Progress on monitoring of adhesive joints using multiaxis fiber grating sensors

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ABSTRACT

Previously, the results of embedding multi-axis fiber gratings into adhesively bonded joints were discussed [1]. This paper presents more information on the testing of the adhesive joints and techniques employed to successfully embed a fiber grating sensor into such structures. These techniques include orienting the fiber, marking its orientation, and preparing it for embedment into the adhesive. Also discussed are strain relief methods for the egress of the fiber.

Keywords: aluminum, transverse strain, testing, embedded, adhesive, optics, egress, strain relief

1. BACKGROUND ON MULTI-AXIS FIBER GRATING STRAIN SENSORS

The Blue Road Research multi-axis fiber grating strain sensor has the capability to measure both axial and transverse strains when embedded into a structure (
Figure 1) [2,3.] The sensors used in these tests were coated with Polyimide and have a diameter of 135 µm.

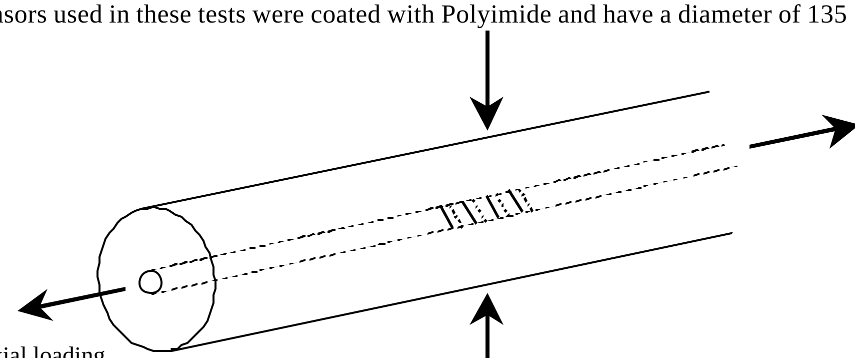

Figure 1. Axial and transverse load sensing directions of multi-axis fiber grating strain sensor.

The multi-axis sensor is formed from dual overlaid Bragg gratings written onto polarization preserving fiber (
Figure 2.) Figure 3 shows how the multi-axis fiber grating strain sensor responds to axial and transverse strains. When a broadband light source is directed into the sensor, four spectral peaks are reflected (one peak for each grating and polarization axis.) Axial strain is measured by calculating the amount of wavelength the peaks shift. Transverse strain is measured by the amount of peak to peak separation.

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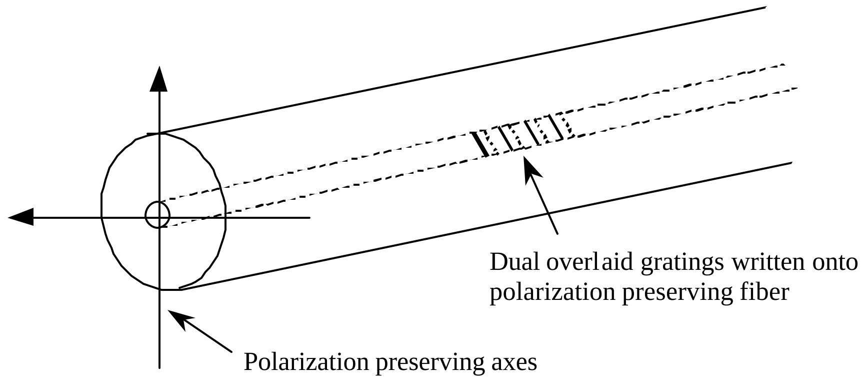

Figure 2. Multiaxis fiber grating strain sensor capable of measuring axial and transverse strains

This set of dual spectral peaks occurs for each grating written onto the polarization maintaining fiber. Although fibers with dual overlaid gratings were used to support these tests, only one set of peaks was necessary to measure the transverse strains in the fiber correlating to shear strain [1.] The second set of peaks was used as verification in the tests.

