TEXTILES FOR SPECIAL APPLICATION

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Abstract

The main aim of this contribution is to present some special results in the field of textile material science and their transfer into practice. Selected example is utilization of side emitting optical fibers for creation of safety textiles with active illumination in conditions of reduced visibility. Illumination intensity of polymer side emitting optical fibers measured in straight and bend state is described. Prototypes of textile structures with embedded optical fibers were created by the Faculty of Textile Engineering of the Technical University of Liberec with collaboration with a Czech company STAP a.s. These works were supported by research project FR-TI1/242 "High Visibility Protective Textiles". The project was sponsored by the Czech Ministry of Industry".

Introduction

Standard optical fiber is a light guide transmitting the light beam along its axis working in accordance with Snell's law of reflection. Typically, the optical fibers are used in telecommunication technologies [1]. Side-emitting optical fibers illuminate part of the rays through their surface. These fibers incorporated into textile structures may be used as the active visibility textiles in conditions of reduced visibility [2].

When light rays are transmitted through optical fiber, attenuation occurs [3-8]. It mainly depends on the light wavelength, fiber type, fiber structure (i.e. crystallinity and orientation), impurities and accompanying substances (dopants), the distance from the source, and also on the outer geometric shape (micro-bends, macro-bends, surface damage). When bending of fibers occurs, the part of the emitted light rays is dependent on the ratio between fiber diameters and bending radius [9-10]. Bends caused by incorporation of end emitting optical fibers to textile structures are actually needed to achieve their surface illumination [11-13]. The bending of side-emitting optical fiber leads to a loss of illumination uniformity.

Attenuation characterized by the decrease of illumination intensity for optical fibers is undesirable when used in telecommunications technologies because information is lost. Due to the huge differences in the illumination intensity the attenuation is usually expressed in decibels. Attenuation coefficient α in decibel [dB] is usually defined as a logarithm ratio between the illumination power on the input P_1 and on the output P_2

$$\alpha = 10\log(P_1 / P_2) \quad (1)$$

Eq. (1) implies that a change in the power ratio by one order is shown by changing attenuation of 10 dB. The attenuation rate α_L is defined as the ratio of attenuation coefficient and the distance between measuring powers P_1 and P_2.

$$\alpha_L = \alpha / L = \frac{10}{L}\log(P_1 / P_2) \quad (2)$$

The unit of the attenuation rate is dB per unit length. The attenuation rate is ideally constant [14], but generally it may be a nonlinear function of the length L. In the case when αL = const. it follows from equations (1) and (2), see [15-17]

$$P_2 = P_1\, 10^{-\alpha_L L/10} \tag{3}$$

Working fiber length *Lp* is the length of the side-emitting optical fiber, in which it can be realistically used. At the end of this length illuminated power P_{Lp} is still sufficient. For the purposes of this work attenuation α_{Lp} = 20 and 30 dB were selected. The working length of the optical fiber can be calculated from Eq. (4).

$$L_p = \frac{10}{\alpha_L} \log(P_1 / P_{Lp}) \tag{4}$$

1 Illumination Intensity of polymeric side emitting optical fibers – straight state

Special devices for measurement of optical fiber illumination intensity in straight state and bend state were created. Illumination system with light emitting diode (LED) was created and used as a light source for side emitting optical fibers. Polymeric side emitting optical fibers "Grace-standard" and "Grace-flexi" (produced by a company Grace POF Co., Ltd. China) with different diameters were used for measurement of illuminating intensity in straight and bent states. The POF end connected with light energy source was prepared by cutting with heated wire and then by polishing with diamond powder. The illumination intensity of source was 43.9 Wm^{-2}.

Illumination intensity as a function of the distance from a source for optical fiber "Grace-standard" having diameter 0,25 mm is shown in Fig.1 and for fiber "Grace-flexi" having diameter 14 mm is in Fig.2.

