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Aspects of Influencing Factors in the Polishing of Plastic Optical Fibers

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Abstract: The interaction between the X-ray beam and the scintillating core of the optical fiber creates photons. The generated photons propagate through the fiber until the fiber end where they are captured by a solid state photon sensitive detector. This very sensitive detector converts generated photons into a low-level electronic signal that is amplified for later processing. For industrial, medical domains or for detection of contraband objects in custom control, flexible detectors can be built using 1 mm plastic scintillating optical fiber. The paper presents aspects related to the influencing factors of the optical fiber polishing process. Experiments related to the influencing factors of optical fiber polishing were performed. The results related to the influencing factors for cutting the optical fiber are presented. A proposal for plastic fiber cutting tool was given. The results related to factor of influence for polishing of plastic scintillating fiber were presented. In conclusion a possible technology for plastic scintillating fiber with 1 mm diameter is described.

Keywords: Fiber optics, Plastic fiber optics, Polish, Technology

Introduction

Fiber optic are used from many years in communication in order to send signals over the fiber length. The purpose of replacing copper wire in telecom is due to the following advantages: lower weight, lower power consumption, higher bandwidth. Fiber optic made from plastic or glass are used to transmit video, data, audio over long distances with reduced losses and distorsion. Fiber optics are flexible and durable. Plastic fiber with scintillating material in core is used from many years in scientific experiments, medical imaging, industrial application and other applications. The scope of paper is to present the results of researches related to low cost polishing technology developed. Based on a polishing model, we develop a polishing technology for plastic fibers, we make experiments and we get results. For experiments we use plastic scintillating fibers, SCSF 78 made by Kuraray (n.d.). Fibers used in experiments are produced with core from polystyrene and cladding from PMMA and has 1 mm diameter, We define the optimum process for polishing fibers used to make a flexible detector described by Panagopoulos et al. (2023).

Our investigations in literature related to modelling the polishing plastic scintillating fibers published papers found just few papers. In a technical document company describe how they make a trial to polish plastic scintillating fiber. (Kuraray, n.d.) There is a general method to polish plastic fiber produced by Kuraray, considered as starting point to perform polishing, without full details of operations.

Few methods for polishing plastic scintillating fiber are described by Hanlet et al. (1999). In that paper there is a comparison between 3 methods for polishing plastic fibers: first method uses a teflon block, second method uses

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an ice block and third one uses a FiberFin III polishing machine. Fibers polished were HFBR-RUS500 from Avago Optoelectronics with 1 mm core diameter and 2.2 mm outer diameter. Fibers were used in Muon Scintillator Counters (MSC) and in the InterCryostat Detector (ICD). Such detectors uses a large number of fibers so an industrial polishing method is necessary and reccomended over manual method. Other papers present polishing of plastic fibers for industrial or telecommunication application.

Process Modelling

For our researches we use polystyrene core and PMMA cladding fibers with 1 mm diameter fully described in Kuraray (n.d.). catalogues Plastic Scintillating Plastic lens used in industrial, medical or scientific applications are manufactured from polymer materials like: polycarbonate, TPU, PET or other materials. Those materials has similar characteristics and we consider appropriate to use same modeling process. For plastic scintillating fiber material removal modelling process, it is considered appropriate to use, Preston hypothesis as is described in Kaufmann (2017).

$$\frac{dz}{dt} = C_p * \frac{F}{A} * \frac{ds}{dx} \tag{1}$$

Were: z - material removal [mm];

t - polishing time [s];
C_p - Preston coefficient;
F - polishing force [N];
A - polishing tool footprint size [mm^2];
s - oscillation length [mm].

In our case, of polishing plastic fiber, process parameters are followings: polishing tools (pad, flat surface), polishing solution, temperature, dilution, raw material, time, etc. Material removal thickness are influenced by pressure and speed because of polymer materials viscoelasticity behavior. A factor of influence of the tool positioned on the fiber is footprint size. In our experiments we check force distributed over the probe to verify if the value is constant.

During the polishing process of fibers we notice that we have no chemical reaction between abrasive grain and fiber surface. From this reason we may make a consider polishing plastic fiber a process similar with plastic lens lapping process. Kaufmann (2017) consider that is posible to compute material removal thickness if Preston coefficient is know and process parameters are also known. In fig. 1 we have the case of static load for penetration depth calculation. Penetration depth is a parameter of stock removal process.

