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STUDY OF PHYSICAL PROPERTIES OF TAPER STRUCTURED FIBER OPTIC SENSORS

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Abstract

Along with its development, optical fiber has been modified into sensors because of its various advantages. In the fabrication of a modified fiber optic sensor in the form of a taper innovation, the sensor geometry becomes the main parameter that can affect the sensitivity of the sensor. The fiber taper works by allowing the evanescent waves out of the waveguide to interact with the stimulus, thus providing a sensor mechanism. The fabrication of the fiber taper in this study was carried out using the drawing and heating method continuously and simultaneously. Based on this fabrication process, the optical fiber is pulled using an autograph until it enters the plastic deformation region. Mechanical properties analysis showed that the optical fiber has a stress of 54.21 MPa and an elastic modulus of 2.46 GPa. It was also found that the optical fiber experienced an elongation of up to 11.02%. The results of the digital microscope test showed that the taper process succeeded in reducing the diameter of the optical fiber by 18.40%. Besides the ease of processing, the advantage of fabrication using this method is that the mechanical properties are measured in real-time, making this method reproducible on a mass scale.

Keywords: *fiber optic sensor, innovation, fiber taper, evanescent wave, autograph*

INTRODUCTION

Along with the times, information technology, especially data transmission, is growing rapidly. Many discoveries have been made by scientists to meet the demand for transmitting large data over great distances, one of which is the invention of fiber optics. In recent research, optical fiber was developed as a sensor. The sensor is a device that functions to receive a stimulus and respond to it with an electrical signal [1]. Optical fiber has many advantages such as high measurement accuracy, no direct contact, practical, non-electric, and resistance to ionizing radiation, small size, and remote monitoring capability [2]. These advantages make optical fiber widely innovated as a sensor.

One of the uses of optical fiber as a sensor is to modify its shape into a taper structure. Fiber taper-based sensors have been widely applied in physics, chemistry, and biology optical sensors [3]. Fiber taper is one of the innovations in the form of optical fiber which is heat-treated and pulled in certain areas so that the diameter is reduced in that area [4]. Sensors that use fiber tapers as sensing elements have several advantages over other sensors,

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namely allowing the occurrence of larger evanescent waves. The evanescent waves that occur can be scattered and interact with the surrounding medium to increase the sensitivity of the sensor. Changes in the diameter of the optical fiber due to tapering cause a drastic change in the critical angle resulting in a lot of light coming out of the waveguide so that the transmission power captured by the detector will decrease [5].

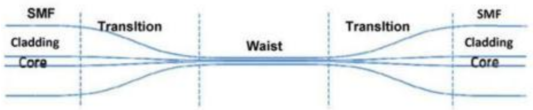

Figure 1. Fiber taper scheme [4]

There are various methods that have previously been developed to fabricate fiber tapers, such as using flame brushing [6] and tapering rig [7] techniques. This method has weaknesses, such as in the flame brushing technique where the pull is not measurable resulting in the fabrication often failing due to fracture. Likewise, the fabrication using the tapering rig technique where the physical parameters during fabrication cannot be observed, making this method not reproducible. Therefore, it is necessary to develop other methods that have advantages such as physical parameters that can be measured directly, practically, and are expected to be reproducible.

This study aims to fabricate fiber tapers using autograph pulling techniques, primarily to examine the physical properties during the fabrication process such as stress, elongation, and the measured modulus of elasticity. After the fabrication process, the results were obtained in the form of a tapered fiber that experienced a reduction in diameter, a digital microscope test was carried out to determine the cross-section of the fabricated results. The optical fiber used is multimode fiber with type FD 620-10 produced by Autonics, USA.