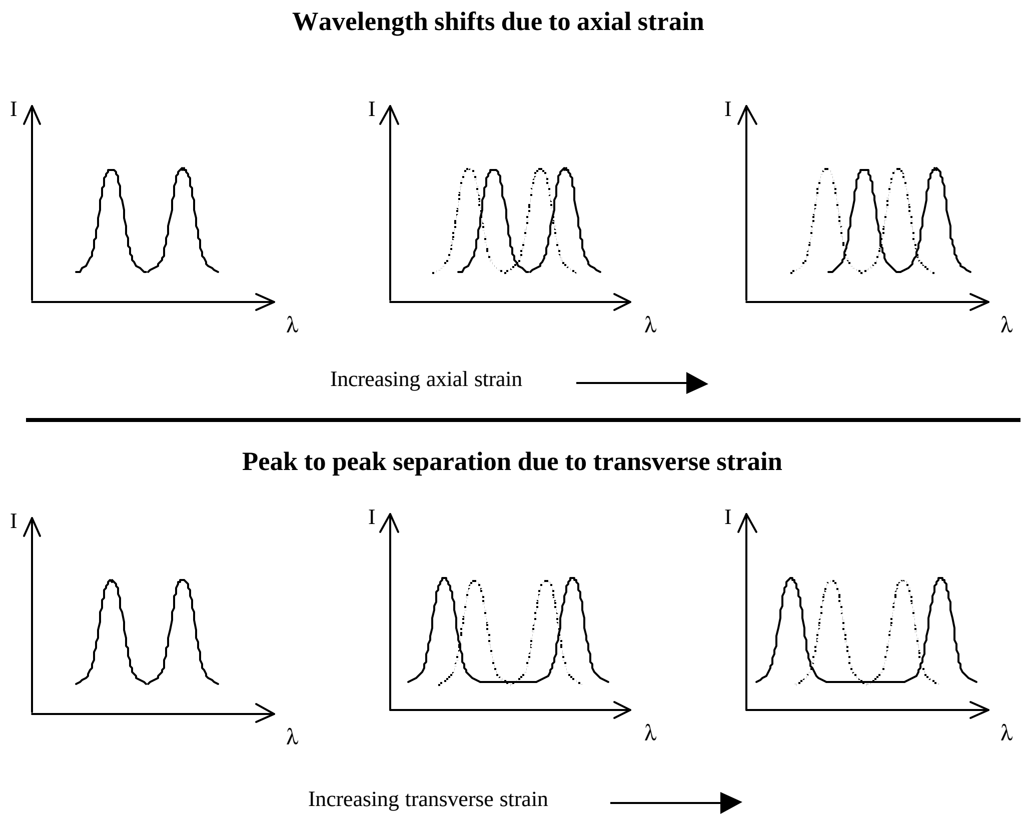

Figure 3. Response of multi-axis fiber grating strain sensor to axial and transverse strains.

2. ADHESIVE JOINT INSTRUMENTATION

The test specimen baseline in this work was a double lap adhesive joint (Figure 4.) This symmetric configuration was chosen to simplify joint modeling. The joints were fabricated from Al7075 with 9394 adhesive cured for 1 hour at 200^{o}F. The multi-axis strain sensors capability to measure transverse strain requires that its orientation be carefully controlled during the embedding process.

