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# Optical Properties of Woven Fabrics by Plastic Optical Fiber

MASUDA Atsuji[a,*], MURAKAMI Tetsuhiko[a], HONDA Keiichi[b], YAMAGUCHI Shinji[b]

[a] *Industrial Technology Center of Fukui Prefecture, 61 Kawaiwashizuka, Fukui, Fukui 910–0102, Japan*
[b] *Material Sci. and Eng., University of Fukui, 3-9-1 Bunkyo, Fukui, Fukui 910–8507, Japan*

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**Abstract**

Plastic Optical Fiber (abbreviate POF) is used in the various fields; short range communication, sensor, illuminate exploitation and so on. The fabric is one of the forms in illumination fields, but there are no reports about the lighting properties of POF fabrics. In addition, for the fabric development, it is very important to estimate the optical characteristic in the textile design stage.

In this report, the lighting properties of POF fabrics are measured and the new method to estimate the optical properties of POF fabric is suggested.

*Key Words*: Plastic optical fiber, POF fabric, Lighting fabric, Lighting properties

## 1. Introduction

Plastic Optical Fiber (abbreviate POF) is used in the various fields; short range communication, sensor, illuminate exploitation and so on[1]. In the illumination fields, there are various forms like a rope (plaited cord), a net (a fishing net), and so on, but the fabric was few[2].

For the last several years, as the technology of the light source has been innovated, some commercial products are actively developed with POF fabric for the decoration, illumination, display[3, 4] and so on. There are some unique properties in POF fabric. At first is easy handling that the form is thin and flexible, second is the light is softer than general light like a LED, and final is little heat radiate from POF fabric. Therefore POF fabric is receiving a favorable review as a flexible plane lighting system for various fields, decoration, building, electronics, etc. It will be some products, after some problems are solved, luminosity, quality, cost, and so on.

The concepts of lighting fabrics with POF have designed about 40 years ago, and already published in patents[5]. However, though the bending loss of POF has been researched up to now[6], the research on POF fabric is hardly done. Figure 1 shows the principle of the lighting POF fabrics. For the lighting in POF fabric, one reason is that the micro bending of POF increases the refractive angle of the light and the light leaks out. The other is a leak from cracks on the POF surface. Though the crack makes very

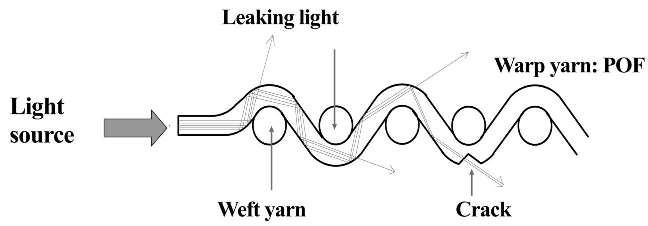

Fig. 1 The principle of lighting in POF fabric.

bright POF fabrics, the transmission distance of the incident light is very short[7]. However, the optical leak by the micro bending is less than one of the cracks, and the fabric can shines to long distance. Moreover, it is also possible to make the crack after the weaving processing, for example the leaser treatments, the chemical treatments, the hot stamp method, and so on, though the micro bending depends on the weaving condition and the textile design.

Then, in this report, it is concerned with study about the optical effect by the micro bending in POF fabric and try to estimate the fabric luminosity at textile design stage.

## 2. The method of experiments

### 2. 1 Sample

POF of the commercial products is used in the experiments, that is, ESKA is made by MITSUBISHI RAYON Co., LTD. It is uses PMMA (acrylic), a general-purpose resin as the core material, and fluorinated polymers

* Corresponding author: E-mail: amasuda@fklab.fukui.fukui.jp, Tel: +81-776-55-0664, Fax: +81-776-55-0665

Table 1 The detail properties of POF [8].

| Diameter of POF | NA | Diameter of core (mm) | Thickness of clad (mm) |
|---|---|---|---|
| 0.25 mm | 0.50 | 0.240 | 0.010 |
| 0.5 mm | 0.50 | 0.486 | 0.014 |
| 0.75 mm | 0.50 | 0.738 | 0.012 |
| 1.0 mm | 0.51 | 0.980 | 0.020 |

