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Influence of Embedded Fiber Optic Sensor on Performance of Single-lap Bonded Joint

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Abstract. This article describes experimental research on properties of adhesive joints with embedded optical fibers. The objective was to determine whether fibers may cause a reduction of mechanical properties of joints. Specimens with single-lap joint for tensile test were made with various configurations of optical fibers in an adhesive layer. Shear strength and fatigue life tests were performed and results were evaluated using the statistical analysis methods.

Introduction

With an increasing use of bonded structural joints, even in demanding applications such as aircraft wing spar, increasing attention is focused on monitoring of their condition. In [1] we have demonstrated that optical Fiber Bragg Grating (FBG) sensors, integrated in the adhesive layer, are suitable for monitoring of joint disbonding. However, it was necessary to confirm, that optical fiber which is embedded in the adhesive, does not have degrading effect on the properties of the joint.

Several research works deal with quasi-static stress measurements in bonded joints using the fiber optic sensors. For example, in [2] measurement of adhesive joints of honeycomb sandwich is described, in [3] tensile test is described; in [4] FBG sensor is used for monitoring of adhesive joint during the pressure test; three-point bending test of glass composite parts with FBG sensors in a thick adhesive joint is described in [5]. But the influence of the embedded fiber optic sensors on the mechanical properties of adhesive layer is not covered in available literature.

Composite specimens with single-lap bonded joint were designed to evaluate influence of optical fiber with ORMOCER® primary coating on shear strength and fatigue properties of such joint. This type of coating is usually used for FBG sensors manufacturing, especially for embedded solutions.

Description of Specimens and Experimental Set-Up

Specimens Set-Up. Base parts of all specimens were made from Carbon/Epoxy composite using the prepreg technology. Single-lap bonded joints were made with HYSOL EA 9394 two component adhesive, which is commonly used for bonding large and uneven surfaces of composite aircraft parts. Configuration and dimensions of tested specimen is pictured in Fig. 1. Typical thickness of bonded joint in this case is at least 0.2 mm, which is enough for integration of optical fiber with outer diameter of 0.195 mm. Minimal thickness is defined by glass beads (with outer diameter 0.200 to 0.315 mm) added to adhesive.

Eighty four pieces of specimens were made and tested in total. The basic configuration is the bonded joint without optical fibers. Specimens with fibers in the joint were made in 5 modifications, differing in number of fibers and their orientation to the loading force direction.

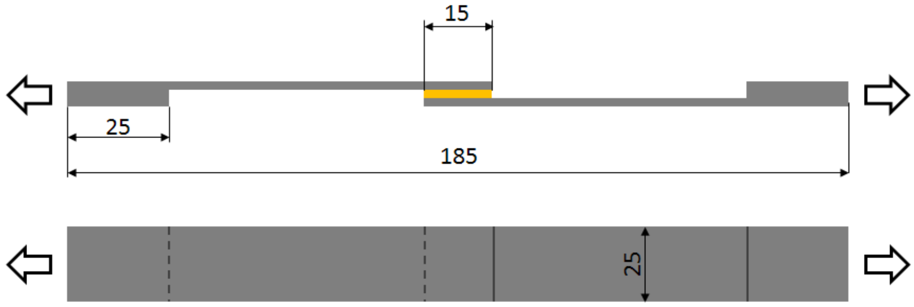

Fig. 1. Configuration and dimensions of tested specimen.

All configurations and numbers of specimens, that were tested, are shown in the Fig. 2 and in the following list:

- conf. A: specimens without optical fibers in an adhesive joint
- conf. B: one longitudinal fiber, oriented in a direction of loading force
- conf. C: three longitudinal fibers, oriented in a direction of loading force (for detail see Fig. 3)
- conf. D: one longitudinal fiber fixed with a cyanoacrylate adhesive
- conf. E: one transverse fiber oriented perpendicularly to loading force
- conf. F: two transverse fibers oriented perpendicularly to loading force

Configuration D was designed to confirm that small drops of cyanoacrylate adhesive, used for fixation of long fiber optic sensors before applying epoxy adhesive, don’t cause flaws in the adhesive joint.