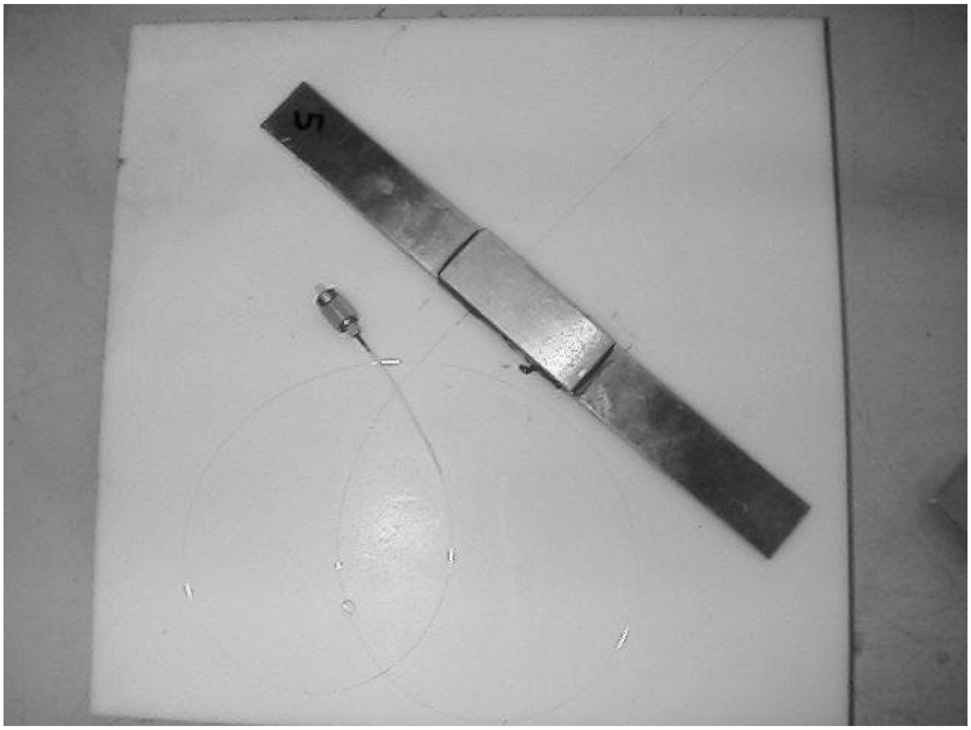

Figure 4. Instrumented double lap aluminum adhesive joint

2.1. Orienting and marking the multi-axis strain sensor

One method to orient the transverse sensing axes of the multi-axis fiber grating sensor is to use a transverse load fixture in conjunction with a demodulation device such as an optical spectrum analyzer (Figure 5) [4.] The fiber is placed into rotation stages on either side of the fixture to allow for rotation without twisting. The load fixture places the fiber in diametrical compression, in which axial strain can be neglected, to apply the necessary transverse load. The spectrum analyzer is then used to measure the relative position of the spectral peaks as the load arm is lifted and the rotation stages are incremented for the next load. The orientation can be determined by noting a reversal in peak movement (or a lack of movement in the case of 45°) as the fiber is transversely loaded at different angles. Once the desired orientation has been located, it is necessary to mark the fiber to retain this orientation during the embedment process.

One way to mark the fiber orientation is to place tabs on the fiber to provide a reference. For this project, UV curing epoxy was used to create these tabs (Figure 6.) Once, the fiber was oriented, glass slides were placed underneath it on either side of the grating. UV curing epoxy was then applied and cured leaving a flat against the glass slide and providing a visual indicator to the orientation of the fiber. The oriented fiber is then ready for embedding.

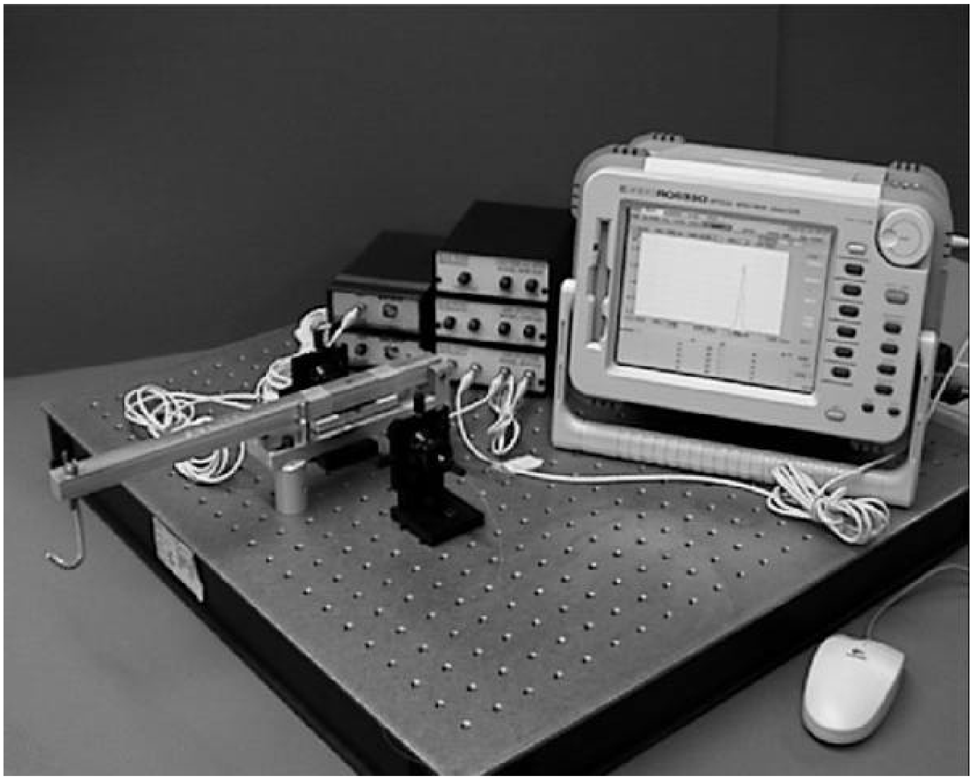

Figure 5. Transverse load fixture used in conjunction with an optical spectrum analyzer.

