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THE EFFECT OF DAMAGE LOCATION ON THE PERFORMANCE OF COMPOSITE CANTILEVER BEAMS

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ABSTRACT

This paper highlights the results of an investigation carried on composite cantilever beams to determine the effect of damage location on its behaviour. Beams with damage at different locations were manufactured and experimentally tested. Furthermore, the experimental tests were used to validate numerical Finite Element simulations. Results have shown that the damage location changes the stiffness of the beams. For damage near the fixed end of the beam the stiffness reduction is greater as compared to damage near the free end. The results obtained demonstrate that the flaw position is an important parameter in the behaviour of the cantilever beam under load.

***Keywords**:* Composite, beam, damage, piezoelectric, pvdf

1. INTRODUCTION

During the lifetime of a structure damage might occur due to an event or series of events. The presence of damage or flaws compromise the load carrying capacity of a structure and normally tends to make the structure weaker due to material degradation [1].

From a wide perspective, damage could be anything from a void to a notch, to a crack, to a kink, which compromises the normal behaviour of a structure or system. Depending on the levels of exposure, certain types of damage may not show their effects for a long time. However, damage may be related to a number of surrounding factors which are associated with its initiation and propagation.

Most common types of damage are related to fatigue, creep, corrosion, wear (typically found in metals), interlaminar/ intralaminar delamination or debonding and fiber fracture (mostly found in composites). Crack damage is a type of damage that manifests with discontinuities at the scale of the structure [2]. The discontinuity feature may be in the form of an interior or surface line crack which can take different shape, size and orientation. This type of damage is studied by fracture mechanics theory and has received a considerable amount of attention over the past years.

Debonding or delamination is another type of damage typically found in layered/laminated materials and composites. The debonding normally happens at the interface of the laminate creating separation of the layers. The separation lowers both the compressive and tensile load carrying capacity of the structure [3, 4]. Damage due to delamination has also received great amount of attention over the past years due to the increased usage of composite materials. These types of damage may result from material imperfections during the manufacturing process or generated during service and operation.

The ability to locate and assess damage in flexible structures is important for improving the performance and life span of these structures.

2. METHODOLOGY

The method used to detect damage consisted of the fabrication of composite cantilever beams with internal flaws which were made intentionally to simulated manufacturing imperfections. Static experimental tests were conducted

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to determine the response of the beams under defect free and damaged conditions, and in order to validate, FE simulations using ANSYS Software were conducted. Beam models with defect parameters were simulated and observed under static conditions.

2.1. Static Analysis of the Beam

The free end displacement of a defect free beam under a point load is given by:

$$w = \frac{PL^3}{EI}, \tag{1}$$

P is the applied free end load (in N)

L is the total length of the beam (in m)

EI is the beam rigidity (in Nm^2)

The bending stiffness of the beam is expressed as:

$$k = \frac{3EI}{L^3}, \tag{2}$$

2.2. Beam's Fabrication

The defect free and flawed beams were manufactured from a 500mmx500mmx1mm clear Poly Methyl Methacrylate (PMMA) extruded sheet also known as acrylic glass or Perspex (supplied by Maizey's plastics SA). The fabricated beam specimens consisted of five layers of acrylic glass. The layers were glued together using chloroform. Flaws were introduced under the surface by isolating a section along the beam length using transparent adhesive tape. The adhesive tape prevented the chloroform to contact the isolated area thus creating a separation between the surface and layers on that section. The flaws were made intentionally to simulate manufacturing imperfections which would compromise the elastic properties (stiffness) of the beams. In total four specimens were fabricated. One was made defect free and the rest had flaws with a length of 35mm at distances of 47.5mm, 82.5mm and 117.5mm respectively from one end of the beam to the centre of flaw area. The beams were manufactured at room temperature. The specimens were left for 24 hours to ensure proper bonding between layers.