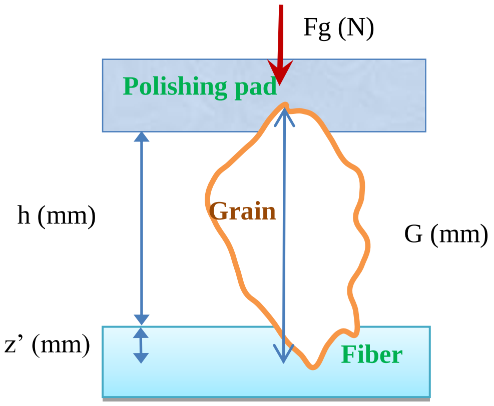


Figure 1. Polishing gap between tool and fiber with abrasive polishing grain (Kaufmann, 2017)

Based on the fig. 1, we may wrote following formula:

$$z' = \frac{Fg * S * G}{H * h} \tag{2}$$

Were: z´ - penetration depth of the polishing grain [mm];

F_g - force per polishing grain;
S - shape of the polishing grain;
G - grain size [mm];
H - Young´s modulus of the fiber material [$N*mm^{-2}$];
h - thickness of the fluid layer between tool and fiber [mm].

Kaufmann (2017) verify the influence of the abrasive grain and he conclude that when increase the size of abrasive grain, increase the pressure applied on the material and the results is the increasing of thickness of material removal. He claim that when slurry density increase, the force per grain decrease because force is applied on increased number of grains. As consequence, the quantity of material removed, is reduced. When number of grains increase, the quantity of material removed is increased. Pad used for polishing purposes has a natural porosity were grain are kept. Using a pad with higher porosity, number of grains increase and decrease the force per grain because the area is not modified. He perform a penetration test and understand that geometry of the grain influence mechanical behavior of the penetrated material. As consequence a higher grain size increase the penetration depth.

The Young´s Modulus influence is not easy to be understood due to the viscoelastic behavior of most of the polymer materials. Young´Modulus depends on the load level and loading rate. Also, he claim that pressure applied during the polishing process is important because of the elastic and plastic deformation. Thickness of the abrasive film depends on the viscosity, the polishing pad roughness, the fiber end face roughness, the relative speed between tool and fiber and the pressure applied.

A particular interest is the viscosity, and the influence of grain number in the slurry and pH. Less agglomeration in slurry mean less sedimentation and this is important factor for lifespan. Number of grains in the polishing gap is important factor of stock removal process. pH-value is important for the amount of water in the polymer surface because can change the hardness of the fiber end face surface.

Experiments

Plastic Scintillating Fiber Polish Technology

A principle for polishing plastic fiber was described in Kuraray (n.d.) but they do not provided fiber diameter and other details. (Hanlet et al., 1999). Present also by comparison 3 methods for polishing plastic fiber: teflon block, ice polishing and FiberFin III. First two methods are manual methods, recommended for prototypes and a reduced number of fibers. Third method uses an industrial machine recommended for large number of fibers. For experiments were used as fiber HFBR-RUS500 from Avago Optoelectronics, with 1 mm diameter core and 2.2 mm diameter clad. In an manual related to connectorization of fibers produced by Thorlabs (2020) it is present principle for manual glass fiber polishing: tools, consumables, materials, etc. According with Hanlet et al. (1999) and manual for connectorization (Thorlab,2020), polishing fiber has few steps: coarse, medium and fine.

We start experiments by cutting fiber using FiberFin inc razor blade (figure 2). Cutting tool is composed by a metallic block provided with a number of holes with different diameters. Metallic block has a channel used to guide blade with purpose to avoid cutting errors. Fiber diameter is verified, inserted in proper hole and then blade is pressed.

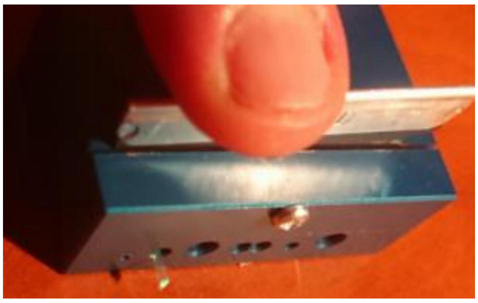


Figure 2. Fiberfin fiber razor blade (POF razor cutter multiple size fibers)