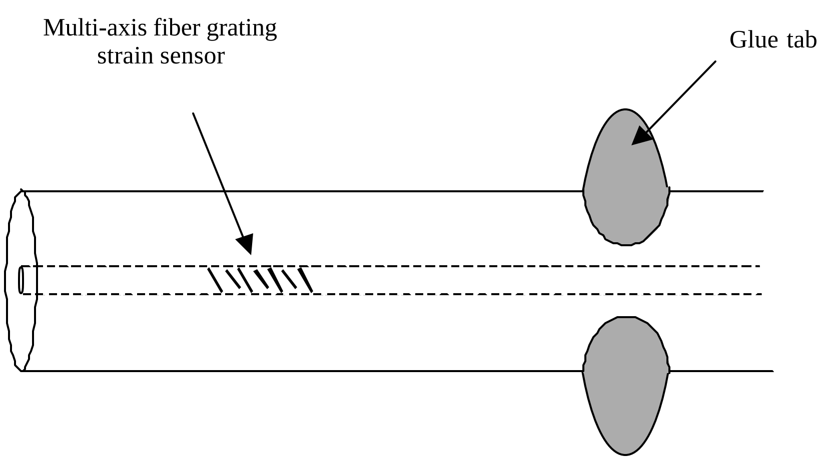

Figure 6. Glue tabs on fiber to control orientation of transverse strain sensing axes.

2.2. Embedding the fiber sensor

To ensure that the adhesive consolidated well around the fiber, adhesive was first placed on the fiber prior to embedding (Figure 7.) As the adhesive joint was built up, the fiber grating sensor was placed into the adhesive (Figure 8.) To maintain an even bond height, a dummy fiber was used as a spacer. As the sensor was placed into the joint, the tabs were placed on a flat surface to ensure proper sensor orientation.

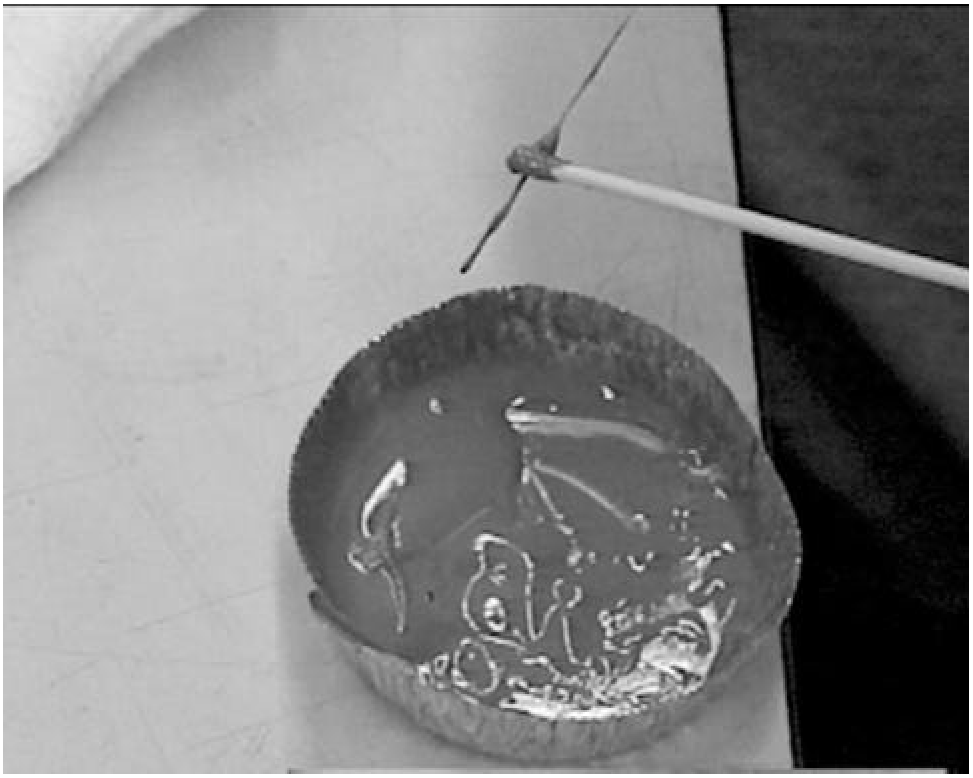

Figure 7. Placing adhesive onto fiber prior to embedding to ensure consolidation around the fiber.