Experimental illumination intensity data can be used for creation of a regression model (see eq. (5)) and corresponding parameters can be obtained by the standard nonlinear or linearized regression using least squares criterion. Eq. (3) can be written into the model form

$$P(L) = P(0)\, 10^{-\alpha_L L/10} \tag{5}$$

where $P(L)$ is illumination intensity at the distance from the source L, $P(0)$ is illumination intensity on the fiber input and α_L is attenuation rate. By logarithmic transformation of eq. (5) the straight line $\log P(L) = -\alpha_L L/10 + \log P(0)$ results. The slope of this straight line k can be used for calculation of mean attenuation rate $\alpha_L = -10\, k$ and intercept q can be used for calculation of illumination intensity on the fiber input $P(0) = 10^q$. By using of regression straight line parameters k and q, coefficient of determination R^2 and parameters $P(0)$ and α_L were calculated, see table 1.

For expression of working length of optical fiber L_p must be illuminating power P_{Lp} on the end of this length at sufficient value of attenuation coefficient α_{Lp}

$$P_{Lp} = P(0)\, 10^{-\alpha_{Lp}/10} \tag{6}$$

Illuminating power P_{Lp} can replace *P(L)* in Eq. (5) and then working length of optical fiber *Lp* can be calculated

$$L_p = \frac{10}{\alpha_L} \log(P(0) / P_{Lp}) \tag{7}$$

The working length of the optical fiber calculated for attenuation coefficient α_{Lp} from 10 to 20 dB is shown in table 1 for optical fiber "Grace-standard" with diameter 0,25 mm and fiber "Grace-flexi" with diameter 14 mm.

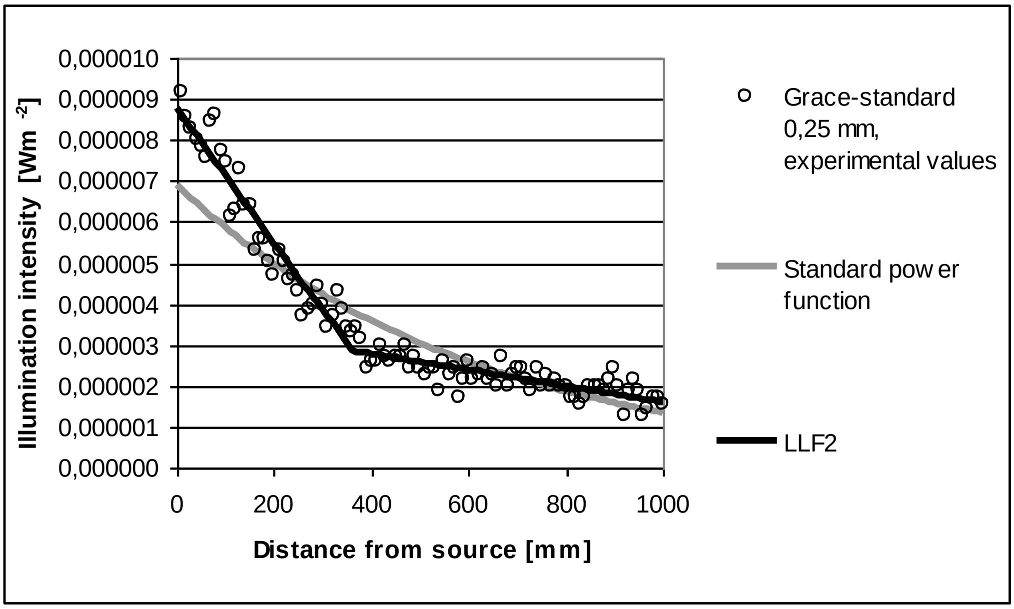

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Fig. 1: *Illumination intensity of fiber "Grace-standard" – fiber diameter 0,25 mm*