Table 2 The weaving pattern and the radius of curvature of POF fabric samples.

| Weaving Pattern of POF fabrics | 2/2 | 10/2 | 4/4 | 16/4 | 1/1 | 8/8 |
|---|---|---|---|---|---|---|
| Radius of curvature (mm) | 3.14 | 6.7 | 8.6 | 9.9 | 12.5 | 33.6 |

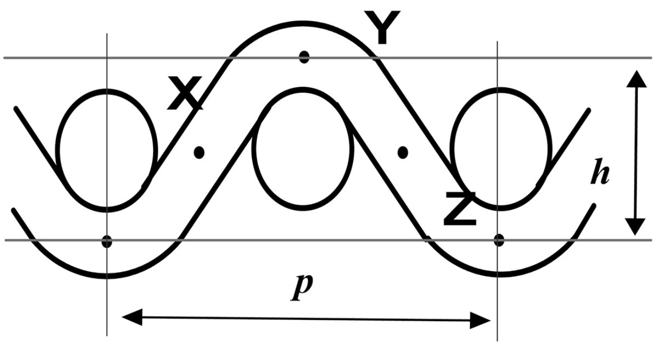


Fig. 2 The concept of calculation for expressing the curvature of POF fabric.

for the clad material. They are SI-type, and the detail properties are described in Table 1[8].

The produced samples are the two types. One is the sheet that is made as the fabric model without the bending, and POF is arranged straightly without the space. They are made from 0.25 to 1.0 mm in POF diameter.

The other is the fabric, and is made with the various POF curvatures. POF with 0.25 mm in diameter is used for the warp yarn and polyester monofilament is used for weft yarn. The POF curvature in the fabric can be changed by the fabric design (a weaving pattern, weft-yarn density and etc.). As general method, the radius of yarn curvature in fabric is expressed by the radius of the circle that passes through the three points, X, Y and Z that shown in the Fig. 2[9]. As that three points is expressed by the period of POF crossing "$p$" and the fabric thickness "$h$", the radius of curvature of POF "$r$" is calculated by equation (1). The period of POF crossing and the fabric thickness are measured from the image pictures of POF fabric cross-section that are observed by the microscope.

$$r = h/4 + p^2/(16 \cdot h) \qquad (1)$$

$p$: the period of POF crossing,
$h$: the fabric thickness,
$r$ : radius of curvature of POF

In case of POF fabric, the fabric thickness "$h$" is much smaller than the period of POF crossing "$p$" because POF is monofilament and harder than normal synthetic fibers. Therefore it is approximated to equation (2). Moreover, the results of approximation are shown in Table 1.

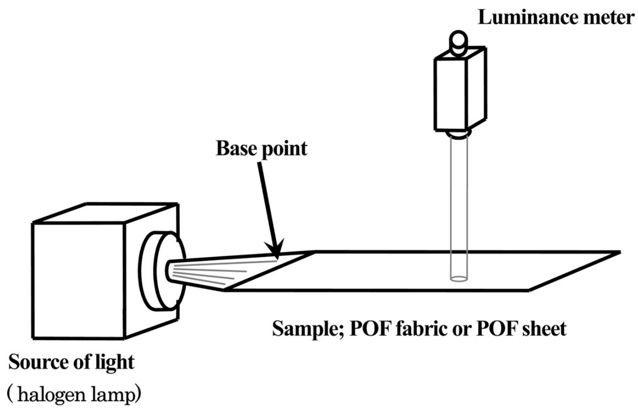


Fig. 3 The system of luminosity measurement.

$$r = p^2/(16 \cdot h) \qquad (2)$$

### 2. 2 Luminosity measurements

Luminosity of POF fabric and POF sheet were measured with the luminance meter (BM–8; TOPCON), and shown in Fig. 3. Then, the measurement was done in the darkroom in order to avoid the influence of the disturbance light. Moreover, a halogen lamp with 100W (PICS–EP/V 100W; NIPPON P • I Co. Ltd.) is used for the light source.