3. EXPERIMENTAL PROCEDURE

3.1. Static Measurements

Free end static displacement measurements were performed to determine the apparent modulus of elasticity of the defect free and flawed beams. The measurements were obtained with the help of a digital dial gauge with an accuracy of 0.001mm, full spring compression of 14.25mm. Masses of 50g, 100g, 150g, 200g, 250g and 300g respectively were applied to the tip end of the beams.

3.2. Experimental Results and Discussion

Flaws closer to the fixed end of the beams result in higher free end displacement which indicates reduced apparent elastic modulus and stiffness compared to flaws closer to the free end. The apparent elastic modulus is higher for the defect free beam as expected and decreases as the flaw moves towards the fixed end of the beam. The obvious reason is that near the fixed end deformation varnishes and higher stresses are captured. On the other hand, near the free end of the beam stresses are very small and maximum deflection occurs. This demonstrates that the stress discontinuity introduced by the defect influences the stiffness as the elastic modulus is related to the strain and stress. The displacement for the different applied loads indicate a linear relationship.

4. FINITE ELEMENT MODELLING OF THE BEAM

In order to numerically investigate the effect of flaw position on the static response of the cantilever beams, the defect free and flawed beam models were constructed in Solidworks V2007 and analysed using the multipurpose finite element software ANSYS. Solid 186 element type was used for the analysis. This is a higher order 3 dimensional

20-node solid element that exhibits quadratic displacement behaviour. The element is defined by 20 nodes having three degrees of freedom per node: translations in the nodal x, y, and z directions. The beams were meshed with 25 elements per division (which correspond to the ratio of length over thickness).

Damage is represented by a reduction in elastic modulus of the beam elements at the flaw region. Four beam models were built. The flaw sections have a length of 35mm. The sections are located at a distance of 47.5mm, 82.5mm and 117.5mm respectively from one end of the beams. The defect free and flawed beams have a total length L_b = 145.5mm, width B = 27.75mm and height H = 5.8mm as with manufactured specimens. The elastic modulus at the flaw section was reduced to 14% of the apparent modulus of the defect free beam.