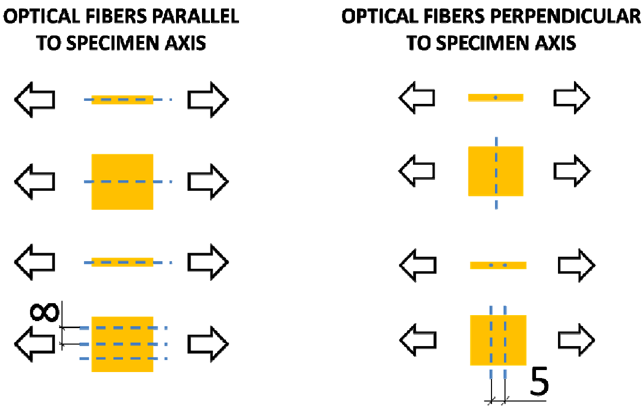

Fig. 2. Configurations of fibers in an adhesive layer.

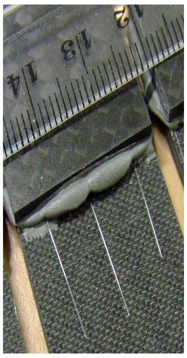

Fig. 3. Detail of optical fibers in an adhesive joint (conf. C).

Experimental Set-Up. Quasi-static tests of bonded joint shear strength were performed on TiraTEST testing machine. Specimens were loaded by axial force with controlled displacement until final damage.

Fatigue tests of bonded joint fatigue life during the cyclical shear loading were performed on Amsler testing machine. Maximum tensile force during one cycle corresponded to 20 % of maximum tensile force reached during the quasi-static tests of specimens without optical fibers.

Experimental Results

Influence of embedded optical fiber on the shear strength was tested on 37 specimens, fatigue properties were examined using 47 specimens. Results are shown in the Table 1.

Table 1. Summary of the experimental results.

bonded joint configuration	**number of specimens, shear strength/fatigue life**	**τ_{MAX} [MPa]**	**N [1]**
A	13/19	17.6±2.2	386014±235279
B	5/5	17.1±1.7	521738±280770
C	4/6	21.2±1.2	817163±265337
D	5/5	18.7±1.7	584327±232513
E	5/7	17.9±2.3	377680±107822
F	5/5	19.9±1.6	572858±280608

Statistical analysis of experimental data was performed to verify the following hypotheses:

- optical fiber in an adhesive layer has no influence on a shear strength of the joint
- optical fiber in an adhesive layer has no influence on a fatigue life of the joint

Statistical methods of the F-test and unpaired t-test were used, with the significance level of 0.05. For summary of results see Table 2. Hypotheses about no downgrading influence of embedded fibers on bonded joint performance were not rejected. In case of configuration C (three fibers in joint) and F higher shear strength, compared to specimens without fibers in joint, was observed. Furthermore, specimens with three fibers in a joint showed an improvement of their fatigue life.

Table 2. Summary of the results of statistical analysis (p-values).

bonded joint configuration	**shear strength**		**fatigue life**	
	F-test	**t-test**	**F-test**	**t-test**
A	ref.	ref.	ref.	ref.
B	0.349	0.640	0.271	0.289
C	0.196	0.007	0.324	0.001
D	0.348	0.350	0.552	0.112
E	0.395	0.822	0.071	0.940
F	0.294	0.047	0.272	0.150

This is most likely due to more even distribution of adhesive in joint. Glass beads (spacers in adhesive) can be slightly pressed into composite parts of specimen during the joint assembly process, which can cause local decrease of adhesive thickness. Optical fibers work as the additional spacers.

Conclusions

In total, 84 specimens with 6 configurations of fibers in the bonded joint were tested. No negative influence of embedded fiber on the single-lap bonded joint shear strength was investigated. It was found that embedded optical fibers do not reduce the fatigue life of this type of bonded joint. Especially specimens with optical fibers embedded in a loading direction reached higher levels of fatigue life than specimens without fibers. This could be explained by more even thickness of cured adhesive, secured by fibers acting as spacers.

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