When the fabric luminosity is measured, there is free POF between the light source and POF fabric in order to connect with the both. Therefore, the base of fabric length is defined at nearest light source, and there is called base point.

### 2. 3 Transmission loss measurements

Transmission loss of POF is measured with the optical spectrum analyzer (Q8381A OPTICAL SPECTRUM ANAYZER; ADVANTEST). The measurement area is from 400 to 700 nm, which means the visible light area.

## 3. Results

### 3. 1 POF sheet experiments

The luminosity of each POF sheet was measured at the same length from the light source by the luminance meter, after it was bended at various curvatures. The result is shown in Fig. 4.

By this result, the luminosity is decreasing as the radius of curvature become large, regardless of POF diameter. It is obvious that the luminosity decreasing ratio is depended on POF diameter. It will be approximated by the experimental

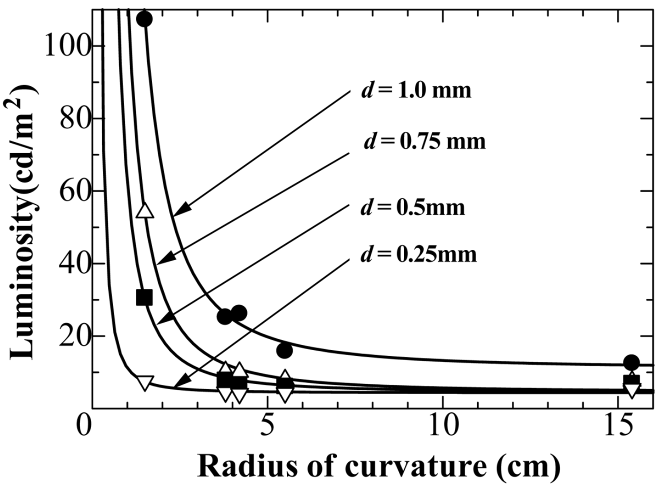


Fig. 4 The relationship between luminosity and the radius of curvature of POF in the sheet.

data that luminosity is increasing in inverse proportion to the 2nd power of a radius of the curvature, and equation is shown below.

$$L_0\,(r) = A\,(d)\,/\,r^2 + B \qquad (3)$$

$L_0$ : luminosity of POF sheet at the base point, $r$: radius of curvature of POF

$d$ : POF diameter, A ($d$): the function, which makes "$d$" a variable

B : constant dependent on the light source, measuring condition, etc.

The relationship between POF diameter and the function "A" in the approximate equation (3) is shown in Fig. 5. By the result, it is obvious that the relation between both is the proportionality, but the detail function is not approximated.

Considering about the relationship between the light transmission in POF and the diameter, the light transmission in POF is increased in proportion to the 2nd power of POF diameter. Moreover, it is known that the minimum bending curvature is increased in proportion to POF diameter in case of below 1.0 mm[8]. By these two factors, the function "A" will increase in proportion to the third power of POF diameter, and it is proved that the calculated curve fits the experiment data well.

After all, the equation (4) that is expressed the luminosity of POF sheet was derived by the experiments.

$$L_0\,(r, d) = (C \cdot d^3 \cdot m)\,/\,r^2 + B \qquad (4)$$

$m$ : the yarn density of POF

C : constant dependent on the light source, measuring condition, etc.

### 3. 2 POF fabric experiments

At first, it was measured to examine the relationship between the radius of POF curvature and the luminosity of POF fabric at the base point. The result is shown in Fig. 6. The graph shape is the same as one of sheet experiments, and the luminosity is decreasing when the radius of curvature becomes large. And it can be adapted the approximated curve calculated by the equation (3), in which is derived by the experiment of POF sheets. This means the following two points. One is that there is little influence to POF through the weaving process, for example, the crack generating etc. The other is that there is hardly a difference between the approximated radiuses of POF curvature in this report and the actual one of POF in a fabric. As a result, it will predict that POF fabric can be adapted equation (4).