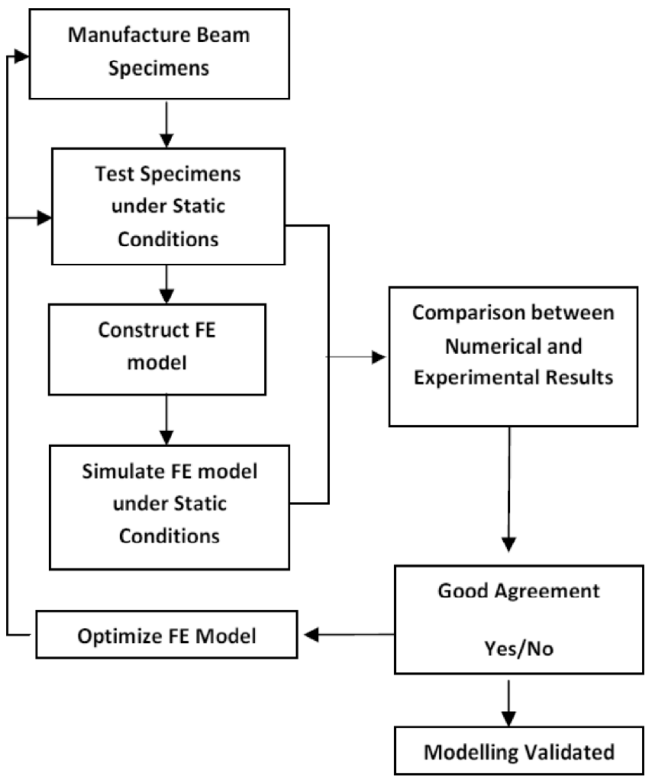

Figure 1: **Validation Method**

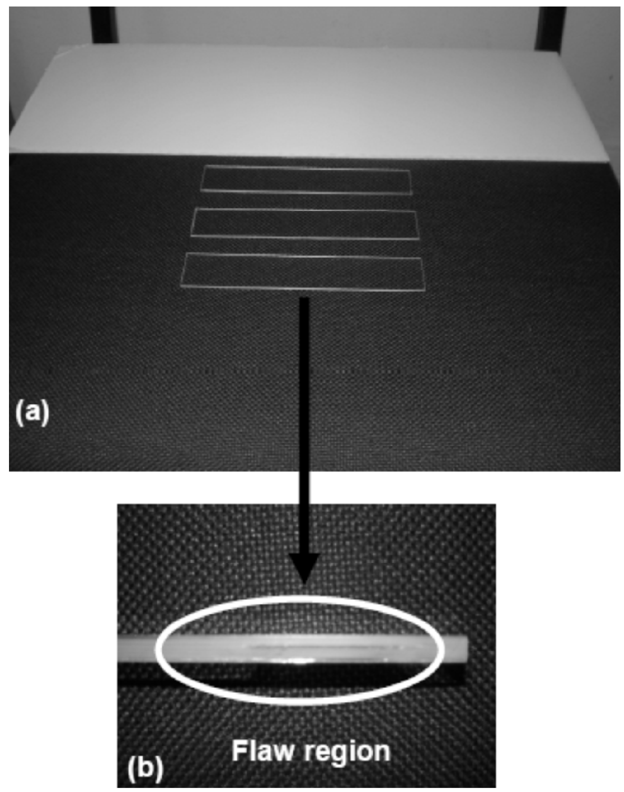

Figure 2: (a) Beam Material; (b) Side View of Flawed Beam

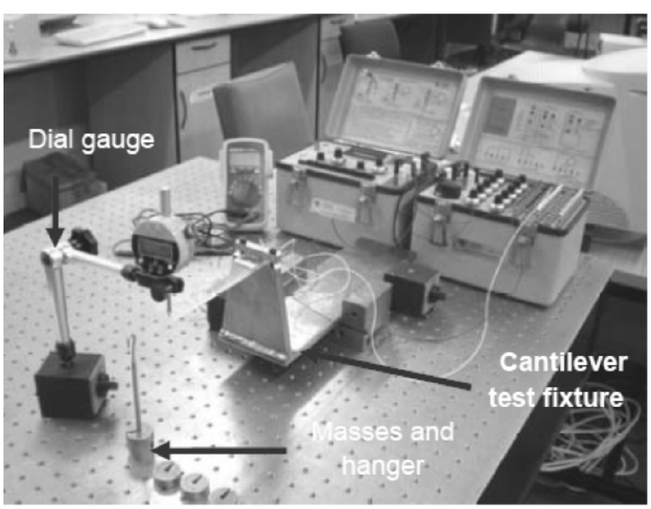

Figure 3: **Experimental Set-up for Free end Displacement Measurements**