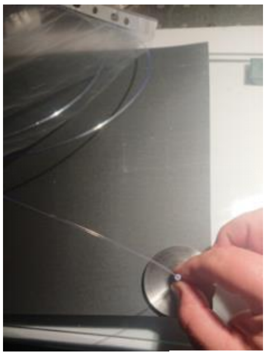


Figure 3. Glass plate (Thorlabs,2020)

For experiments we place on glass plate (figure 3) sandpaper fixed with few DI water drops. In the Guide (Thorlabs,2020) for manual polishing fiber, a movement of fiber in shape of number 8 it is reccomended (fig. 4a). Fiber is pressed gently fiber on abrasive surface. We experiments also complex movement from figure 4b . This a complex movement used especially in industrial polishing machines. We will compare results obtained using both movements.

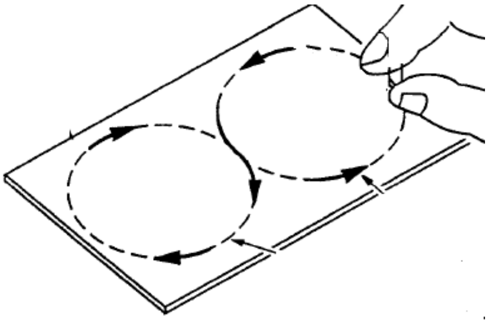


Figure 4a. Manual polishing pattern (Thorlabs, 2020)

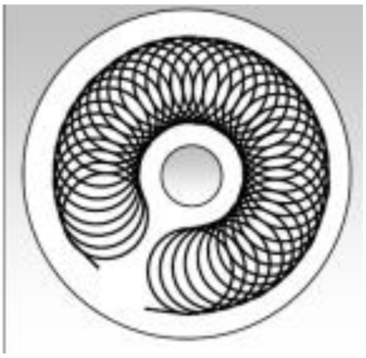


Figure 4b. Orbital pattern (Rubin, 2017)

We use a tool as in figure 5 to polish fibers. Tool is a 5 mm stainless steel circular plate with a central hole were fiber connector is fixed. Contact surface has anular channels (figure 5b) used to accumulated abrasive and plastic particle.

Figure 5a. Stainless steel tool back side

Figure 5b. Stainless steel tool front side

For coarse polishing we press gently fiber over flat surface with P800 sandpaper and tool is moved 3 times. Fiber endface is cleaned using pure air, DI water and non abrasive optical tissue. Sandpaper is changed from P800 to P1500 and as consequence abrasive grain size is reduced from 20 to 12 microns. Tool is pressed gently over sandpaper using 5 times movement. Fiber endface is cleaned. For medium polishing we change sandpaper from P1500 with P3000 and as consequence grain size is now 5 microns. Tool is pressed gently and 7 times movement is applied. Endface is cleaned.

For fine polish we use Buehler micropolish alumina solution with abrasive grain size of 0.3 microns. Solution is spread a non abrasive tissue fixed on flat surface (figure 6). Tool is press gently over abrasive surface and is rotated 10 times. Endface is cleaned and inspected. In next step it is used 0.02 microns abrasive particle size and a number of 15 complex rotation are applied.

Figure. 6. Abrasive suspension placed on non abrasive tissue

We investigate followings during our experiments: influence of abrasive particles: size, concentration in solution, influence of pressure in polishing, influence of gap between fiber and hole diameter in razor block, influence of tool pressure, influence of complex rotation. For investigations we use 2 tools: a stand described by Comanescu et al. (2023) and an optical microscope (videomicroscope n.d.) recommended by Fiber Optic Association. In figure 7a is a 30x portable magnification microscope, a flexible tool used especially for investigation of fiber cutting and coarse polishing. In figure 7b there is a video microscope from Edmund Optics, modified to work horizontally. This tool has 100x magnification and main advantage is screen visualization.

