99	0.887 ± 0.023	52.348 ± 3.998	0.790 ± 0.040
10% PASE/PMMA	5.78 ± 0.698	0.860 ± 0.067	2.606 ± 0.365	0.866 ± 0.010
20% PASE/PMMA	9.851 ± 0.317	0.885 ± 0.043	18.660 ± 1.033	0.902 ± 0.021
25% PASE/PMMA	–		3.766 ± 0.580	0.929 ± 0.017

Note * The attenuation was measured at 50 cm frist and then were cut to 20 cm. and the numerical aperture was measured at 30 cm fiber's length.

6.4.2 Numerical Aperture (NA)

Fiber's length in this experiment is 50 cm except PMMA-cladding type fibers which are set only at 30 cm length because at 50 cm length, the fiber have very less light intensity until detector cannot detect. The numerical aperture of the obtained fibers (Table 6.1) is about the same— NA is about 0.8. This result indicate that NA is not depending on cladding thickness. The NA in this work is nearly the same with Zubia J.'s research (2001) (NA=0.78). Zubia J. (2001) reported that the more refractive difference, the larger N_A value. Furthermore, the higher numerical aperture which facilitate handling and light coupling (Aldaldetreku G., *et al.*, (2010)).

6.4.3 Bending Loss

The bending loss where the total internal reflection (TIR) failed was reduced when increasing the mandrel radius. At a sharp bend, light rays which propagate by TIR on straight fiber are lost into the cladding. (Farrell, G., 2002). The smaller radius of curvature, the higher bending loss, see Table 6.2. This experiment is the measurement of macrobending loss— radius of the bend is much greater than the radius of the fiber. However, the microbending is contributed to the loss. The one factor that affect to microbending loss is the cracking of cladding (Aldaldetreku G., *et al.*, (2010)). The claddings in this work are so brittle; therefore they have some crack when they were bended.

6.4.4 Maximum Operating Temperature

The operating temperature was evaluated by the maximum temperature at which the intensity of the emitted light is reduced by 10% from that at room temperature (25 ^{o} C). The maximum operating temperature of fibers is shown in the table 6.3. Comparing with the same type of cladding; the operating temperatures are reduced when decreasing in cladding thickness and core diameter. In the fact that, there are only 10% PASE/PMMA-cladding type fibers which can measured at 10 % of light reducing. The other fibers that have higher PASE content are soften at the same time as the light decreased. Furthermore, that light is rapidly decreased more than 10 percent.

Table 6.2 Summary of bending loss of the fibers

Cladding type	Bending loss (dB)					
	Piston speed (mm./min)					
	20			24.5		
	bending radius (cm.)			bending radius (cm.)		
	10 cm	7.7 cm	5.8 cm	10 cm	7.7 cm	5.8 cm
Free falling						
PMMA	7.739	10.421	10.895	10.903	10.903	11.057
10% PASE/PMMA	2.798	4.189	10.416	0.355	3.35	12.396
20% PASE/PMMA	2.465	3.42	3.522	0.600	0.600	0.668
25% PASE/PMMA	0.328	1.52	3.210	–		
20 rpm draw ratio						
PMMA	4.038	4.973	8.899	3.9	7.421	9.920
10% PASE/PMMA	0.552	1.451	1.610	3.772	5.635	7.293
20% PASE/PMMA	0	1.644	2.013	0.8275	1.182	2.138
25% PASE/PMMA	–			0.592	0.695	1.228

Table 6.3 The operating temperature of the fibers

Cladding type	Maximum operating temp. (^{o}C)	
	Piston speed (mm./min)	
	20	24.5
Free falling		
10% PASE/PMMA	196	207
20% PASE/PMMA	171*	212*
25% PASE/PMMA	213*	–
20 rpm draw ratio		
10% PASE/PMMA	161	179
20% PASE/PMMA	142*	150*
25% PASE/PMMA	–	113

Note * the fiber is soften when the light decrease.

6.5 Conclusion

The fibers exhibit quite the same numerical aperture that is about 0.8 which are nearly many researches which were developed recently. The attenuation is difference which depends on the fiber's dimension and uniform cladding thickness. These affect on the optical loss. The optical fibers which were developed in this work are higher attenuation than commercial POFs. The maximum operating temperature of the fibers is higher than 100 ^{o}C.

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