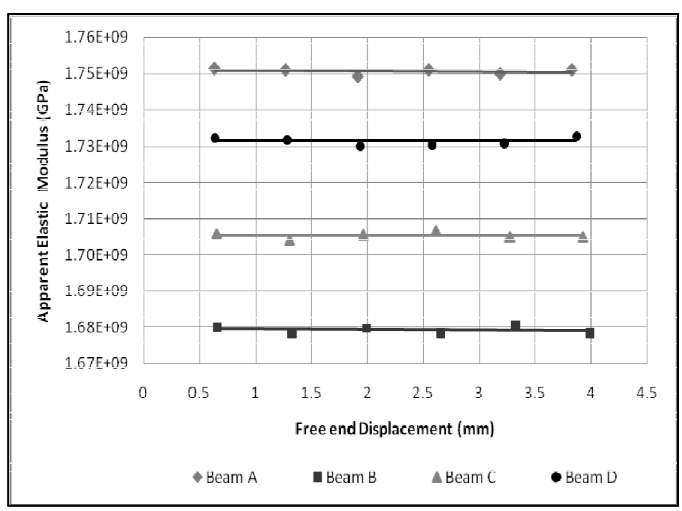

Figure 4: **Apparent Elastic Modulus for Defect Free and Flawed Beams**

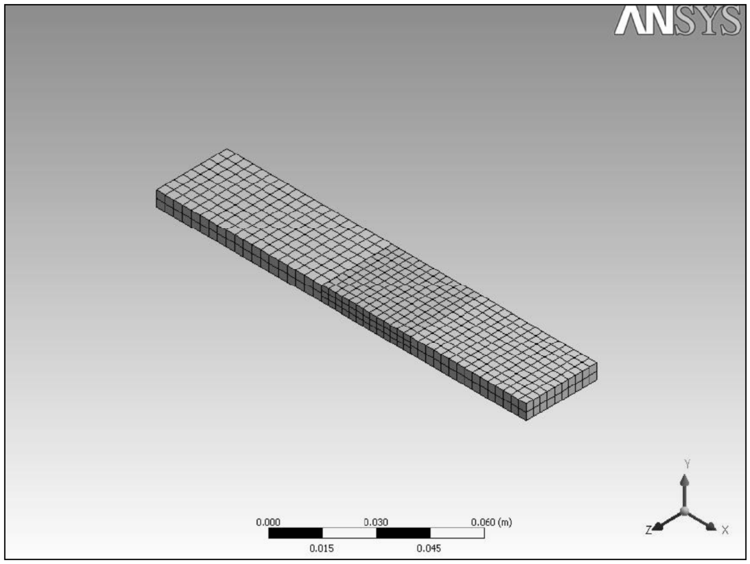

Figure 5: **Mesh Model of the Beam**

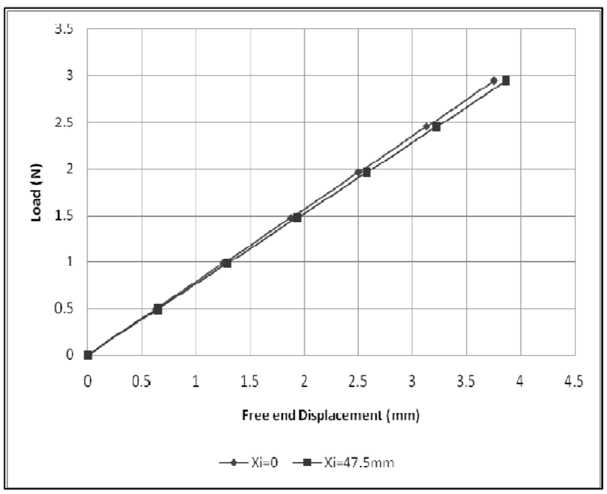

Figure 6(a)

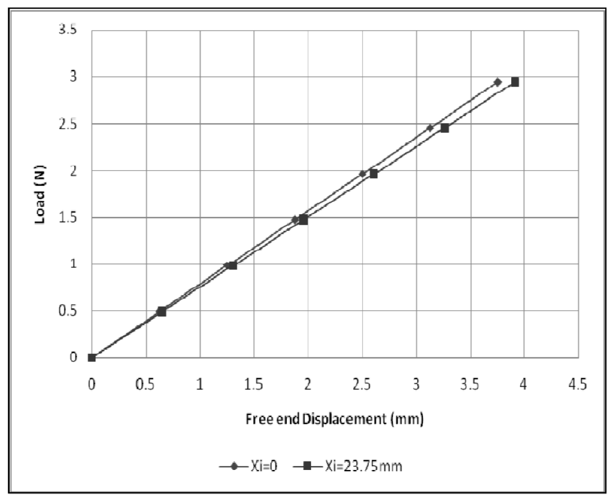

Figure 6(b)