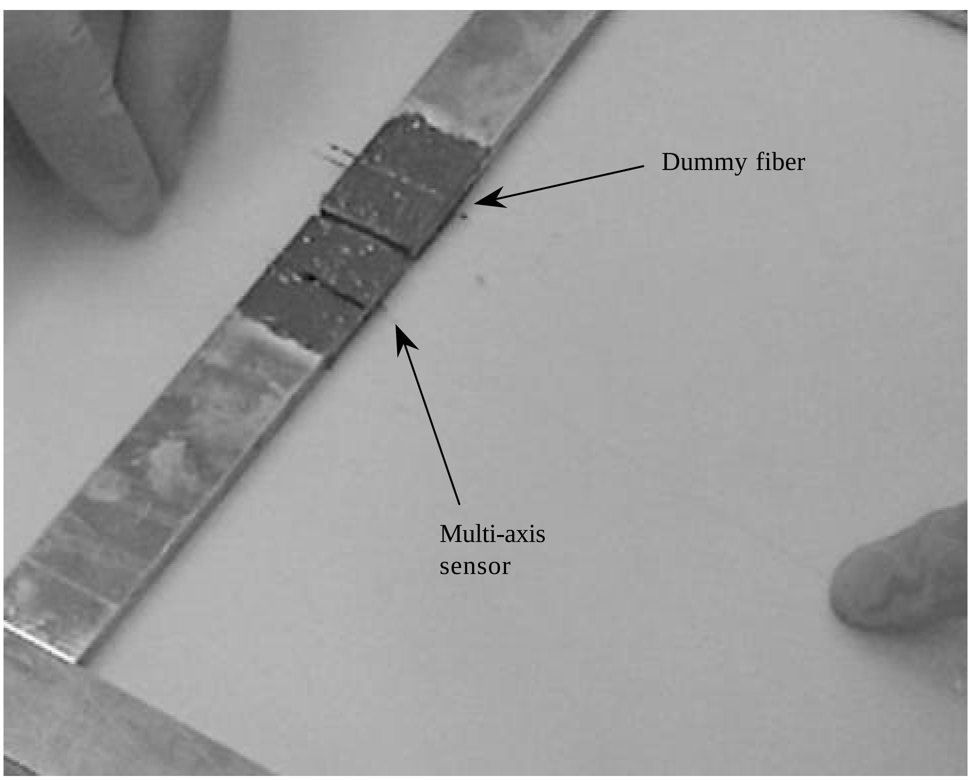

Figure 8. Placing oriented multi-axis fiber grating into adhesive area.

In addition to sensors being embedding into the interior of the joint, pre-fabricated joints were retrofit with the multi-axis sensor by applying adhesive onto the fiber and placing the sensor at the edge of the adhesive bond (Figure 9.) Once the build up of the instrumented joints was completed, they needed to be placed into an oven to cure (200°F for 1 hour) the adhesive in a reasonable timeframe.

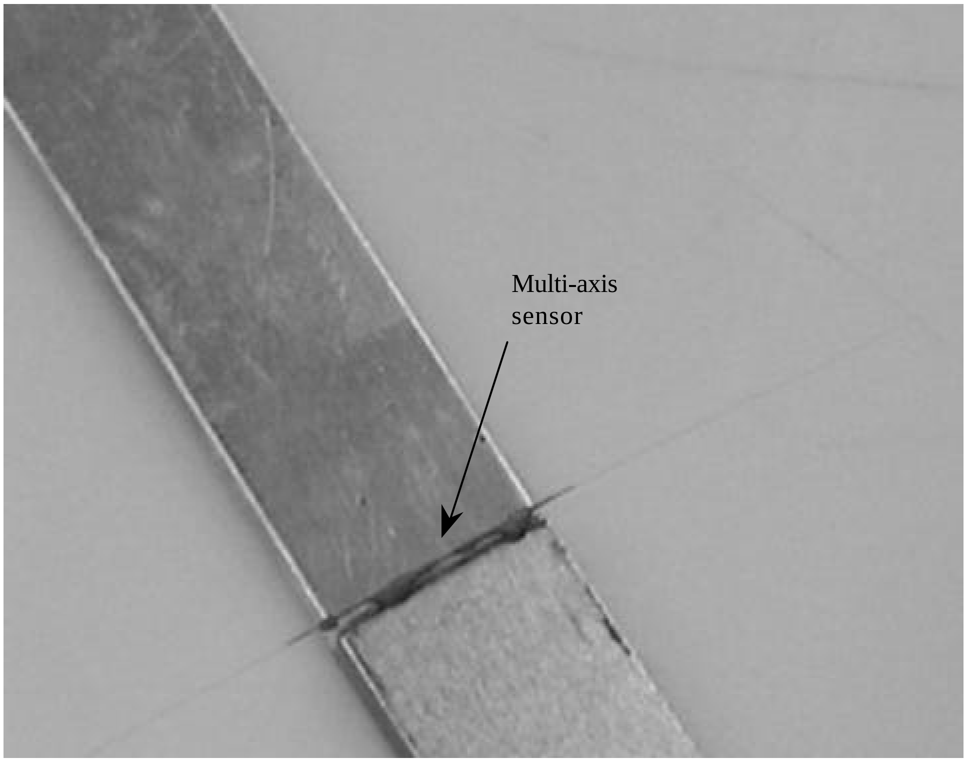

Figure 9. Retrofitting sensor to pre-fabricated joint.

