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Effect on strength due to optical fibre embedding in advanced composites during structural health monitoring

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Abstract: The influence of embedded optical fibre on the strength of flexurally loaded composite laminate is studied in this paper. In a given structure, different loads create a complex state of stresses in the structure. In-situ structural health monitoring of composite structures could be achieved by using embedded optical fibre as sensors. The primary goal of this research is to assess whether the inclusion of optical fibre creates a local stress concentration which could trigger delamination and final collapse of the structure. In the current study optical fibres are embedded in three types of specimens; first at the neutral axis (50% thickness) and second at 75% thickness from the mould surface and at last without optical fibre. The resin rich area is around the optical fibre and the bonding between the optical fibre and the resin is studied using Scanning Electron Microscope (SEM). An attempt is made to assess the structure using C-Scan method. It was concluded that the embedded optical fibres could be successfully used as sensors in composite laminae and will not significantly compromise the strength and integrity of the composite host.

Keywords: Glass fibre reinforced composite (GFRP); Optical fibre; Embedded; SHM; Three-point bending test; Flexural strength.

I. INTRODUCTION

Composite structures are widely used in many areas such as, aerospace, automobile, structural engineering, industrial engineering, oil and gas etc. The composite structures are used in many harsh environments because of its good strength to weight ratio, good quality and reliability. So it's necessary to monitor the structure. Many NDE techniques, such as ultrasonic scanning, acoustic emission (AE), sonics, radar, shearography, vibration testing, and conductivity were a part of cure monitoring in the past, and helping structures to improve its performance. But there were a big challenge to combine NDE technology with cure monitoring methods. Hence structural health monitoring (SHM) provides a solution to the structures to keep safely during service condition. In SHM, fibre optic sensors are used along with structures because of their many advantages such as small diameter, light weight, capability of embedded inside composite and many more.

There is possibility to compromise in mechanical properties of structures by inclusion of fibre optic sensors (smart materials) along with composite structures. Strength is the primary factor in the mechanical property of composite material. So it's very important to analyse the effect on strength due to optical fibre embedding in advanced composites during structural health monitoring.

In this paper, an experimental test procedure was designed and determined the flexural bending strength of glass fibre reinforced composite structures. This is achieved by using three point bending experiment. It is observed that inclusion of optical fibre in the composite specimen will not affect significantly.

II. THEORY OF SIMPLE BENDING

A plate is loaded a bending load at the centre by using simple support as shown in Figure 1.1(a). The middle section is subject to the maximum load. Figure 1.1(b) shows the normal stress distribution of a section. The normal stress distributes linear along the height. The value of the normal stress reaches a peak at the surface of the beam. Therefore, the bending strength of a sample can be calculated by using the below equation.

$$\sigma = \frac{3P_b l}{2bh^2}$$

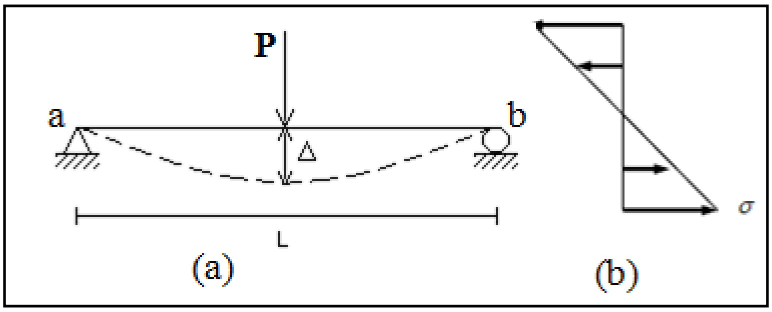

Figure 1.1: (a) Three-point bending (b) Normal stress along the height

III. EXPERIMENTAL PROCEDURE

a) Materials:

- Reinforcement fibres: E-glass fibres.
- Resin System: Epoxy resin Lapox L-12 (MY740).
- Hardener: K5 27%.
- ATH (Alumina Trihydrate) powder, 20%.

b) Stacking sequence:

The stacking sequence chosen for specimens was as below.