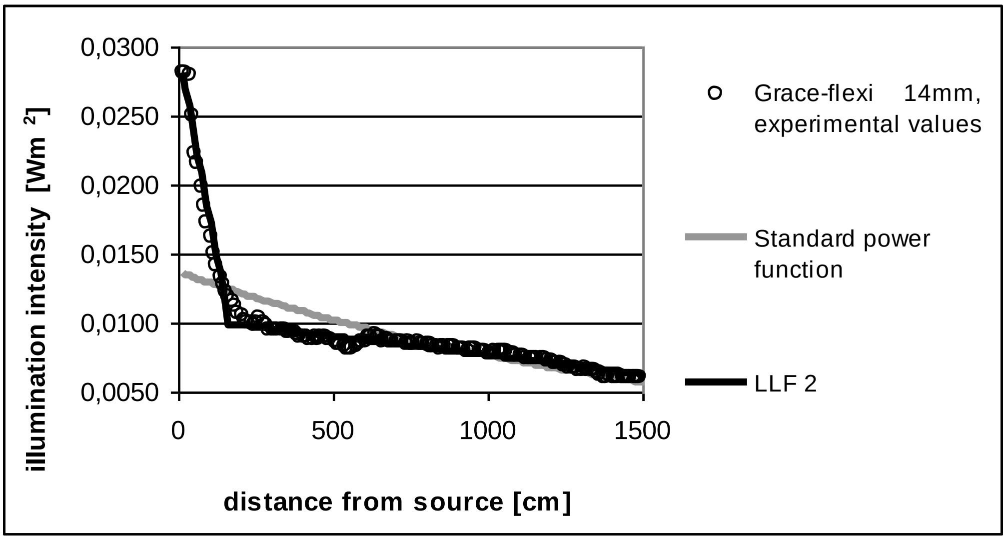

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Fig. 2: *Illumination intensity of fiber "Grace-flexi" – fiber diameter 14 mm*

Tab. 1: *Parameters of regression model (eq. (5))*

Fiber type	"Grace-standard" 0,25 mm	"Grace-flexi" 14 mm
Illumination intensity on the fiber input $P(0)$ [Wm^{-2}]	0.000007	0.01367
Attenuation rate α_L [dBmm^{-1}]	0.0071	0.00254
Working length of optical fiber L_p for attenuation α_{Lp}=10-20dB [mm]	1409 and 2817	3937 and7874

Source: Own

The model curve of illumination intensity expressed as standard power function (Eq.(5)) derived from assumption of constant rate of attenuation is shown in Fig. 1 and Fig. 2 as gray curve [1]. It was found that at short distances from the light source the illumination intensity is strongly decreasing especially for optical fibers with higher diameter (higher than 1 mm).

Estimation of parameters $P(0)$ and α_L is not accurate and the standard power function (Eq.(5)) is not suitable for these purposes. Black piecewise solid line in Fig. 1 and Fig. 2 is so called LLF2 model, it is a linear piecewise function consisting from two different straight sections. This model is based on the assumption that in short distances from light source there are some no uniformity in side emission due to accommodation to aperture and critical angle. In second phase the illumination intensity is slowly decreasing with distance from source L (system is accommodated). Local slopes of LLF2 are in fact sensitivity coefficients a_1, a_2. Corrected illumination intensity on the fiber input is $P_{cor}(0)$. LLF2 model is described by the following equation (it is in fact linear regression spline with one knot):

$$LLF2 = P_{cor}(0) + a_1 L + a_2 (L - L_c)_+ \tag{8}$$

where function $(x)_+ = 0$ if x is negative and if x is positive, function $(x)_+ = x$. L_c is the distance of transition between the first and second phase. By using modified linear regression [18] parameters of LLF2 for optical fiber "Grace-standard" with diameter 0,25 mm and "Grace-flexi" with diameter 14 mm were found, see table 2. By using Eq. (7) working length of optical fiber L_{pcor} for attenuation $\alpha_{Lp\ cor}$ from10 to 20dB was calculated see Fig. 4 and table 2.

Tab. 2: *Parameters of smoothing curves of illumination intensity calculated by using of LLF2*

Fiber type	"Grace-standard" 0,25 mm	"Grace-flexi" 14 mm
Minimal residual sum of squares S [Wm^{-2}]^2	1.372E-11	0.00037
Corrected illumination intensity on the fiber input $P_{cor}(0)$ [Wm^{-2}]	0.000009	0.02993
Slope of first straight line a_1 [Wm^{-2} mm^{-1}]	-1.64E-08	-0.000121
Slope of second straight line a_2 [Wm^{-2} mm^{-1}]	-1.96E-09	-2.72E-06
Distance of transition between first and second phase L_c [mm]	359.9	165.0
Working length of optical fiber L_{pcor} for attenuation $\alpha_{Lp\ cor}$ =10 and 20dB [mm]	1378 and 1791	2709 and 3699

