FIBER OPTIC SMART MONITORING OF KOREA EXPRESS RAILWAY TUNNEL STRUCTURES

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1 Introduction

For monitoring of railway structures, optical fiber sensors are very convenient. The fiber sensors are very small and do not disturb the structural properties. They also have several merits such as electro-magnetic immunity, long signal transmission, good accuracy and multiplicity of one sensor line. Strain measurement technologies with fiber optic sensors have been investigated as a part of smart structure. In this paper, we investigated a monitoring system for large infrastructures using pre-strained FBG sensors fixed with partially stripped fibers. The sensor package has pre-strain controllable fixtures. In order to fix tightly to the structure, the partially stripped parts of the sensor glued to the package and slip phenomenon between fiber and acrylate jacket was prevented. Pre-strain of the sensor was imposed by controlling the two fixed points with bolts and nuts in order to measure compressive strain as well as tensile strain. Tensile and compressive strain of the structure could be measured without slip. Fiber optic sensor package showed good durability and long term stability for continuous monitoring of the large infrastructures as well as good response to the structural behaviors during construction. The behavior of large infrastructure such as tunnel lining structure could be monitored very well.

2 Characters and Principles of Fiber Gratings

As shown in <Figure 1>, reflecting Bragg wavelength is a function of effective refractive index and grating distance such as formula (1), and when the physical properties such as temperature or stress of the fiber optic grating sensor are permitted, the Bragg wavelength become different. Therefore, if you measure the change of the Bragg wavelength, it will be able to get the approval physical property on the fiber optic grating sensor.

First, the change($\Delta\lambda_B$) of Bragg center wavelength (λ_B) about strain (ϵ) change could be written as formula (1).

$$\Delta\lambda_B = \lambda_B\,(1 - P_e)\,\epsilon \qquad (1)$$

P_e is Photo-elastic Constant, and on the case of Germano-silicate glass, it has approximately the number of 0.22. ϵ is the strain given on fiber optic grating.

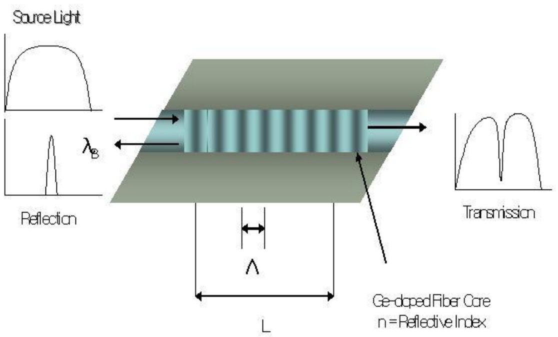

Fig. 1. Structure of FBG sensor

To move exactly 0.01nm of Bragg wavelength, each strain and resolution of temperature has to be approximately 8 x 10-6 ε , 0.9℃, and by using equipment with high resolution, measurement of smaller movement of Bragg wavelength can be achieved.

3 Fiber Optic Sensor Packaging Method

3.1 Sensor packaging method with partially stripped fiber

Optical fiber consists of glass core and glass cladding and the sensing element of fiber grating is formed in the core and cladding. The outer part of glass fiber is the coating of acrylate polymer jacket.

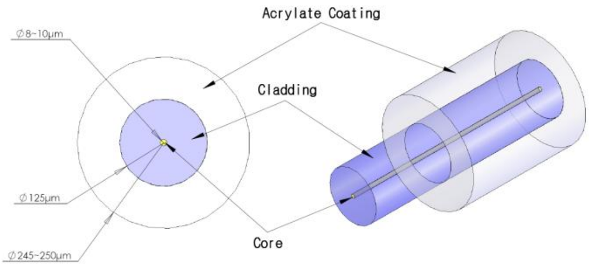

Fig. 2. Core, cladding and acrylate jacket

Polymer jacket protects glass fiber, but the sensor package with the jacket leads slippage between glass fiber and jacket while the stress is applied to the package and the structure as shown in figure 3. Because of the slippage, to detect the long term deformation is impossible.

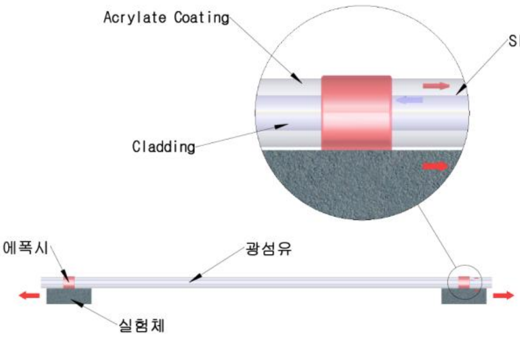

Fig. 3. Ordinary fixing method of optical fiber

In order to detect the accurate long term deformation values of strains, the fixing parts of the fiber must be stripped as shown in figure 4. and fixed tightly.