- Type A: $[90/0/OF/45/-45/0/90/OF/45]_s$
- Type B: $[90/0/OF/WR/90/0/OF/45]_s$
- Type C: $[0/90/OF/CSM/45/-45/OF/WR]_s$.

In the current study of optical fibres are embedded in three types of specimens of each type; first at the neutral axis (50% thickness) and second at away from the neutral axis (75% thickness) and at last without optical fibre.

c) Sample preparation:

Laminates were produced by hand lay-up process. Two cast iron moulds of size 600 X 600 X 12 (mms) were used for casting of polymer matrix composite slabs and it was heated in180o C for an hour. The specimens of dimensions 200mm and 20mm are cut from casted panel using diamond tool cutting machine.

d) Three-point flexural testing:

In this work, the specimens of composite materials were loaded at the centre and subjected to three-point support bending tests to assess and compare their flexural strength It was decided that non-destructive bending tests are useful tools to predict the behaviour of composites in complex bending situations and to optimize their design.

e) Numerical analysis of composite specimens:

The static structural analysis of a glass fibre reinforced composite embedded optical fibre specimens is done by using the NASTARN/Patran. The specimens CAD modelling, meshing and analysis is carried out in NASTARN/Patran. The numerically analyzed bending strength is as shown in Table 1.1.

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Specimen Id	Numerical Bending Stress (MPa)
Aa (Type A, Near neutral axis)	265
Ab (Type A, Away from neutral axis)	270
Ac (Type A, Without optical fibre)	275
Ba (Type B, Near neutral axis)	185
Bb (Type B, Away from neutral axis)	191
Bc (Type B, Without optical fibre)	195
Ca (Type C, Near neutral axis)	234
Cb (Type C, Away from neutral axis)	237
Cc (Type C, Without optical fibre)	240

Table 1.1: Numerically analyzed bending strength

IV. RESULTS AND DISCUSSION

a) Bending strength

Bending strength is a mechanical parameter of any material, is defined as a material's ability to resist deformation under load. The bending strength of the GFRP specimen embedded optical fibres was carried out by experimentally and numerically. The experiment result is validated by numerical results and also enhanced the percentage error as shown in below Table 1.2 and Figure 1.2.

Specimen Id	Experimental Bending Stress (MPa)	Numerical Bending Stress (MPa)	Percentage Error
Aa (Type A, Near neutral axis)	255.93	265.00	3.4%
Ab (Type A, Away from neutral axis)	256.84	270.00	4.9%
Ac (Type A, Without optical fibre)	257.47	275.00	6.4%
Ba (Type B, Near neutral axis)	181.9	185.00	1.7%
Bb (Type B, Away from neutral axis)	188.53	191.00	1.3%
Bc (Type B, Without optical fibre)	190.63	195.00	2.2%
Ca (Type C, Near neutral axis)	210.84	234.00	9.9%
Cb (Type C, Away from neutral axis)	214.17	237.00	9.6%
Cc (Type C, Without optical fibre)	215.75	240.00	10.1%

Table 1.2: Bending strength analyzed experimentally and numerically

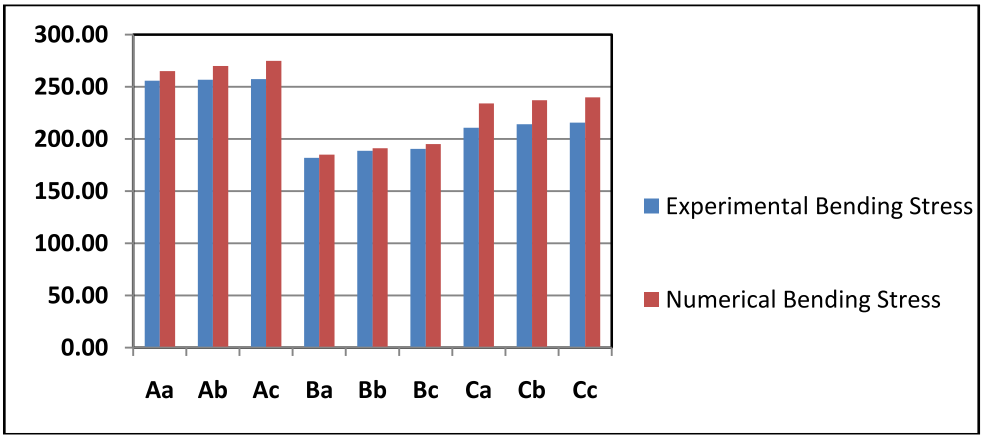

Figure 1.2: Comparison of experimental and numerical bending strength

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b) Comparison of bending strength of the specimens with and without embedding optical fibre