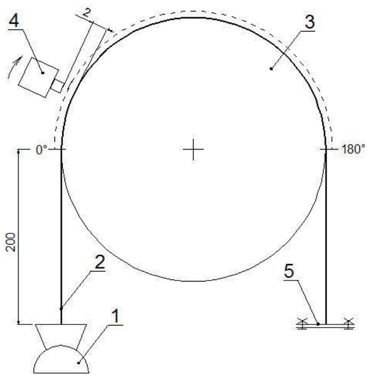
Source: Own

Two methods for smoothing of experimental values of illumination intensity i.e. standard power function and LLF2 model were tested. It was found that LLF2 model is much better for description of experimental illumination intensity, see Fig. 1 and Fig. 2 The LLF2 model leads to better estimate of illumination intensity on the fiber input $P_{cor}(0)$ which represents the quality of the illumination system and it is necessary for calculation of other parameters. The quality of the illumination system is dependent on its construction and on the quality of the fiber cross-section. By using LLF2 it is possible to calculate the distance of transition L_c between the first and second phase. The working length of optical fiber Lp_{cor} calculated by LLF2 is shorter than working length L_p calculated by standard power function (Fig. 4).

The LLF2 provides other parameters as the distance of transition between the first and second phase and slopes of straight lines, which express sensitivity of mean attenuation rate on the distance from the source [20].

2 Illumination Intensity of polymeric side emitting optical fibers – bent state

A technique for measurement of changes in light intensity along bent fiber was proposed. The principle of light intensity measurement along bent fiber is shown in Fig. 5. The first prototype of the measurement device was created.



1 – light source, 2 – optical fiber, 3 – cylinder, 4 – sensor, 5 – clamp jaw

Source: Own

Fig. 3: *Measurement of illumination intensity at bending of optical fiber*

The illumination intensity of side emitting optical fibers “Grace-standard” with different diameter was measured at bending region around the cylinder with diameters from 30 mm to 350 mm. Illumination intensities for 1 mm diameter fiber bent around cylinder of different diameter are shown in Fig. 5 as function of bending angle. The illumination intensity along straight fiber of the length corresponding to perimeter of cylinder (with 40 mm diameter) is included here for comparison. Illumination intensity as a function describing ratio of cylinder diameter D and fiber diameter d for bending angle 40°, 90° and 140° for group of polymeric optical fibers “Grace-standard” is shown in Fig. 5. For smoothing of experimental data model LLF2, see eq. (8), was used, too.

By using bent fibers, the illumination intensity is significantly increased. According to preliminary results, illumination intensity is decreasing function of ratio D/d. Illumination intensity is divided to two phases. First phase represents no uniformity in side emission due to accommodation to aperture and critical angle and illumination intensity is strongly decreasing. In the second phase, the system is accommodated and illumination intensity has a low level and it is slowly decreasing. This phenomenon is used for illumination of end emitting optical fiber embedded in woven fabric. For embedding of POF into woven or knitted fabrics, it will be necessary to investigate micro-bending of fibers with ratio D/d about 1 also. In this case, illumination intensity is strongly increasing and it can be applied for design or for construction of textiles with application in medicine [16]. For higher values of ratio D/d macro-bending of fibers was studied because it is typical in application of side emitting polymer optical fibers for high visibility protection textiles. One example of fiber embedded in textile in straight state and with macro-bends is visible in the Fig. 6 a) and its application in active visible textile is shown in Fig. 6 b).

