Damage behaviors of fiber Bragg grating sensor in fabrication

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ABSTRACT

It is has been noted that for fiber Bragg grating sensor (FBGS), the tensile strengths of fiber Bragg grating sensors (FBGSs) were decreased after the gratings were written, which may reduce the sensor's measurement range obviously. In this paper, we focused on the damage behaviours of FBGS after fabrication experimentally. Firstly, the tensile tests were carried to measure the tensile strengths of naked optical fiber, decoated optical fiber and optical fiber with Bragg gratings to learn deduction of the tensile strength of optical fiber in the cases respectively. Further, the microscope photography was used to observe the surfaces of optical fiber with or without exposure of excimer laser. The main conclusion is that the UV pulse is the main contribution to reduce the strength remarkably, and the mechanical decoating method also can induce the surface damage on the optical fiber.

Keywords: Fiber Bragg Grating Sensor, Fabrication Damages, Strength Reduction

1. INTRODUCTION

Because of some essential advantages such as small in size, flexibility, absolute measurement, the fiber Bragg gratings sensor (FBGS) were widely used for strain measurement in structural health monitoring[1-6]. Because the phase-mask based method excimer laser is the most popular method for Bragg grating fabrication, but which may also the main cause of the strain limit reduction of optical fiber. The strain limit of FBGS became small after the fabrication of the grating, which also reduced the measurement range of the FBGS. It is because that the strength of the optical fiber reduces significantly after the gratings are written. Some researches[7-10] support the conclusion, the UV effects on the strength were considered [7-8] at beginning, and the mechanical damage induced by decoating (or stripping) of the polymer before UV exposure was concerned [9-10] now.

Because the phase mask based fabrication of the Bragg grating for FBGS includes two main steps which may damage the optical fiber, one is the decoating of stripping of the polymer form a naked optical fiber(Fig.1), another is the UV exposure to optical fiber to write grating by excimer laser (Fig.2).

Fig.1 Decoating the polymer of naked optical fiber

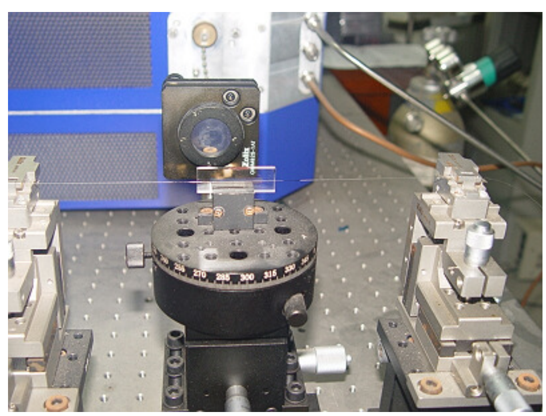

Fig.2 Grating written by phase mask based UV exposure from a excimer laser

In order In order to discover the mechanism of the damage phenomenon fully and quantitatively, we studied the problem experimentally. The tensile tests were carried out to measure the tensile strengths of the optical fiber in different stages

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during the grating fabrication to learn the damage effects in each stage. Further, the microscope photography was used to observe the surfaces of optical fiber with or without exposure of excimer laser.

2. TENSILE TEST

2.1 Experimental Scheme

In order to study the effects of decoating methods on the damages of optical fiber, there are two methods to be compared, one is mechanical method shown in Fig.1, another is called chemical method which a chemical liquid is used to dissolve the coating. Therefore, the samples for tensile test were clarified into following cases (marked "C0", "C1", "C2" in table 1). In order to study the effect of UV power and pulse on the damages of optical, the UV exposure with different pulse number (marked "N") and power intensity (marked "P") were considered. Here, the UV pulse numbers have 500, 3000 and 5000 three cases, the pulse powers have 8mJ, 10mJ, 12mJ and 14mJ four cases provided by Bragg Star 2000.