RESEARCH METHODS

1. Fiber Taper Fabrication

The fiber taper fabrication process in this study was carried out by drawing and heating methods. The tool used in this method is an autograph microcomputer control universal testing to pull optical fiber and a dryer as a heater. The realization of the tool and the fabrication mechanism can be seen in Figure 2. The fabrication process is first carried out by peeling off the optical fiber cladding so that it leaves the core. Then the optical fiber is clamped to the autograph clamp at both ends. The peeled part is then heated to a temperature of about 70 0C with a distance of 7.00 cm from the heater to the optical fiber. During the heating process, the optical fiber is pulled slowly at an autograph pulling speed of 2 mm/min to the desired elongation. During this process, due to the tension of the optical fiber, its diameter shrinks. Optical fiber that experiences a reduction in its core diameter is usually called a fiber taper.

The taper method using an autograph has advantages such as adjustable pulling speed, measurable stress and strain, and a

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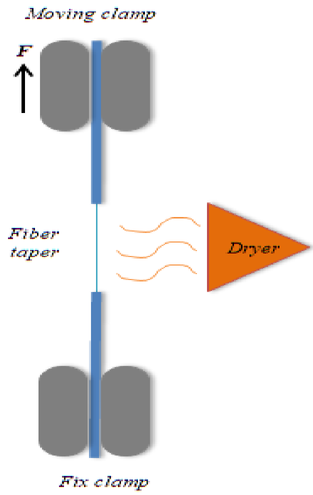
stress-strain graph that can be monitored for changes. This graphic display simplifies the fiber taper fabrication process to ensure that the fiber optic pull reaches the plastic deformation area, and also ensures that the taper process does not exceed the fracture point.

(a)



(b)

Figure 2. (a) Realization of the autograph, **(b)** Mechanism of fabricating fiber taper

2. Analysis of Mechanical Properties of Fiber Taper

Fabrication using autographs provides data in the form of stress-strain graphs, from which various mechanical properties of optical fibers can be analyzed. One of them is stress which is the ability of the material to be pulled with a load at both ends of (F) per unit area of the material. The amount of pressure (stress) is formulated in the following equation :

$$\sigma = \frac{F}{A} \qquad (1)$$

The tensile load force is given continuously by adding a load so that it will result in a change in the shape of the cross-section of the object in the form of an increase in length. Strain is a measure of the flexibility of a material whose value is usually expressed in percentage units. The percentage of elongation can be expressed with the following relationship :

$$\varepsilon = \frac{\Delta L}{L_0} \times 100\% \qquad (2)$$

The modulus of elasticity is the ratio between the stress and the corresponding strain as long as it is at the elastic limit, and its magnitude is always constant for a particular material. The magnitude of the modulus of elasticity is formulated as follows :

$$ME = \frac{\sigma}{\varepsilon} \qquad (3)$$

RESULTS AND DISCUSSION

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1. Fiber Taper Mechanical Characterization

The fiber taper fabrication process in this study was carried out by pulling the optical fiber up to its plastic deformation area but not exceeding the fracture point of the material. Pulling up to the area of plastic deformation can be ascertained by monitoring the stress-strain graph displayed on the monitor of the autograph device, indicated by the sloping area on the graph. The stress-strain graph in fiber taper fabrication can be seen in Figure 3.

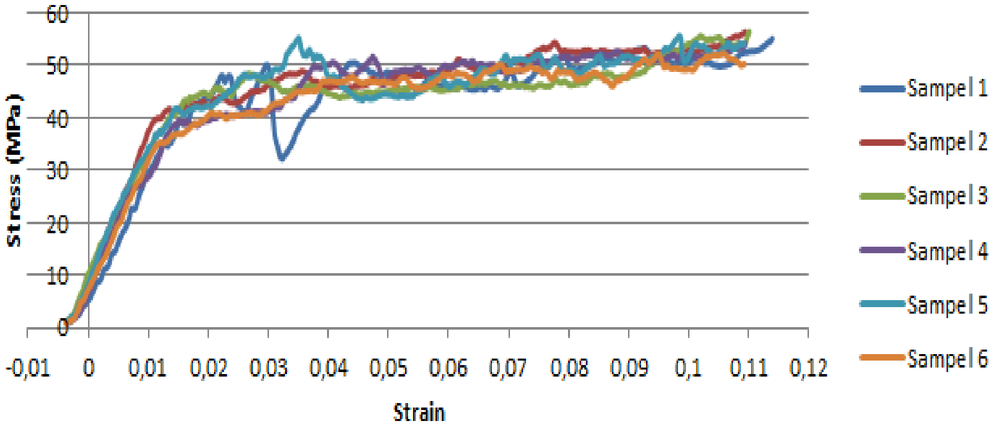

Figure 3. Graph of stress-strain in fiber taper fabrication

Furthermore, from the graph above, various mechanical properties can be determined during the fabrication process which can be seen in Table 1 below :