Next, it was measured that POF fabric length effects on the luminosity, and the result was shown in Fig. 7. The

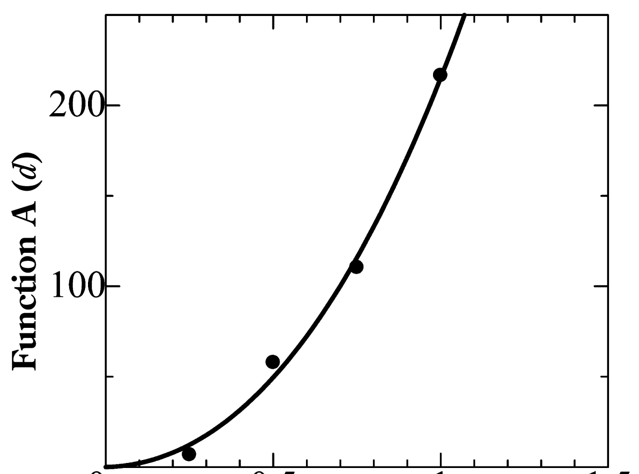


Fig. 5 The relationship between function "A ($d$)" and POF diameter.

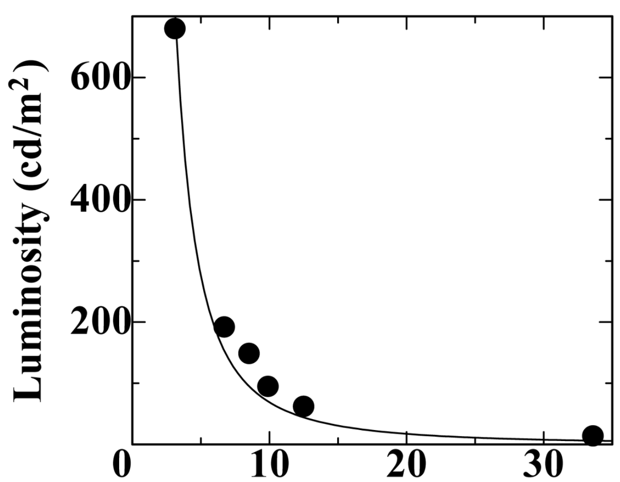


Fig. 6 The relationship between luminosity and the radius of curvature of POF in the fabric.

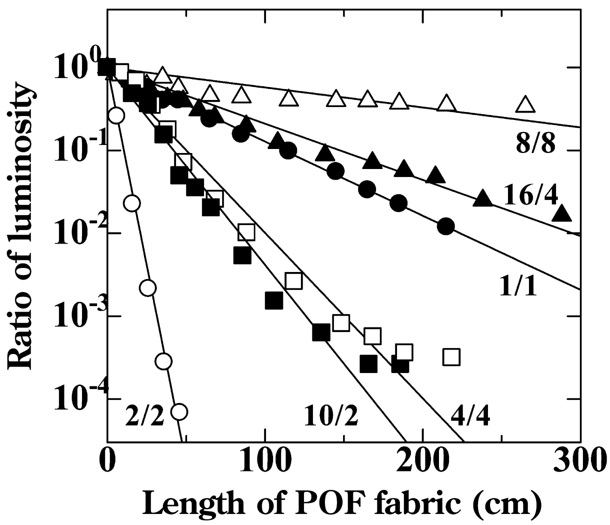


Fig. 7 The effect of a length of POF fabric on the ratio of the luminosity.