This need to expose the joints to a higher temperature raised the question of the fiber connector's ability to handle such a temperature (Figure 10.) To determine this, a sample fiber connector was placed into the oven along with some un-instrumented joints and exposed to the full cure cycle. This test showed that the connectors could survive this higher temperature. Once this had been established, the instrumented joints were placed into the oven for curing (Figure 11.) After the joints were fully cured, it was necessary to protect the fiber from breaking at the edge of the joints.

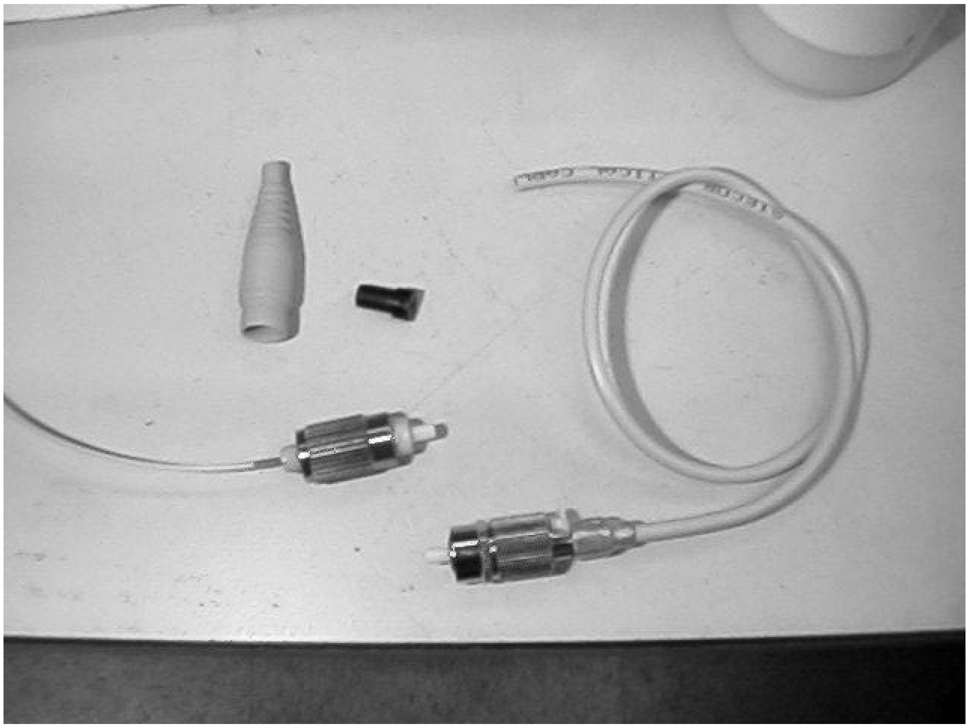

Figure 10. Fiber connectors after 1 hour at 200°F in oven to ensure survivability during adhesive joint curing.

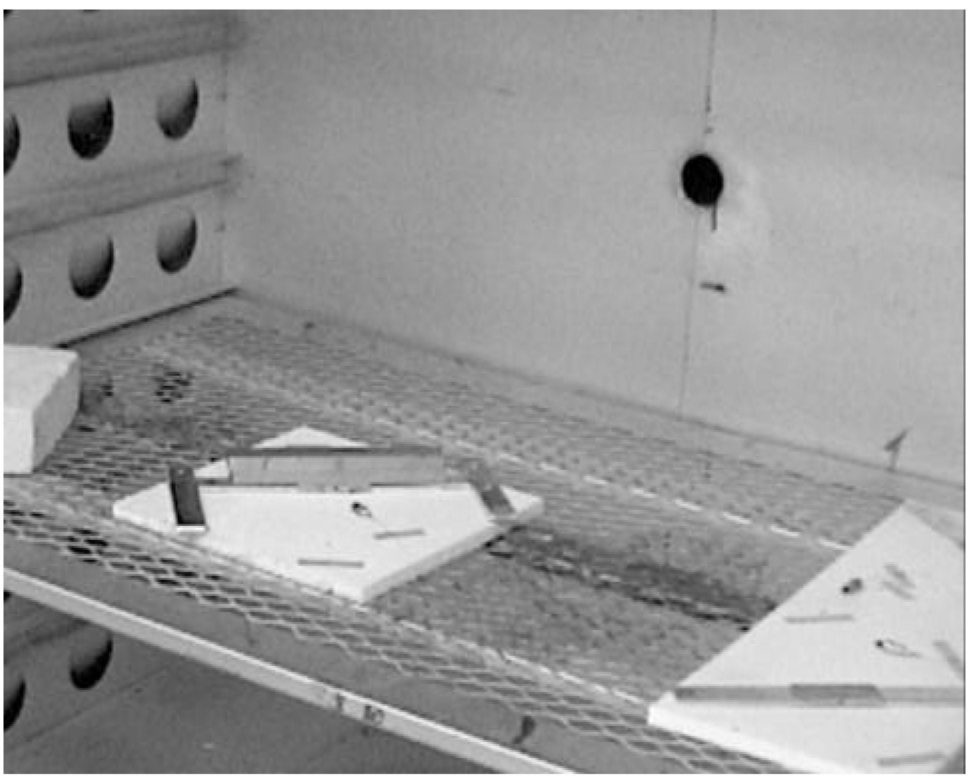

Figure 11. Curing adhesive at 200°F for 1 hour.