The inclusion of optical fibre creates a local stress concentration which could trigger delamination and final collapse of the structure. The experimental and numerical bending strength comparison has done with respect to optical fibre inclusion in different location as shown in Table 1.3. The bending strength of all different types at near neutral axis, away from neutral axis and without optical fibre observed experimentally and numerically and plotted as shown in Figure 1.3 and Figure 1.4.

Bending Stress (MPa)	Specimen Id	Near NA	Away From NA	Without OF	Percentage Difference in Near NA	Percentage Difference in Away From NA
Experimental Bending Stress (MPa)	Type A	255.93	256.84	257.47	0.6%	0.2%
	Type B	181.9	188.53	190.63	4.6%	1.1%
	Type C	210.84	214.17	215.75	2.3%	0.7%
Numerical Bending Stress (MPa)	Type A	265.00	270.00	275.00	3.6%	1.8%
	Type B	185.00	191.00	195.00	5.1%	2.1%
	Type C	234.00	237.00	240.00	2.5%	1.3%

Table 1.3: Experimental and numerical bending strength comparison wrt OF inclusion

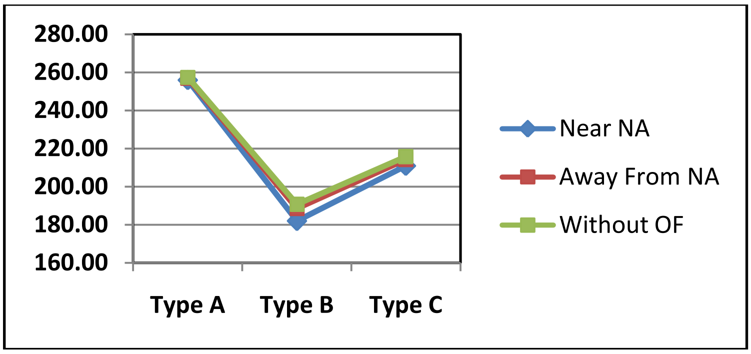

Figure 1.3: Experimental bending strength comparison wrt OF inclusion

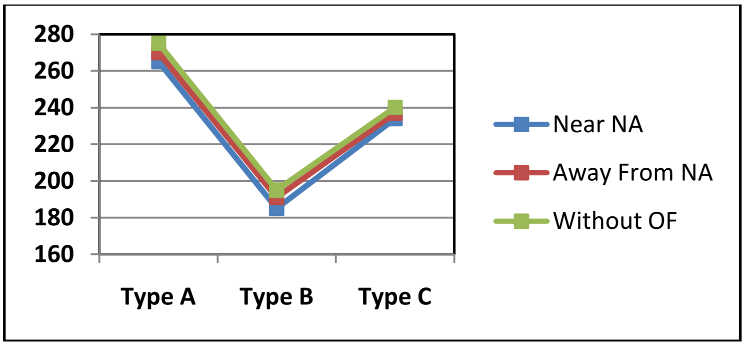

Figure 1.4: Numerical bending strength comparison wrt OF inclusion

It is observed that bending strength of composite specimens with optical fibre embedded away from neutral axis show better convergence with respect to those without optical fibre as compared to the specimens with optical fibre of embedded at the neutral axis.

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c) Non destructive evaluation of GFRP composite by C-Scan

The specimen is tested with a speed of 300 mm/s with a grid of 2 mm, to achieve a frequency of 5 MHz. Figure 1.5 shows a C-scan of a GFRP sandwich component with optical fibre embedded in it, which gives a clear indication of good quality, and defect free specimens.