Table 1. Mechanical properties data in fiber taper fabrication

Sample iteration	Elastic stress (+0,00005) (MPa)	Elastic strain (+0,00005)	Maximum stress (+0,00005) (MPa)	Maximum strain (+0,00005)	Modulus of elasticity (GPa)
1	39,2670	0,0160	55,0730	0,1140	2,46
2	42,7450	0,0170	55,3530	0,1090	2,53
3	43,3600	0,0160	56,3980	0,1100	2,68
4	39,3610	0,0160	54,0640	0,1090	2,41
5	41,5000	0,0170	54,1170	0,1090	2,49
6	39,0610	0,0180	50,2440	0,1090	2,19
Average	40,8223	0,0167	54,2082	0,1102	2,46
Deviation	1,9095	0,0006	2,1260	0,0018	0,16

Based on the average analysis results from the graph, several mechanical properties of fiber taper were obtained, namely having a stress of (54.21+2.13)

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MPa, experiencing elongation up to 11.02%, and having an elastic modulus of (2.46±0.16) GPa.

2. Fiber Taper Fabrication Results

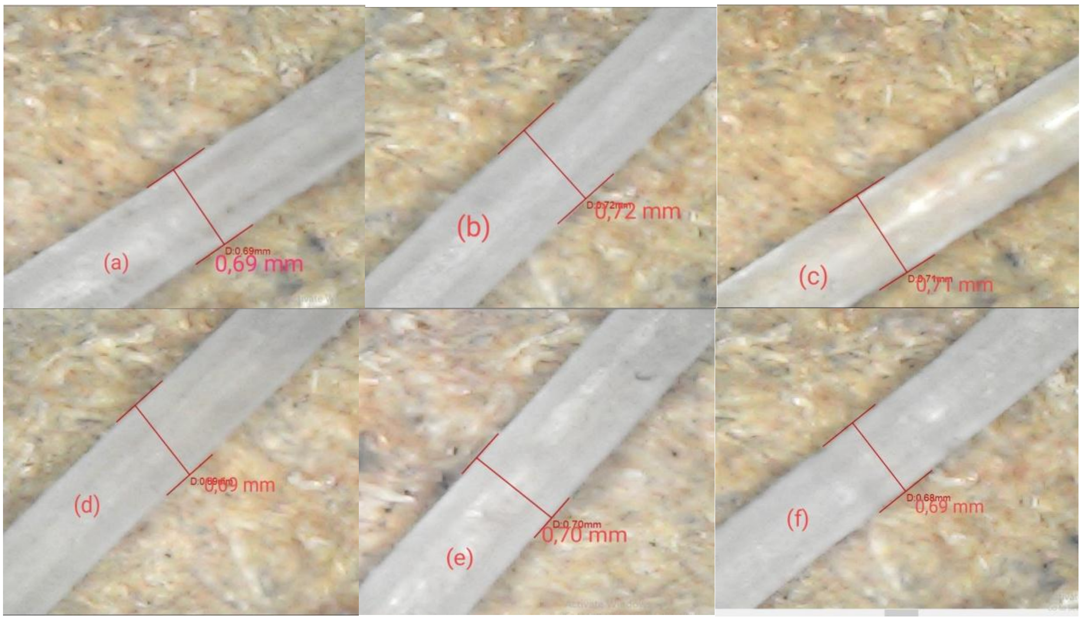

Figure 4. The fabrication results of each fiber taper **(a)** sample 1, **(b)** sample 2, **(c)** sample 3, **(d)** sample 4, **(e)** sample 5, **(f)** sample 6

The results of the fabrication of each sample were observed using a digital microscope as shown in Figure 4.