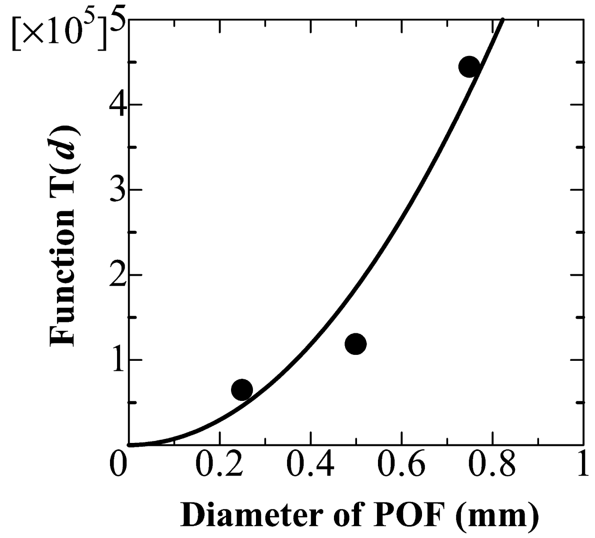


Fig. 9 The relationship between function "T" and the diameter of POF.

vertical axis adopts the ratio of the luminosity to compare the different fabric samples, and it was expressed on the basis of the luminosity at the base point. Even if the curvature of POF in fabric differs, it turns out that the luminosity decreases exponentially, and equation (5) is derived. By Fig. 7, the slope of the straight line depends on the radius of curvature and increases when the radius of curvature becomes large.

$$\mathrm{Log}\,(L/L_0) = S\,(r)\cdot x \quad (5)$$

$x$ : length of POF fabric from the base point

S ($r$) : the function, which makes "$r$" a variable

By the way, the slope of the graph in Fig. 7 means the decreasing ratio of POF fabric luminosity per unit length, and it is the same as the transmission loss of POF, that is, and there must be the strong correlation in among.

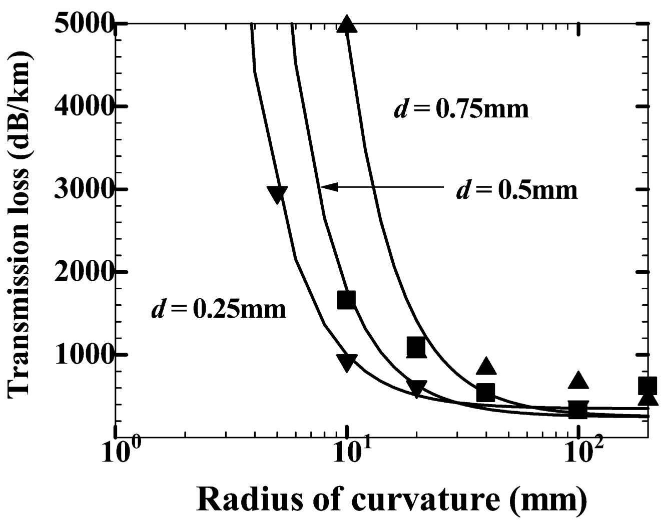


Fig. 8 The relationship between the transmission loss and the radius of curvature of POF.

The transmission loss of POF was measured, and the result is shown in Fig. 8. In the previous research, it is known that the transmission loss of POF is approximated in inverse proportion to the radius of curvature[10] (equation (6)). Moreover, it represents that Function "T" in equation (6) is depended on the POF diameter, and the relationship between both is shown in Fig. 9. When POF diameter is small, from 0.25 to 0.75 mm, it is derived from experiment data that "T" is increasing in proportion to the 2nd power of the POF diameter.

$$\text{Transmission loss}\,(r) = T\,(d)\,/\,r + E \quad (6)$$

T ($d$) : the function, which makes "$d$" a variable

E : constant dependent on the light source, measuring condition, etc.

Figure 10 shows that the relationship between the slope of the POF fabric luminosity ratio and the radius of curvature, and the relationships that are derived by the POF transmission losses are applied to the POF fabric. The experiment data is fitted well by the approximated curve that is in inverse proportion to the radius curvature. In addition, it can guess easily that the slope of the ratio of POF fabric luminosity also depend on POF diameter as it is shown in Fig. 8.

After all, the equation (7) that expresses the luminosity of POF fabric was derived.