Figure 7a) Optical microscope used for fiber optic polishing quality investigation (video microscope n.d)

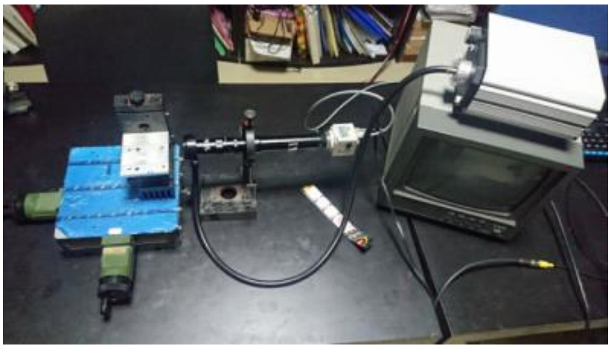
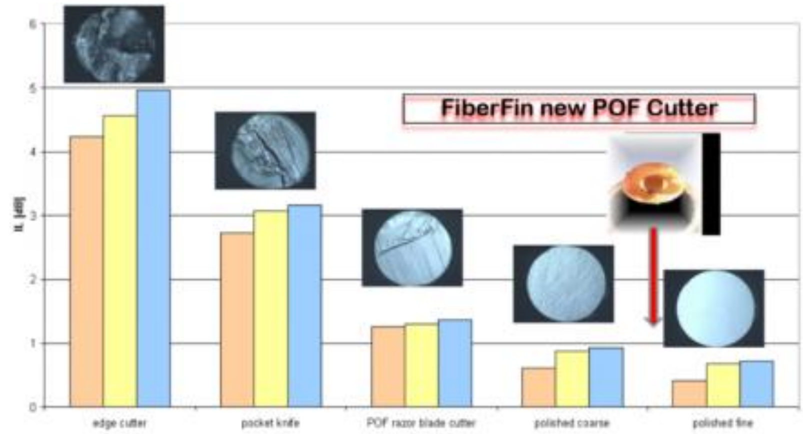


Figure 7b. Video microscope

Results and Discussion

We use as comparison for our experiments the cutting results from a fiber optic cutting and polishing operation from presentation New Termination Techniques for POF (Mulligan, 2009).



a) b) c) d) e)

Figure 8 Plastic fiber cutting (Mulligan, 2009)

According with Fiberfin presentation, New Termination Techniques for POF (Mulligan, 2009) for razor blade cutting plastic fiber, they offer the ability to cut fiber without the need to polish fiber or to have reduced polishing manpower resource consumption. In figure 8a is presented the results of fiber cutting using a scissor. In the figure 8b is presented another cutting process of plastic fiber. Figure 8c present the result of razor blade plastic fiber cutting. Comparing the fiber cutting using all processes we noticed that razor blade is a good tool for plastic fiber cutting compared with other types of cutters. In figure 8d is the image of fiber polished after cutting. Analising image based on roughness criteria that it is need to continue to polish. In the figure 8e is the results of fine fiber polishing after continuu the process analised in image 8d.

We cut 10 pieces from a Kuraray 1 mm plastic fiber using FiberFin razor blade and the results are presented in figure 9a,b. The endface is partial cut and it is need to be polished. In figure 9c we present a graphic for 10 cutting. On the vertical axis is the percentage of cutting endface and on the orizontal axis is number of cuttings. Based on our results presented also in figure 9 a, b, c we claim that cutting of endface is between 40 to 60%in the most of cases. There is also a reduced number of case when cutting of endface is full.

Figure 9a. Cutting a fiber well fixed in tool

Figure 9b. Cutting a fiber not well fixed in tool

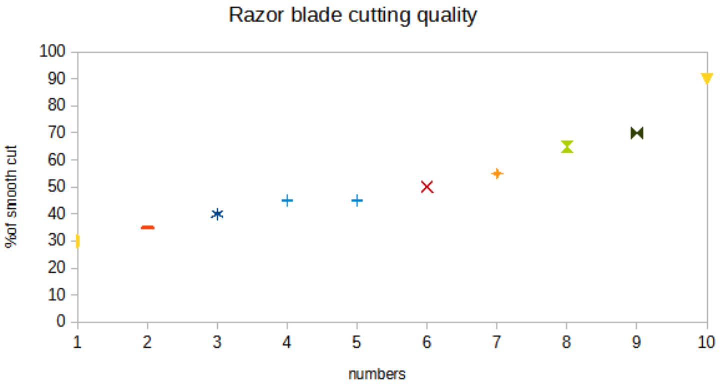


Figure 9c. Cutting quality

After (coarse) polishing using P800 sandpaper , the endface roughness is modified , traces of abrasive grains and dirty points are present as in figure 10a. We continue to polish using P3000. Depth of abrasive grains trace decrease and number of dirty points increase as in figure 10b.