Comparison of the diameter size between the original optical fiber, the optical fiber that has been slightly peeled off the cladding, and the fiber taper can be seen in Figure 5.

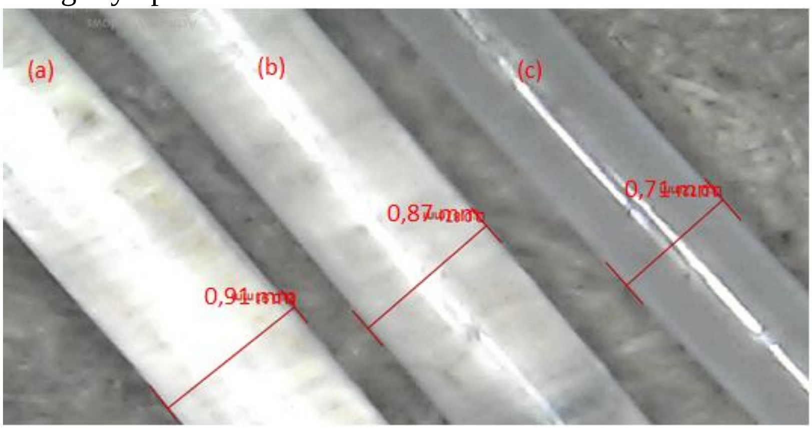

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Figure 5. (a) The original optical fiber, **(b)** The optical fiber that slightly peeled off the cladding, **(c)** Fiber taper

Based on the picture above, it appears that the fiber taper fabrication process using the autograph draw method has been successful. The original optical fiber originally had a diameter of (0.910$\pm$0.005) mm. Then after peeling a little in the cladding, the optical fiber shrinks to a diameter of (0.870$\pm$0.005) mm. Furthermore, on the fiber taper, it appears that the diameter has shrunk to (0.710$\pm$0.005) mm. Based on these results, it is concluded that optical fiber is proven to experience a diameter reduction of 18.40%.

CONCLUSION

Fiber taper fabrication using the drawing and heating method succeeded in reducing the diameter of the optical fiber by 18.40%. The results of the mechanical properties analysis show that the fiber taper has a stress value of 54.21 MPa, an elongation of 11.02%, and an elastic modulus of 2.46 GPa. The tapering method using an autograph has many advantages with various ease of use, a fabrication that can be monitored directly, as well as measurable mechanical parameters, making this method reproducible so it deserves to be further developed.

THANK-YOU NOTE

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BIBLIOGRAPHY

[1] Krohn, DA,. (2014). *Fiber Optic Sensor Fundamental and Application 4th Edition.* ISA. New York

[2] Tiwari, D., dkk. (2016). An Ammonia Sensor Based on Lossy Mode Resonance on a Tapered Optical Fiber Coated with Porphyrin-Incorporated Titanium Dioxide. *Sensors and Actuators B* 242, 645-654.

[3] Fraden, J. 2015. *Handbook of Modern Sensors. Physics, Designs, and Applications. 5th edition*. Springer

[4] Harun, S.W., Lim, K. Jasim, A. Ahmad , H. 2010. Fabrication of Fiber Taper Based Ring Resonator. *Laser physics.* 20(7):1629-1631.

[5] Frederick, C.A., 1990. *Fiber Optics Handbook For Engineers and Scientists*. McGraw-Hill, Inc.,New York.

[6] M. Yasin, N. Irawati, N.M. Isa, S.W. Harun, F. Ahmad. (2018). Graphene coated silica microfiber for highly sensitive magnesium sensor. *Sensors and Actuators* A 273 67–71.

[7] Aminah, N.S., dkk. (2016). Fabrikasi Sensor Serat Optik dengan Struktur Taper. *Prosiding SNIPS 2016.*

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