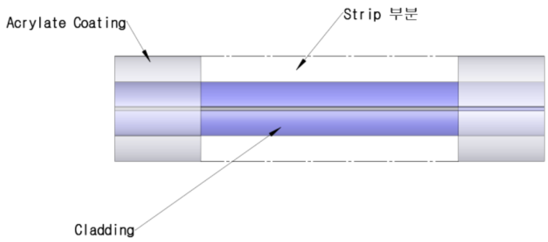

Fig. 4. The fiber with stripped jacket

The stripped fiber is very fragile and has very low bending strength. It could be easily broken with small stress and very hard to make various packages which can measure strain, stress, pressure and temperature. In order to compromise the low strength of the stripped fiber, external protecting tube for the stripped fiber is applied as shown in figure 5.

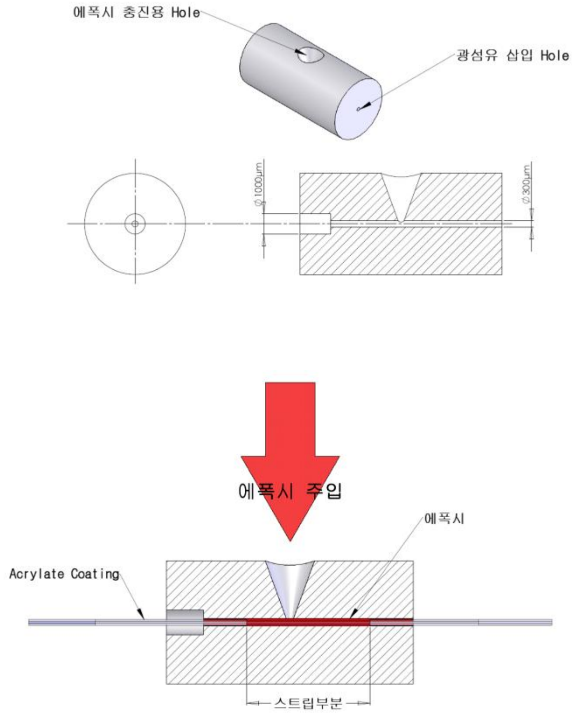

Figure 5. Protection tube for stripped fiber and fixing the tube with epoxy.

4 Performance Evaluation of the Sensor Package

The sensor packages which applied the above mentioned fixing methods compared to ordinary fixing methods were tested in the laboratory. Two sensor packages for strain measurement with partially stripped fibers and two strain sensor packages without strip were tested as shown in figure 6.

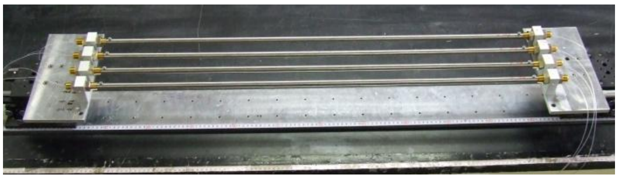

Fig. 6. Test set up for strain sensor packages

Strains were applied using micrometer up to 9000 microstrain with the step of 1000 micro strain.
The sensors with stripped fiber show very coincident data with micrometer while the sensors without strip loose their tension when the strain reach 4000 micro strain because of slip between the optical fiber and the polymer jacket as in Figure 8.
To measure compressive strain, usually, pretension of 3000 micro strain is applied in the fiber. Even though there is no tensile stress, the optical fiber in the strain sensor package has 3000 micro strain. Therefore the packages with stripped fiber are valuable technique for accurate long term strain measurement.

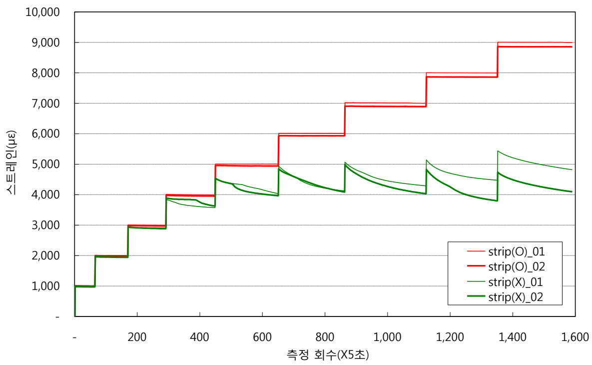

Fig. 7. Sensor response up to 9000 micro strain

5 Various FBG Packages for Tunnel Structure

5.1 FBG Displacement Sensor

Figure 8 is a schematic diagram of FBG displacement sensor, and figure 9 is the picture of installed FBG displacement sensor. In case of upper part of FBG displacement sensor on section 378km385, 370, 340, 310, two pieces of displacement sensors were installed on each installation area such as figure 9. Therefore, the two sensors will distinguish between compression and tension, and will watch the change of diameter of the tunnel.

On the upper part of the FBG displacement sensor, as explained before, for the other sections except where 12 pieces of sensors are installed, one piece of sensor is installed on each points. On the lower part of the FBG displacement sensor, for every section, one displacement sensor was installed each point.