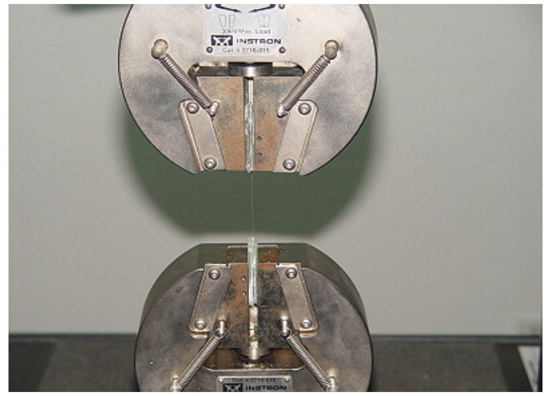

Fig.3 Tensile test in Instron 5567

Table 1. Marks for tensile test samples

Cases of Optical fiber in Grating Fabrication
<u>C0</u> Case 0: Naked optical fiber with polymer decoating by chemical method and without UV exposure
<u>C1</u> Case 1: Naked optical fiber with polymer decoating by mechanical method and without UV exposure
<u>C2</u> Case 2: Naked optical fiber with polymer decoating and UV exposure <u>C2PxxNyyyy</u> The UV exposure with power *xx* mJ and pulse number *yyyy*

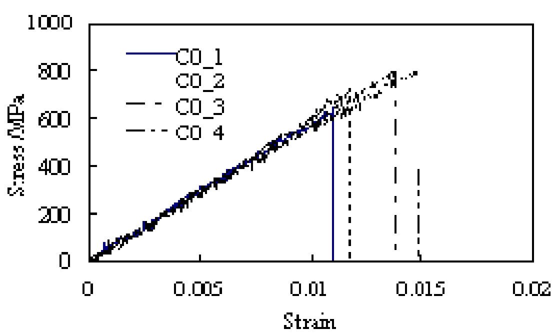

Fig.4 Tensile stress-strain relation of optical fibers in Case 0

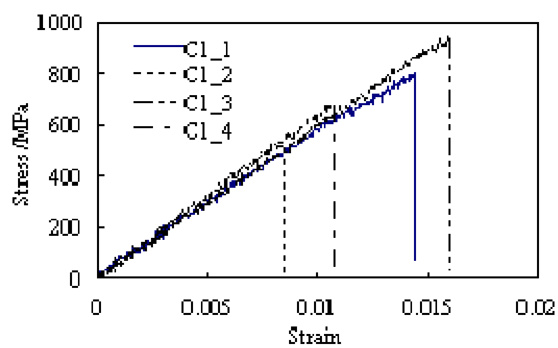

Fig.5 Tensile stress-strain relation of optical fibers in Case 1

The tensile tests were carried out in Instron Universal Testing Machine 5567(Fig.3), a low load cell (50N) is used for tests to ensure the loading accuracy in the experiment. The two ends of the optical fiber were sticked a disk respectively for easily clampping in tensile testing.

2.2 Effect of Decoating Method

Fig.4 is the tensile results of single mode optical fiber without UV exposure and decoated by chemical method which will do no mechanical harm to the optical fiber. The results of 4 samples show that the elastic modulus is about 53~59

GPa, the strength is about 650~796 MPa, its average is 741 MPa. This result indicates that the material properties of the optical fiber have enough uniformity.

For the samples which were applied no UV exposure and decoated by mechanical method, there are some differences. The elastic modulus varies from 53~61 GPa, it is similar to that of optical fibers decoated by chemical method, which means that damage is not very large for the optical fibers decoated by mechanical method. But the strength varies from 516~792 MPa (Fig.5), though its average reduces small (726 MPa), anyhow, such a discreteness of the strength of the optical fibers can only be explained that part of optical fibers were damaged due to the mechanical decoating.

2.3 Effect of UV exposure power

Intuitively, the UV pulses exposed to optical fiber for writing the gratings may induced some damages to the optical fiber. But it is still difficult to give a quantitative description, for the damage may be affect by both the UV pulse's power and number, and the two factors are coupled.

Here, the effect of the UV power on the damages was studied firstly. The tensile tests of optical fiber with UV power 8mJ, 10mJ, 12mJ and 14mJ were shown in Fig 6~9 respectively.

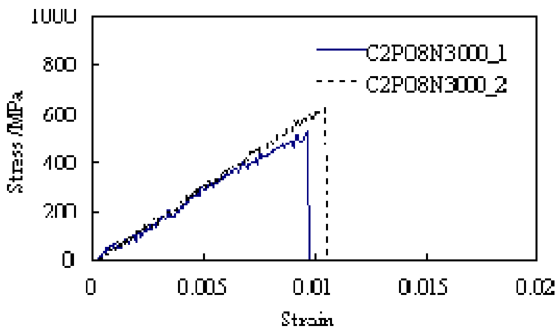

Fig.6 Tensile tests of optical fibers exposed to UV with power 8mJ and pulse number 3000