By the results of these experiments and the consideration, it will be obvious that the approximate equation (8) is applied in case of only using the same light system

$$S\,(r) = -\,G\cdot d^2/r + F \quad (7)$$

$x$ : length of POF fabric from the base point

G, F : constant dependent on the light source, measuring condition, etc.

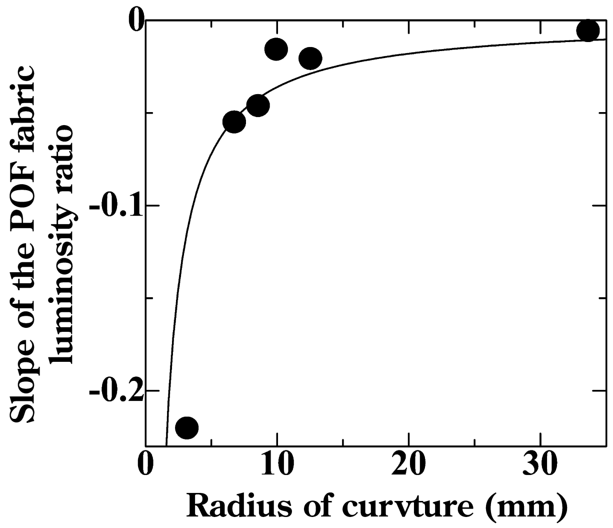


Fig. 10 The relationship between the slope of POF fabric luminosity ratio and the radius of curvature of POF in the fabric.

$$L\,(r, d, x) = \{(C \cdot d^3 \cdot m)\,/\,r^2 + B\}10^{\{-G \cdot d^2/r + F\}x} \quad (8)$$

Where "$r$" is approximated by equation (2), finally POF fabric luminosity is expressed by bellow equation (9).

$$L\,(p, h, d, x) = \{(C \cdot d^3 \cdot h^2 \cdot m)\,/\,p^4 + B\}10^{\{-G \cdot d^2 \cdot h/p^2 + F\}x} \quad (9)$$

Therefore, it becomes possible that the luminosity of POF fabric is estimated from the period of POF crossing fabric thickness, POF diameter and yarn density of POF at the textile design stage. In addition, if it is used the same diameter POF for the warp, the weaving pattern and the weft yarn density are most important factor to affect on the luminosity. Because the period of POF crossing is decided by the weaving pattern and the weft yarn density, and the fabric thickness is almost constant when POF diameter is same.

## 4. Conclusions

In this report, the light property of POF fabrics is examined though the experiments. If there is no crack on the POF fabric, it turned out that the luminosity of POF fabric is depended on the radius of POF curvature, POF diameter, yarn density of POF and the light source. In addition, the approximate equations that will be able to predict the luminosity of POF fabric were grasped in experiment.

Therefore, it becomes possible that the luminosity of POF fabric is estimated from the period of POF crossing, the fabric thickness and POF diameter at the textile design stage in case of using the same light source. In other word, it is possible to make the trial samples quickly and efficiency, and advance the practical developments of POF fabric.

Finally, this research owes much to the thoughtful and helpful comments of Mitsubishi Rayon Co, Ltd. and Shim. Fiber Lighting Office.

## References


[1] POF consortium edition (1997) "Plastic Optical Fiber", Kyoritsu Shuppan, Tokyo

[2] Nakamura K (2006) "Future Textiles", p352, SEN-I SHA, Osaka

[3] Ali H, Mailis M, Anne V (2003) AUTEX Research Journal, **3** (1), 1–8

[4] Vladan K (2005) Optics & Photonics News, **16** (4), 40–44

[5] Japanese Patent No. S47–42534

[6] Gloge D (1972) Applied Optics, **11**, 2506–2513

[7] Murakami T, Masuda A (2004) Textile Processing Technology, **39**, 370–372

[8] "ESKA Products catalogue", Mitsubishi Rayon Co., Ltd

[9] "Sen-i kougaku 4" (1991) p164, Text Mach Soc Japan, Osaka

[10] Gerd K (interpreted by Yamashita E) (1987) "Optical fiber communications", p64, Sangyoutosyo, Tokyo