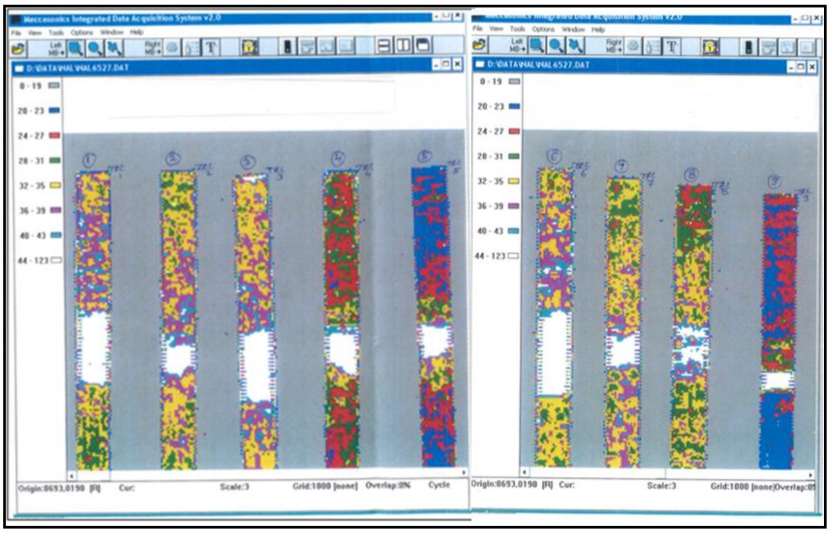

Figure 1.5: Ultrasonic C-Scan image of GFRP composite specimen

d) Scanning electron microscopy (SEM) analysis

The resin rich area is around the optical fibre and the bonding between the optical fibre and the resin is studied using Scanning Electron Microscope (SEM) as shown in Figure 1.6. The cleaned and polished specimen was used for SEM testing. The SEM micrographs were taken at different magnifications as shown below.

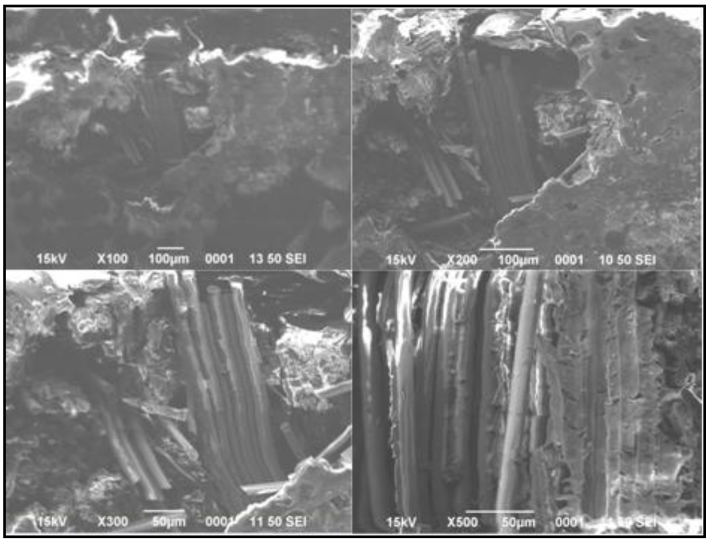

Figure 1.6: Scanning electron microscopy SEM

It is clear from the above figure that the distribution of reinforcement particles such as glass fibre and epoxy resin in the composite is fairly uniform and results in enhancement of the mechanical properties.

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V. CONCLUSIONS

1. Bending strength of the composite specimen are calculate both experimentally and numerically using three different cases i.e., without optical fibre, with optical fibre at the neutral axis and with optical fibre away from the neutral axis. Form this study I concluded that inclusion of optical fibre in the composite specimen will not affect significantly.
2. The bending strength results of the composite specimens with optical fibre embedded away from neutral axis show better convergence with respect to those without optical fibre as compared to the specimens with optical fibre of embedded at the neutral axis.
3. So it can be concluded that optical fibre can be effectively used for structural health monitoring (SHM) of the composite specimens.
4. The strength and fracture behaviour of the structure could be significantly affected by improper alignment and placement of optical fibres in the laminate.
5. The utilisation of embedded optical fibres for damage detection is accurate and reliable.
6. C-Scan gives a clear indication of good quality, and defect free specimens. SEM images shows that the reinforcement particulates are fairly distributed in epoxy resin matrix.

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