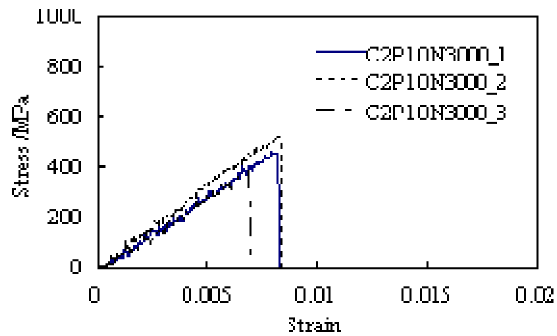

Fig.7 Tensile tests of optical fibers exposed to UV with power 10mJ and pulse number 3000

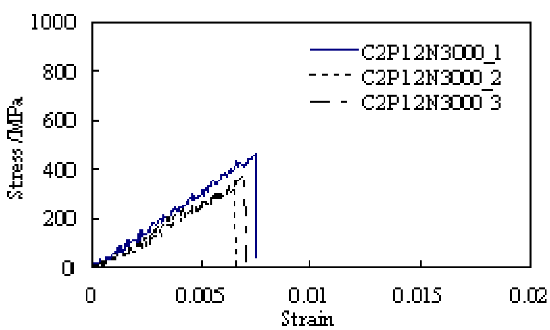

Fig.8 Tensile tests of optical fibers exposed to UV with power 12mJ and pulse number 3000

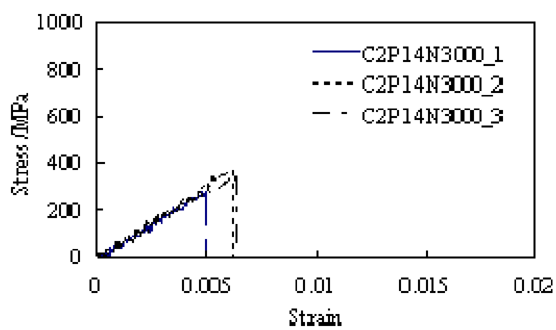

Fig.9 Tensile tests of optical fibers exposed to UV with power 14mJ and pulse number 3000

The results show that the elastic modulus were almost no change under different pulse powers, but the strengths do have some changes. The average strength under the four powers are 571MPa, 439MPa, 371MPa and 323MPa. It indicated that the UV pulses do damage the optical fiber, the larger pulse power induce the more serious damage. Compare to the original average strength, the reduction of the strength is from 23% to 56%, it is remarkable.

2.4 Effect of UV pulse number

Well, the UV pulse number also can affect the change of the strength of the optical fiber. We compare the strengths in three cases---pulse number 500, 3000 and 5000 with same pulse power (14mJ). The results with number 3000 was already shown in Fig.9,the other two results were shown in Fig.10 and Fig.11. The average strengths are 425MPa, 323MPa and 506MPa corresponding to pulse number 500, 3000 and 5000 respectively, which does not provide clear feature about the reduction of the strength with the increment of the pulse number.

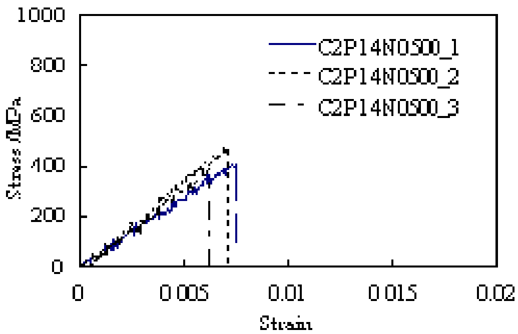

Fig.10 Tensile tests of optical fibers exposed to UV with power 14mJ and pulse number 500

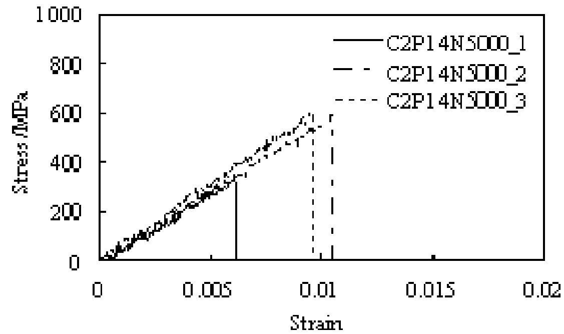

Fig.11 Tensile tests of optical fibers exposed to UV with power 14mJ and pulse number 5000

3. SURFACE MICRO-OBSERVATION

3.1 Microscope photography system

The microscope photography system is Olympus PME3-313UNM (Fig.12) . The system has maximum 1000 times zooming in and maximum 0.2μm resolution, a digital camera is connected to capture the zoomed photograph directory. In the test, the maximum zooming in (1000 times) were used. There are two kinds of optical fiber surface to be captured, one is the surfaces of ordinary optical fiber, another is surfaces exposed by UV with 14 mJ.