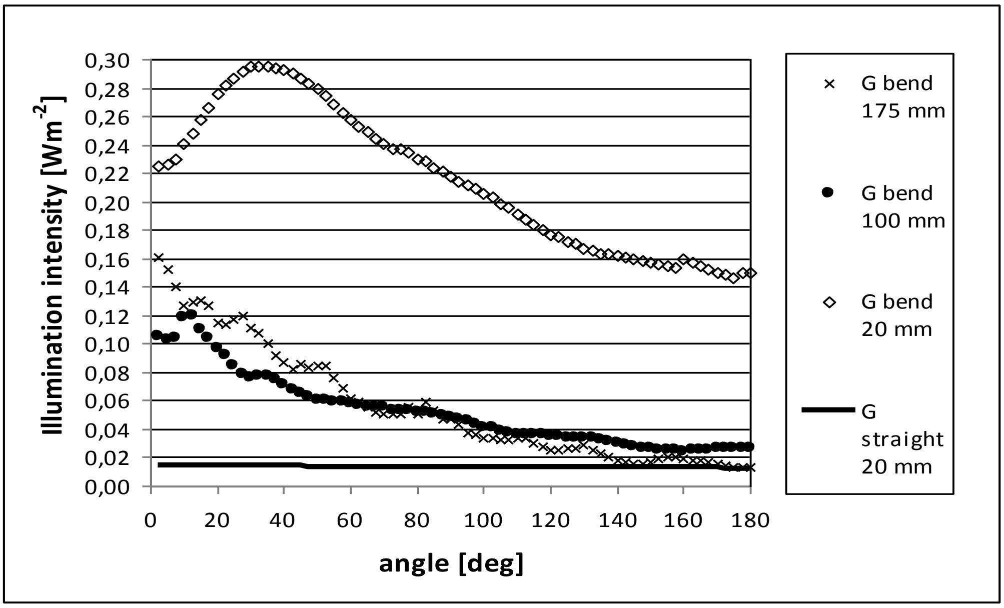


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Fig. 4: *Illumination intensity – bent around cylinder with radius 175 mm, 100 mm, 20 mm, comparison with straight state (corresponds to length around cylinder with diameter 20 mm) for polymeric optical fiber "Grace-standard" with diameter 1 mm*

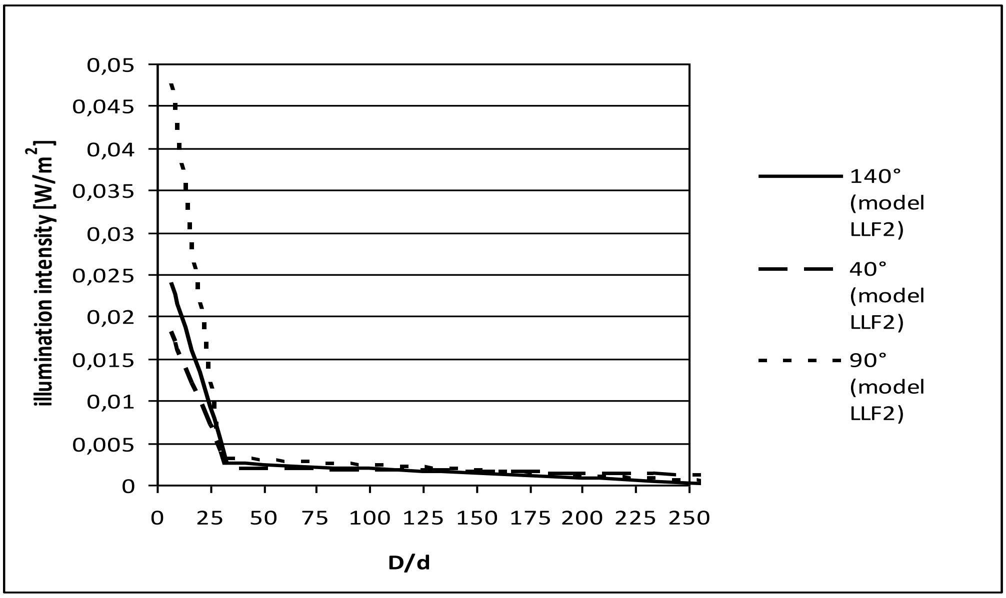

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Fig. 5: *Illumination intensity as function of ratio between bending cylinder diameter D and optical fiber diameter d – smoothing curves LLF2*

a) b)