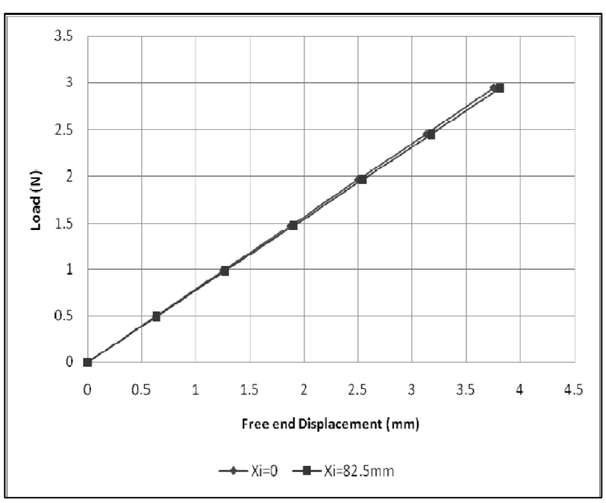

Figure 6(c)

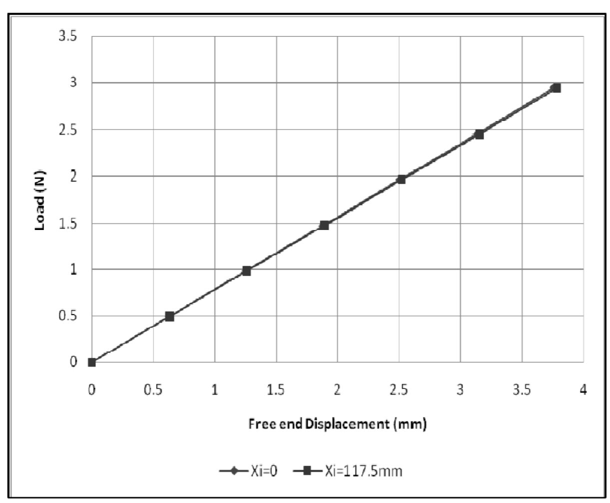

Figure 6(d)

Figure 6: (a) Load Vs Free end Displacement for flawed beam at: X_i = 0 and 23.75 mm.(b) Load Vs Free end Displacement for Flawed Beam at: X_i = 0 and 47.5 mm. (c) Load Vs Free end Displacement for Flawed Beam at: X_i=0 and 82.5 mm. (d) Load Vs Free end Displacement for flawed beam at: X_i=0 and 117.5 mm

4.1. Static Fe Analysis

The static equation for a finite element model of a beam is given by [3]:

$$[K]\,\{u\} = \{F_{app}\} \tag{4}$$

Where:

$[K]$ = Total stiffness matrix (sum of element stiffness matrices)

$\{u\}$ = nodal displacement vector

$\{F_{app}\}$ = Applied nodal force load vector

4.2. Fe Results and Discussion

The beams with defect at different locations were plotted against the defect free beam. As the flaw position gets further away from the fixed end, the displacement decreases approaching the displacement values for the defect free beam. In other words, the closer to the fixed end the greater is the displacement. Also, for each specific location, a reduction in elastic modulus causes an increase in displacement but again more noticeable near the fixed end. This suggests that flaws located near the fixed end of the beam are more critical causing a greater reduction in the load carrying capacity of the beams which is in agreement with the experimental results.

5. RESULTS

The variation in beam stiffness is dependent on flaw position. As the flaw position moves away from the fixed end of the beam the stiffness increases approaching the defect free beam's stiffness.

This suggests that flaws closer to the fixed end of the beams are more critical in the sense that greater reduction in the load carrying capacity of the beam is obtained. Whereas, for the same flaw size, its effect is less noticed near the free end of the beams.

The experimental results obtained are in good agreement with numerical ones. Both have shown that the flaw decreases the stiffness of the beams as a function of position.

6. CONCLUSIONS

In This study, the static behaviour of composite cantilever beams with internal manufactured flaws was experimentally investigated and a finite element model was constructed to verify the results. Results have indicated that the flaw or damage position is an important parameter in determining the strength of the structure.

Acknowledgements

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