Fiber Optic Smart Monitoring of Concrete Beam Retrofitted by Carbon and Glass Sheets

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Abstract

In this paper, we try to detect the peel out effect and find the strain difference between the main structure and retrofitting patch material when they separate from each other. In the experiment, two fiber optic Bragg grating sensors are applied to the main concrete structure and the patching material separately at the same position. The sensors show coincident behaviors at the initial loading, but different behaviors after a certain load.

The test results show the possibility of optical fiber sensor monitoring of beam structures retrofitted by the composite patches.

1. Introduction

For monitoring of the repaired structure with sheet materials, optical fiber sensors are very convenient. The fiber sensors are very small and very similar to the fibers in the sheet materials. 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 since 1980's. We also investigated the possibilities of fiber optic sensor application in various fields such as composites, bridges, buildings and roads. We expect that the fiber optic sensors replace electrical strain gauges. The commercial electric strain gauges show good stability and dominate the strain measurement market. However, they lack durability and long term stability for continuous monitoring of the structures. In order to apply the strain gauges, we only have to attach them to the surfaces of the structures. For optical fiber sensors, we can embed them inside the composites or interface between the composites and the concrete structure. We also can use various packages for evaluation of the structure. In this paper, we investigate the hybrid sheet materials for repairing concrete and apply the fiber optic sensors to the reinforced concrete.

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2. Principles of fiber optic sensors

Among typical fiber optic sensors, fiber Bragg grating sensors (FBGs) and fiber optic Fabry-Perot sensors are widely used. Fiber Bragg gratings can be produced by mass production equipment and they have very good reproducibility.

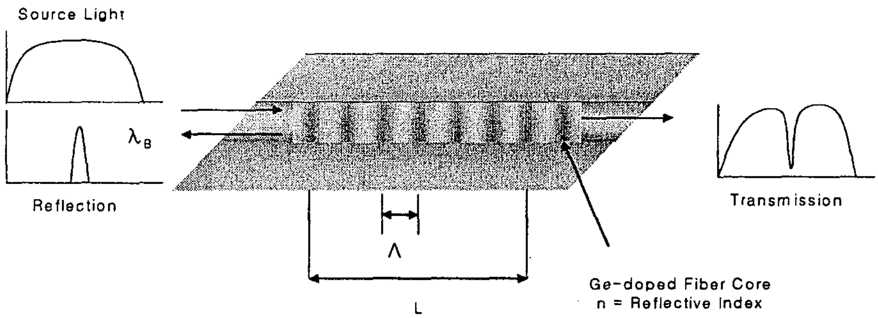

Figure 1. Schematic diagram of FGB signal

As can be seen in figure 1, a broadband incident beam is introduced to the grating and a specific narrow band wavelength beam is reflected.

3. Preparation of specimens

A 15cm×25cm section of reinforced concrete beam with effective depth of 21cm and 240cm length was manufactured for bending tests. It was designed with a maximum ratio of reinforcement (ρ_{max} = 0.75, ρ_b = 0.01466), using compression bar of 2-D10, tension bar of 2-D13s, length 2.8m, rectangular form double layered reinforced beam, the effective span length of which is 2.4m. The sheets of 13cm x 196cm to retrofit the beam were applied to the structure while the distance between the two supporting points in the bottom is 196cm. The distance between the two supporting points on the top of the specimen is 50cm. Tests were performed with 4 point bending.

4. Testing method

While carbon fiber has better performance characteristics than most other fibers, carbon sheets are weak in fire. Glass fiber has fire resistance performance and less detachment than carbon fiber. Therefore, in case of reinforcement with a combination of these two fibers, reinforcement performance and the most efficient mixture of composite material was investigated. We try to find the most effective mixture of the retrofitting composite material by mixing glass fiber and carbon fiber (presented in figure 2). In this paper, bending tests of GCO (mixture of glass fiber and carbon fiber) and GGO (mixture of glass fibers) are conducted and new monitoring techniques are developed, which can give a warning of peel out at early stages. Peel out is a shortcoming of general retrofitting composite materials. In the tests, as shown in figure 3, FBG sensors are protected by using small steel pipe in the interval of composite materials and also between reinforced concrete beams and retrofitting composite materials, then for the warning of peel out, monitoring of strain differences at that point is tried.

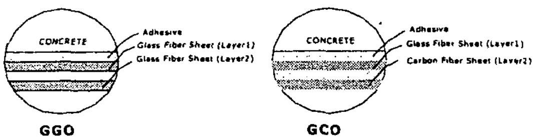

Figure 2. Lay-ups in hybrid type repairing patch

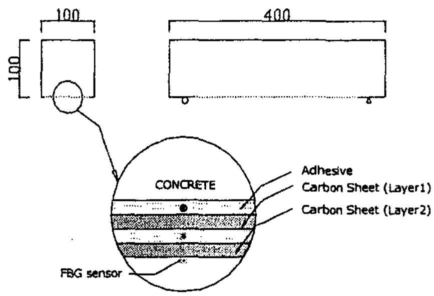

Figure 3. Embedded FBG sensors between the lay-ups

5. Test Results

In two cases of bending tests, it is estimated that GCO (figure 5) is more efficient than GGO (figure 4) because GCO of physically high strength has less danger of sudden brittle failure. As you see in figure 5, the curves show discontinuity points around the strain level of 1500 micro strain. The reason is that the carbon fibers have less elongation capability and higher strength than glass fibers. Then, both GGO and GCO have the strain differences between the side and bottom.

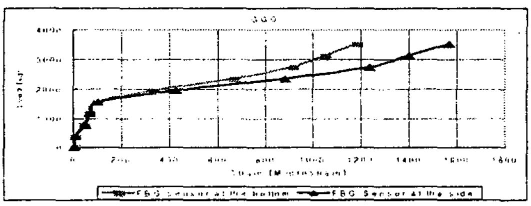

Figure 4. Bending test result from the beam strengthened with two glass fiber sheets

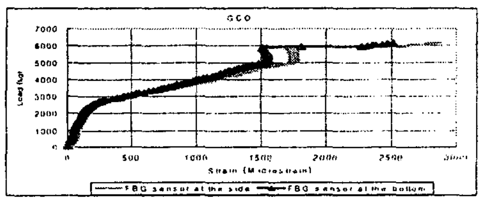

Figure 5. Bending test of the beam strengthened with glass sheet and one carbon sheet

The strains of side and bottom represent the strains of concrete material and repairing composite. The strain in concrete must be smaller than the strain of composite because the sensor in the concrete is closer to the central axis than the sensor in the repairing composite. However, the data in figures 4 and 5 show higher strain in concrete than the strain in composite sheets at the same load level. The difference in strain between concrete and composite becomes larger with increases in load increment. That means the shear between the concrete and the repairing composites becomes larger.

5. Conclusions

The fiber optic sensors in the specimen retrofitted by mixed sheets with carbon and glass fibers show discontinuity points because the carbon fibers have less elongation capability than glass fibers. With this phenomenon, we can give an alarm when carbon fibers break and we can prevent the brittle failure.

The fiber optic sensor measuring technology can be applied to predict peel out effect for retrofitted structures. In particular, strain patterns of FBG sensor at the bottom of Concrete and the fiber sheets show coincident behaviors at the initial loading, but different behaviors after a certain load. The difference in strain between concrete and fiber sheets is the shear of the interface between concrete and the repairing composites. If we monitor the strain behaviors of main material and retrofitting material, we can monitor peel out effects.

Acknowledgement

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