Source: Own

Fig. 6: *Application of optical fiber – active visibility protective textiles*

Conclusion

Illumination system [19] with light emitting diode (LED) was created and used as a light source. Prototypes for evaluation of side emitting optical fiber illumination intensity were developed and tested. The system of data treatment and evaluation of results was proposed and checked. Parameter for evaluation of quality of illumination system as illumination intensity on the fiber input was proposed. Parameters characterizing quality of optical fibers as mean attenuation rate and working length were defined. It was found that illumination intensity and mean attenuation rate are the function of the distance from the light source. A method for calculation of their sensitivity was proposed. Despite of considerable variation in the mean attenuation rate (till 240 mm from light source for fiber "Grace-standard") it is clear that the incorporation of these fibers into active safety textiles will provide sufficient emissivity especially in larger diameter fibers. The working length of fibers, which reach values about 2 m, also supports it. The illumination intensity is a decreasing function of ratio D/d. The results of this work should be used for incorporation of optical fibers into woven and knitting textiles. According to the results of this work, it is suitable to use POF in straight state or with macro-bends for active visibility textiles. It is better to create fibers with textile cover from the durability point of view [2]. Higher fiber diameter generally leads to higher bending rigidity and lower flexibility [18]. The mechanical and thermal behavior of the optical fiber and their durability are important as well.

Acknowledgement

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TEXTILIE PRO SPECIÁLNÍ APLIKACE

Hlavním cílem této práce je uvést některé speciální výsledky, kterých bylo dosaženo v oblasti materiálového inženýrství a ukázat jejich transfer do praxe. Jedná se o uplatnění polymerních stranově vyzařujících optických vláken pro tvorbu aktivně vyzařujících bezpečnostních textilií, které je možno využít v podmínkách snížené viditelnosti. Jsou popsány způsoby měření intenzity stranového vyzařování optických vláken jak v napřímeném stavu, tak při ohybu. Na základě spolupráce mezi Fakultou textilní Technické univerzity v Liberci a českou společností STAP a.s. byly vytvořeny prototypy textilních struktur se zabudovanými optickými vlákny. Tyto práce byly podporovány projektem TIP FR-TI1/242 "Aktivní bezpečnostní textilie". Projekt byl sponzorován Ministerstvem průmyslu ČR.

TEXTILIEN FÜR BESONDERE ZWECKE

Diese Arbeit nennt einige spezielle Ergebnisse, die auf dem Gebiet der Materialwissenschaft erzielt wurden, und zeigt Möglichkeiten von deren praktischer Anwendung. Es handelt sich dabei um die Einbringung polymerer an den Seiten strahlender optischer Fasern zur Bildung aktiv strahlender Sicherheitstextilien, die bei geringer Sicht verwendet werden können. Es wird beschrieben, wie die Strahlungsintensität an den Seiten optischer Fasern sowohl in aufrechter Haltung als auch bei Beugung gemessen werden können. Auf Grundlage der Zusammenarbeit zwischen der Textilfakultät der Technischen Universität Liberec der tschechischen Gesellschaft STAP a.s. wurden Prototypen textiler Strukturen unter Einbeziehung optischer Fasern geschaffen. Diese Arbeit wurde durch das Projekt TIP FR-TI1/242 „Aktive Sicherheitstextilien" gefördert. Dieses Projekt wurde finanziell vom Ministerium für Industrie der Tschechischen Republik unterstützt.

TEKSTYLIA DO SPECJALNYCH ZASTOSOWAŃ

Głównym celem niniejszego opracowania jest pokazanie niektórych specjalnych wyników, jakie osiągnięto w dziedzinie inżynierii materiałowej oraz pokazanie ich transferu do praktyki. Dotyczy to zastosowania polimerowych włókien optycznych ze światłem bocznym do tworzenia aktywnie promieniujących tekstylii ochronnych, które można wykorzystać w warunkach obniżonej widoczności. Opisano sposoby pomiaru natężnienia bocznego światła włókien optycznych, zarówno w stanie wyprostowanym, jak i w zgięciu. W ramach współpracy Wydziału Tekstylnego Uniwersytetu Technicznego w Libercu z czeską spółką STAP a.s. opracowano prototypy struktur tekstylnych z wbudowanymi włóknami optycznymi. Prace te dofinansowano w ramach projektu TIP FR-TI1/242 "Aktywne tekstylia ochronne". Projekt był finansowany przez Ministerstwo Przemysłu RCz.