Sensitivity Enhancement of Strain Sensor Based on Polymer Optical Fiber for Concrete Testing

A Arifin¹*, A Samsu¹, M Yunus¹, B Abdullah¹ and D Tahir¹

¹Department of Physics, Hasanuddin University, Makassar, 90245 Indonesian

*Corresponding author: arifinpide@gmail.com

Abstract. Research has been carried out about sensitivity enhancement of strain sensor based on polymer optical fiber used for concrete testing. Strain sensor testing was done by applying pressure to the concrete using the Ultimate Testing Machine (UTM). Strain sensor was made from polymer optical fiber without coat with straight, U and rectangular configurations. At both ends of the sensor connected with Light Emitting Diode (LED), phototransistor and amplifier circuit that produces output value in the form of analog voltage that is converted by the Arduino Uno microcontroller into the digital voltage value displayed on the computer. The results showed that the greater the load given on the concrete, the greater the strain on the sensor, so that the output voltage read on the computer gets smaller. The best sensitivity value obtained at rectangular configuration with 3 cm amplitude is 0.117 V/cm with 0.008 cm resolution. Strain sensor in the concrete structures testing based on polymer optical fiber has advantages including low cost, simple measurement system, easy fabrication with high sensitivity.

1. Introduction
Concrete is a type of composite material consisting of elements of cement, aggregate (sand and gravel) and water mixed together to become a homogeneous whole. The mixing gives a chemical reaction that result in hardening or addition of concrete strength which is influenced by the quality of material, the method of work, and the treatment of concrete [1]. To maintain the quality of concrete in buildings, concrete can be monitored and controlled using a sensor system. In recent years, sensor systems have experiencing very rapid development for various measurement applications, one of which is sensor system based polymer optical fiber (POF) [2,3]. POF as sensor will continue to be developed and modified into devices that can interact directly with the environment and it have good performance [4,5].

Sensor based on POF can be used to measure various parameters including vibration, displacement, height, humidity, etc. POF has advantages such as high light transmission, small size, and it can be used in location that is difficult to reach [5-8]. POF can also be used as sensors to measure and monitor concrete strain on building structures remotely [9,10]. Strain measurement studies on concrete have been carried out including by Ghimire et al. (2018) about the monitoring of concrete strain using strain sensor (fiber loop ringdown) embedded in concrete. The results of this study found that the greater the strain that occurs in the concrete, the lower the intensity of light received. Some of the weaknesses of this study are using very complicated methods, high cost, and low sensitivity [5].

Improved sensor performance can be done by modifying physically of optical fiber sensor in terms of specific shapes and objectives that are associated to make measurement [2,3]. Other advantages of
the POF sensor are corrosion resistance, easy fabrication, low cost, simple measurement system, easy to connect with other devices, high sensitivity, and elastic properties. Therefore, in this study strain sensor will be developed on concrete structures by utilizing the elastic properties of POF materials by forming to be straight, U, and rectangular configurations. The configurations are used to determine the strain value in the concrete structure due to strain that occurs in concrete. This research is expected to be able to produce sensitivity enhancement in a simple measurement system.

2. Method
In this study, concrete was made based on SNI 2493: 2011 standard and strain sensor testing in concrete structures based on POF with cladding (without coat). Schematic of sensor testing detect strain on the concrete structure as shown in Figure 1.

![Figure 1. Schematic of strain sensor based on POF.](image)

Figure 1 is schematic of strain sensor using POF embedded in concrete. The POF used was made of polymethyl metacrylate (PMMA) with coat, cladding, and core diameters of 2.2 mm, 1 mm and 0.98 mm respectively. The core refractive index is 1.492, cladding 1.402 and numerical aperture NA = 0.5. The supporting tools used in this study are IF-E91A type infrared LED with a wavelength of 400-1100 nm, IF-D92 type phototransistor, power supply circuit, differential amplifier, Arduino Uno microcontroller, and Ultimate Testing Machine (UTM).