2.3. Strain relief

To provide strain relief at the fiber egress points, RTV silicone was applied around the fiber at the edge of the joint (Figure 12.) This technique, along with using UV epoxy in the same manner, resulted in a rugged strain relief solution and survived many of the joint failures during testing.

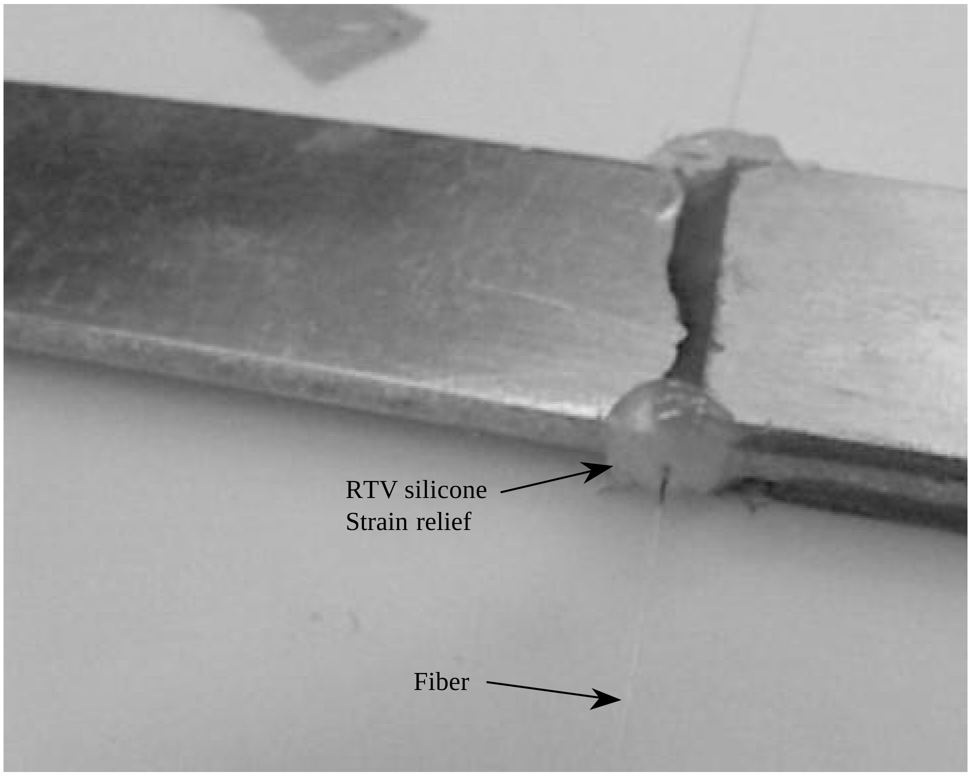

Figure 12. RTV silicone used as strain relief on fiber at edge of joint.

3. TESTING

The instrumented adhesive joints were tested in shear by placing them in a tensile tester [1.] Figure 13 shows one of the joints in the load fixture. The joints were loaded to failure, and one such joint can be seen in Figure 14. The ruggedness of the multi-axis sensor when placed into the adhesive joint became apparent when the sensor survived many of the joint failures. This was verified by using a visible light source to illuminate the grating and check for light at the opposite end (Figure 15.) A broken fiber grating would keep most of the light from passing through.