Fig.12 Olympus PME3-313UNM microscope system

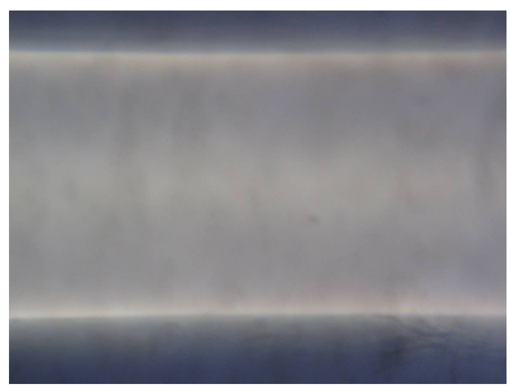

Fig.13 Photograph of optical fiber without gratings, i.e. without UV exposure

3.2 Photograph observation and analysis

The surface's photograph of a plain optical fiber was demonstrated on Fig.13. From the figure, it can be seen that the grey of the surface looks uniform and the boundary looks clear and straight. But for the surfaces of optical fiber with gratings, there are some differences (Fig.14, Fig.15). Firstly, in the each figure, there exist two different areas, the area without gratings looks more uniform as shown in Fig.13, the area with gratings has some diffractive stripes. Second, some photos (not all) of the surface with gratings show that the boundary of the optical fiber becomes rough (as Fig.14), because the phenomenon can be observed only in some samples, so it can be ablated by UV, it is most possible to be the surface damages induced by the mechanical decoating method.

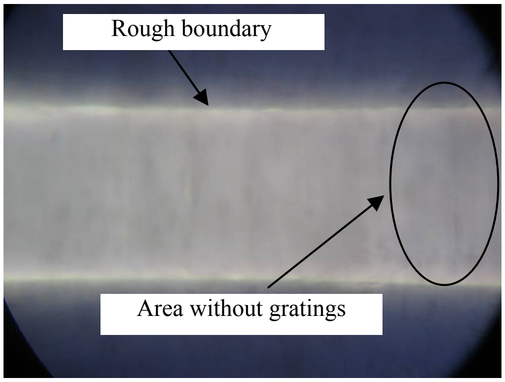

Fig.14 Optical fiber with UV exposure has remarkable rough boundary

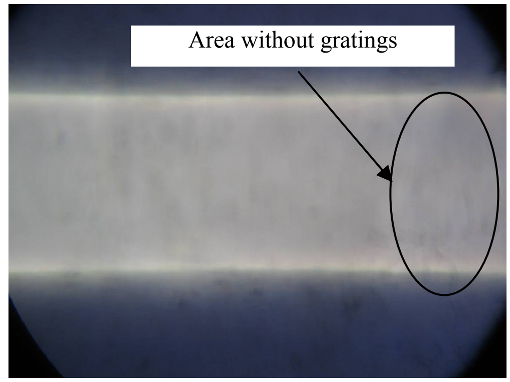

Fig.15 Difference brightness in areas of grating and non-grating

4. CONCLUSIONS

It the paper, the damage behaviours of FBGS after fabrication were studied experimentally, through the tensile tests and the microscope photography to detect the damages of optical fiber indirectly and directly, some conclusions can be drawn as followings:

(1) The UV pulses for writing grating can reduce the strength of optical fiber remarkably, the higher pulse power induces the higher damages. So, it is necessary to use as lower power as possible in writing Bragg gratings by UV pulse.

(2) The mechanical decoating method may induce the deduction of the strength significantly. It is recommended to use chemical method for decoating to avoid the surface damages on the optical fiber.

(3) The surfaces after UV pulse exposure have non-uniform grey distribution comparing with that in ordinary optical fiber surface. Because there is no ablation to be observed on the surface of the optical fiber, the damage induce by the UV pulses may cover the whole cross section of optical fiber.

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