The strain sensor used is an electrical energy signal that is connected to the power supply converted into an optical signal connected to a LED to produce light emitted into POF. When the concrete is experiencing strain, the light intensity and output voltage produced from the LED decrease due to the strain on the concrete structure around the sensor received by the phototransistor. Then the electrical energy signal will be amplified by the differential amplifier connected by the microcontroller and displayed by the computer. The POF used was 50 cm long with a straight configuration with 38 cm coat peel length planted in the concrete and outside the concrete (Figure 2a). U configuration use 18 cm coat peel length with bending diameters of 0 cm, 1 cm, and 2 cm (Figure 2b), while rectangular configuration use 24 cm coat peel length with 8 cm, 4 cm and 3 cm amplitudes bending (Figure 2c), as shown in Figure 2 below:
3. Result and Discussion

Response changes the output voltage to strain sensor with straight, U and rectangular configurations for strain measurements utilize light transmission in POF. Next to analyze the sensor strain value, the data obtained from the test results are used to calculate the range value of the output voltage, sensitivity, and resolution. Range value is calculated by the difference between the maximum output voltage and the minimum output voltage. Sensitivity is measured by the range value of output voltage to the strain measured, while the sensor resolution is determined by the smallest value measured by the sensor to the sensor sensitivity. The range value of the output voltage, sensitivity, and resolution can be determined using equations (1), (2), and (3) as below [11-13]:

\[ \Delta V = V_{\text{max}} - V_{\text{min}} \]  

(1)

\[ S = \frac{V_{\text{max}} - V_{\text{min}}}{l_{\text{max}} - l_{\text{min}}} \]  

(2)

\[ R = \frac{N}{S} \]  

(3)

Where, \( \Delta V \) is the range, \( S \) is the sensitivity, \( R \) is the resolution and \( V_{\text{max}} \) as the maximum output voltage and \( V_{\text{min}} \) as the minimum output voltage. \( l_{\text{max}} \) is the maximum strain and \( l_{\text{min}} \) as the minimum strain of POF. Whereas, \( N \) is the smallest scale result value detected by microcontroller 0.001 Volt. The results of the study can be seen as shown in Figure 3 below:
In Figure 3 shows that the greater the strain that occurs in the POF sensor, the output voltage decreases. The value of the output voltage varies according to the configuration on the sensor. The sensor test results show sensor characteristics such as range, sensitivity and resolution determined using equations (1), (2), and (3) in Table 1 below:

Table 1. The test results of strain sensors in concrete structures

| Characteristics of Sensor | Straight Embedded | Sticked | U 0 cm | 1 cm | 2 cm | 3 cm | 4 cm | 8 cm |
|---------------------------|------------------|--------|--------|------|------|------|------|------|
| Range (V)                 | 0.024            | 0.010  | 0.044  | 0.014| 0.024| 0.114| 0.088| 0.064|
| Sensitivity (V/cm)        | 0.025            | 0.014  | 0.029  | 0.009| 0.015| 0.117| 0.090| 0.065|
| Resolution (cm)           | 0.040            | 0.071  | 0.034  | 0.111| 0.066| 0.008| 0.011| 0.015|

Table 1 shows the strain sensor values in the concrete structure that rectangular configuration with an amplitude of 3 cm with a measurement has a sensitivity value of 0.117 V/cm and a resolution of 0.008 cm best compared to U configuration which only has 0.029 V/cm sensitivity and 0.034 cm resolution at bending distance 0 cm, while the straight configuration sticked outside on the concrete has a sensitivity of 0.014 V/cm and a resolution of 0.071 cm. This states that the smaller the sensor diameter, the better the sensitivity and resolution of the sensor. If the diameter of sensor is smaller, the bending that occur when POF is greater. The large bending causes the light intensity transmits in the POF decreases, so that causing greater power losses.

In a previous study by Chew et al (2018) with singlemode-multimode-singlemode (SMS) measurements using electromagnetic wave interference (EMI) with straight configuration obtained a sensitivity of 0.014 nm/kN [10]. In this study, it is low sensitivity, high cost, and very complicated measurements. If it is compared with this research has a sensitivity value of 0.117 V/cm, that is high sensitivity, low cost, corrosion resistant, small size, lighter, easily connected with other devices, and it has the best range, sensitivity, and resolution values. Therefore, sensor based on POF is suitable for detecting strain in concrete structures because it has very high sensitivity.
4. Conclusion
The results showed that POF can be used for strain sensor in concrete testing. The greater the load given on the concrete, the greater the strain on the sensor, so that the output voltage gets smaller. The results showed that the best strain sensor was obtained at rectangular configuration with 3 cm amplitude gets a sensitivity value of 0.117 V/cm, and a resolution of 0.008 cm. The sensor testing based on POF can enhance sensitivity in a simple measurement system.

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