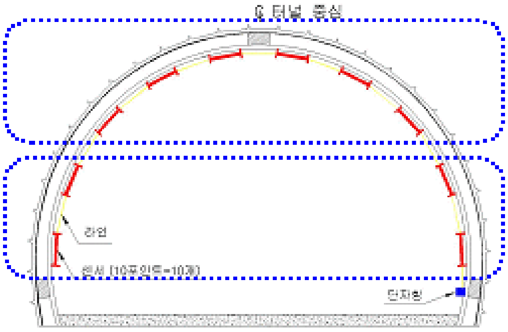

Fig. 8. Schematic Diagram of Fiber Optic Displacement Sensor

Fig. 9. Installed Picture of Fiber Optic Displacement Sensor

5.2 FBG Rod Extensometer

Four pieces of FBG rod extensometer are installed at the installation point by 1.5m distance, such as figure 10 and 11. The locations of the installation point are the left, top, right side of upper side of the tunnel, and the left and right side of lower side of the tunnel.

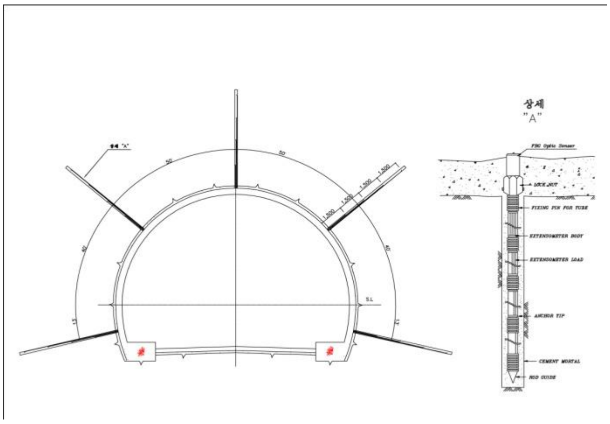

Fig. 10.The Installation Point of Rod Extensometer

Fig. 11. Picture of Installation of Extensometers

6 Application of FBG to KTX tunnel

In Won-hyo Tunnel KTX 13-4 construction site, the automatic measurement was enforced with the FBG sensors at total 13 sections. The installation areas of FBG sensors on the ending point of the tunnel. Basically, it was designed to be installed on each 30m distance. However, 15m distance on the entrance area which could be weak of safety, and observed the changes of diameter of the tunnel.

During two months after the installation of sensors, the displacement change relatively showed a lot; however, after that during about six month, the change was almost not shown. After 14 February 2007, it showed a sharp displacement change. Therefore, we can conjecture that after section 378km310 lower part digging was started at 14 February 2007, the displacement change was occurred on the upper part of the tunnel.

The point of sharp displacement change occur time shows different between the locations of the measurement, such as figure 12. This could be explained as the result of the construction, which was processed separately as two pieces from the middle point of the tunnel. After the digging of the lower part, and after the stabilization of the tunnel, sharp displacement change was no longer shown.

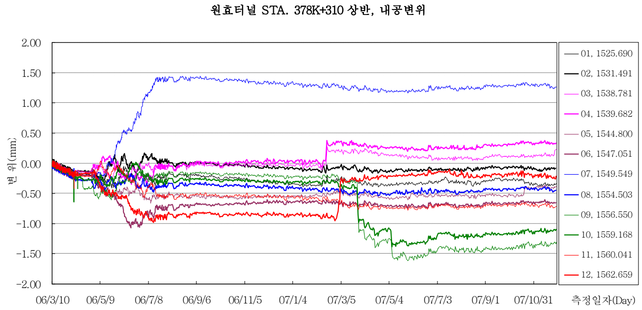

Fig. 12. Section 378km310 Upper Part Displacement Change Measurement Data

This measurement process was continued as a very difficult situation which was performed during construction; however, many sensors are showing good data from the beginning to the end. Compare with the measured data of originally installed electronic sensors in the tunnel or subway construction, this measured data from fiber optic sensors have a remarkable reliability.

6 Conclusions

We analysed the measurement data, from 26 April 2006 to 19 November 2007, of FBG sensors installed at the end point of Won-hyo tunnel of Kyeong-bu Express Railway (KTX) 13-4 construction site. This measurement process was continued as a very difficult situation which was performed during construction; however, many sensors are showing good data from the beginning to the end. Compare with the measured data of originally installed electronic sensors in the tunnel construction, this measured data from fiber optic sensors have a remarkable reliability.

Therefore, except for minor losses of the installed fiber optic sensors at the construction field such as damages from fragments of rocks or impacts from equipments, the FBG sensor which our research team has installed could process an accurate measurement with a superior durability. Moreover, because of the merit of the FBG sensor, such as corrosion resistant characteristic, it has a semi-permanent life span, accuracy, electro-magnetic interference immunity, irrelevance of lightening, and multiplicative characteristics as a sensor. Consider to these many merits, this FBG sensor is the most suitable measuring system for a railway structure, which has electricity of 22 thousands volts.

Acknowledgements

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