Figure 10a. Coarse polishing

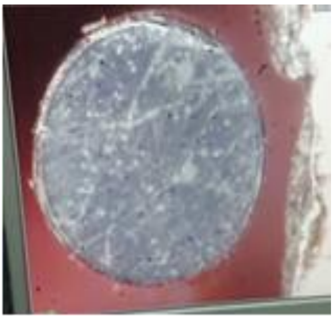


Figure 10b. Medium polishing

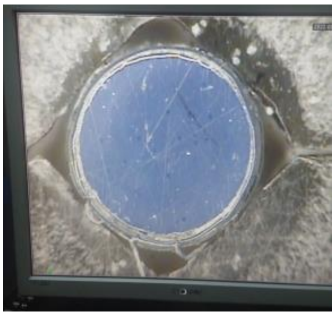


Figure 10c. Fine polishing

Figure 10d. Final result for polishing

For fine polish we change sandpaper with liquid polishing solution. The results of polish using 0.3 microns abrasive grains is presented in figure 10c. The number of abrasive grain trace and dirty points decrease, also the depth of abrasive grain trace decrease. In figure 10d is the results of the fine polishing after using 0.02 microns abrasive liquid solution. There is a single abrasive grain line and no dirty points.

In fig. 13a,b is the results of fine polishing stage after we use 0,02 microns abrasive grain size solution. We obtain a face with almost no inclusions and reduced number of scratches. In order to analyse the influence of abrasive particle we use sandpaper with different grain size. When we increase the grain size, grain traces became deeper and material removal rate increase (figure 10a). When we decrease the grain size, grain traces are smaller and material removal rate decrease (figure 10b,c). We analyse the influence of the grain concentration in abrasive solution. When the grain concentration increase, the material removal rate increases. When the grain concentration decreases the material removal rate decreases. We analyse the influence of distance between fiber and abrasive surface. When the gap increases the material removal rate decreases and when the gap decreases the material removal rate increases. In order to analyse tool pressure influence we increase pressure and as results the material removal rate increase. When the pressure decreases the material removal rate decreases.

We analyse the influence of the fiber probe movement by comparison of “8 shape” and orbital. When we use the “8 shape” rotation we noticed that material removal is homogeneous and is possible to be used to polish the fiber, but the movement is dependent of the operator expertise. When we use the orbital movement due to complex rotation for a non-experienced operator were more easy to polish (figure 10c, d). We use the method for measurement of light at output of plastic fiber a stand as were described by. Comanescu et al. (2023). We obtain for output signal chart from figure 11.

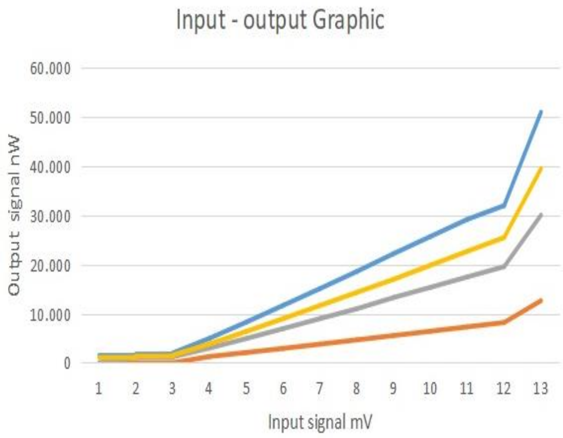


Figure 11. Output signal of polished fiber

When the LED input current increases, the LED light power that is pumped into fiber polished fiber increases, the output signal read by a detector increases as in figure 11. The output signal is measured using few fibers and we see that trend is similar.

Conclusion

Paper present the results after our research concerning the polishing of plastic scintillating fiber with 1 mm diameter. Our investigations related to a possible theory that can be used we found that can be applied for processing. We make two types of experiments: One type is related to fiber cutting and second one is related to fiber polishing.

Our experiments related to fiber cutting bring to us to following conclusions: is not possible to eliminate fiber polishing and a razor blade tool is a good tool to cut plastic fiber. The investigation of influence of abrasive particle shows direct correspondence between abrasive granule size and material removal rate. The investigation of the correspondence between concentation of abrasive grains and material removal rate shows direct correspondence.

The investigations related to influence of distance between fibers on material removal rate demonstrate a direct relation. The investigations related to the influence of the gap between fiber and abrasive surface conclude that there is a direct correlation. Our conclusions related to the using of a stand for measurement the signal through the fiber demonstrate that fibers are well polished.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Aknowledgments

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