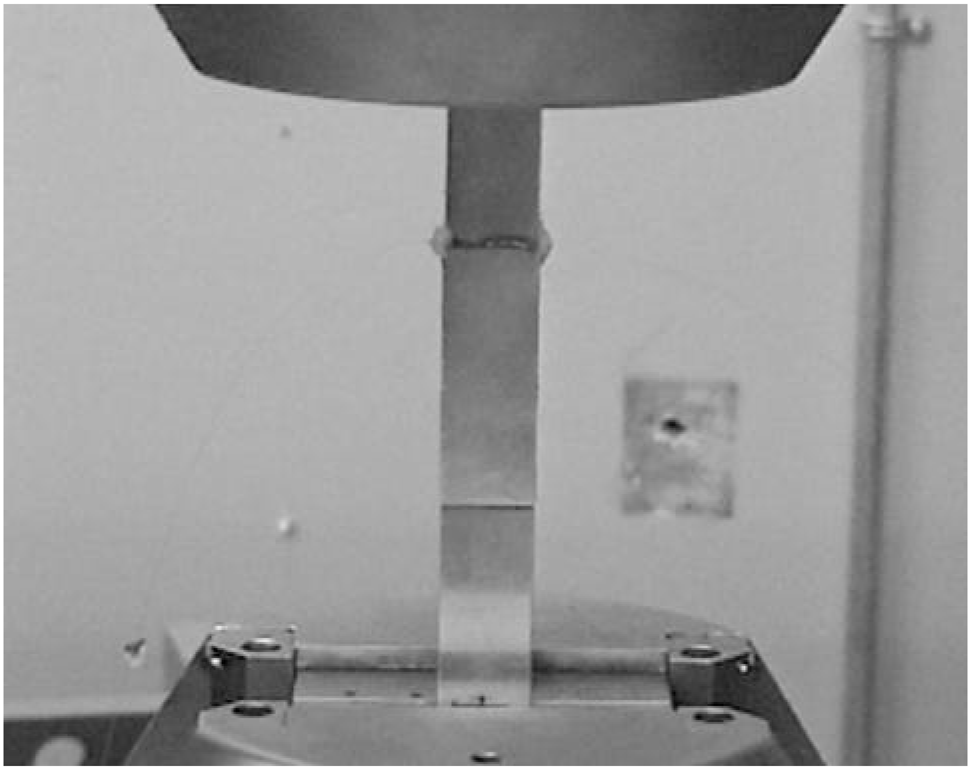

Figure 13. Instrumented adhesive joint in tensile loader.

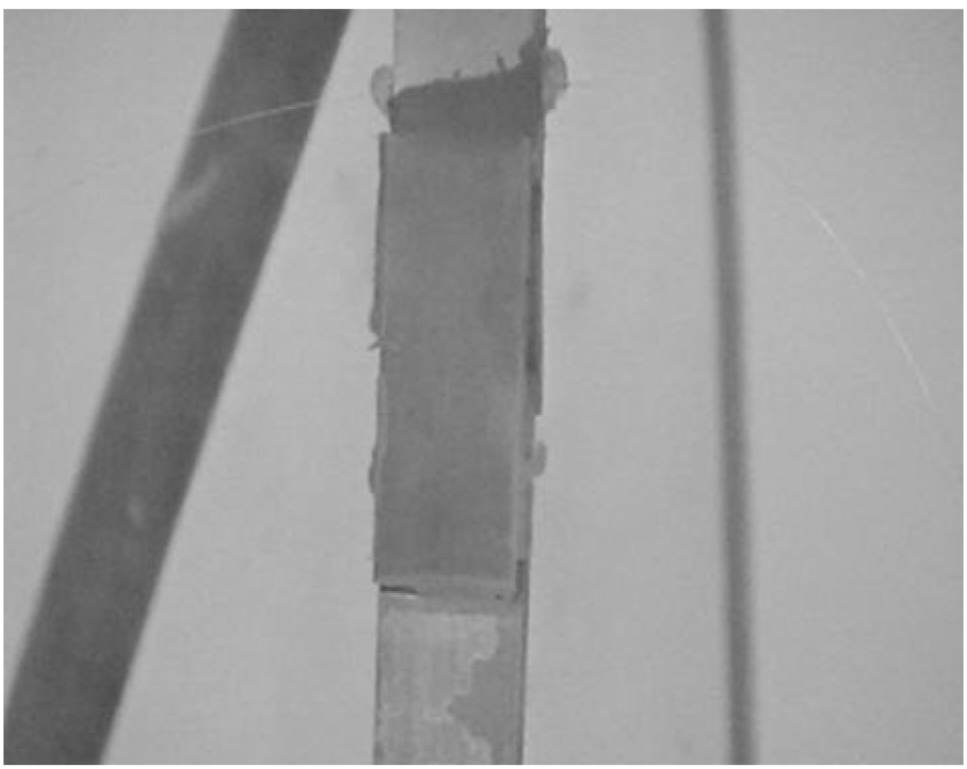

Figure 14. Failed adhesive joint.

Figure 15. Checking integrity of grating sensor with visible light source after joint failure.

4. SUMMARY

Using proper embedding techniques, multi-axis fiber grating sensors can be successfully placed into adhesive joints. These techniques include wetting the fiber with adhesive, properly orienting the multi-axis sensor, and providing adequate strain relief.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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