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EFFECT OF DELAMINATION ON THE BENDING RESPONSE OF COMPOSITE MATERIALS

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1. INTRODUCTION

This work investigates the effect of delamination on the failure progress and strength of composite materials beams under bending loading. Experimental 3-point bending tests in accordance with ASTM D 790-03 standard were conducted and a Finite Element model was developed in order to assess the aforementioned effect. The key parameters examined were delamination length (80 mm, 140 mm and 200 mm) and its position in the thickness direction of the beam (at 0.25t, 0.50t and 0.75t from the tension side). For each case, the experimental and numerical force-deflection and strain-deflection curves were analysed in order to draw conclusions.

2. EXPERIMENTAL STUDY

The vacuum bagging method was implemented in order to produce unidirectional glass fiber reinforced beams with epoxy resin and artificial delaminations varying in extent and position. Each beam consisted of 20 layers and had dimensions 340 mm×72 mm×12 mm. In order to assure repeatability of the results, 3 beams were produced for each case. A displacement controlled load was applied at mid-length with a rate of 3 mm/min and the response sampling frequency was 10 Hz. Based on the analysis of the force – deflection and strain – deflection curves obtained, we can conclude that high repeatability of the test results was achieved. In Figure 1 and Figure 2 we can see these curves for the C-140 case specimens (140 mm delamination length at 0.75 t from the tension side). As shown in Figure 1, the relationship between force and deflection is linear up to the point where the beam starts to deteriorate and finally fail. Furthermore the average maximum force and deflection for these specimens was 15.604 kN and 21.5 mm, respectively. It is important to mention that two kinds of failure modes were observed. For the cases where the delamination was 80 mm long, as well as for the cases where its position was at 0.25t, local failure appeared at the point where the force was applied due to stress concentration. On the contrary, for the majority of the longer delaminations and for delaminations in the middle or at the part of the beam in compression, the failure was the result of crack propagation. Apart from observation, the strain – deflection curves can also help us determine and verify the failure modes. For example, in the strain-deflection response of Figure 2, a sharp rise of the strains is observed for one of the specimens, which is the result of the local failure of the beam on its tensile side. On the other hand, for the other two specimens, a sharp drop is observed, which suggests crack propagation.

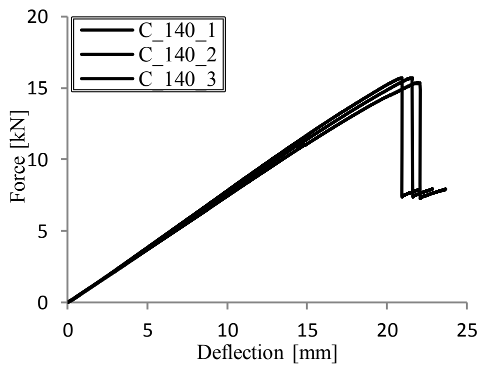

Figure 1. Force – Deflection curve for C_140 specimens

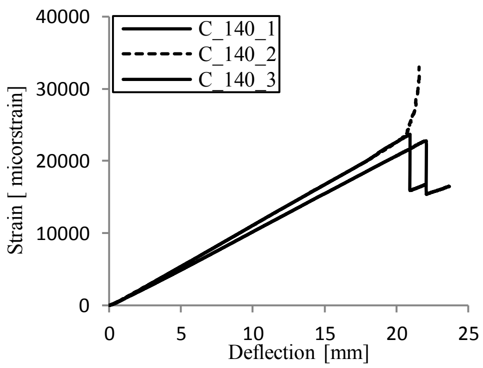

Figure 2. Strain – Deflection curve for C_140 specimens

3. NUMERICAL STUDY

In order to conduct the numerical analyses a Finite Element Method model was developed. Utilizing ANSYS 14.0, a 2D symmetric model was created using plane stress elements (PLANE 182). In order to simulate the delamination and the effect of the supports, contact elements (CONTA171 and TARGE169) were used. The crack propagation was modelled in mixed mode (mode I & II) using cohesive zone modelling. The basic parameters affecting the behaviour of the cohesive elements were investigated in order for the numerical results to be as concurrent as possible with the experimental ones. Due to the non-linear nature of the crack propagation phenomenon, the load (displacement) was applied in small increments, thus the analysis was non-linear static. Since only the delamination propagation failure mode was modelled, the comparison between numerical and experimental results was possible only between the specimens which failed due to delamination propagation. The average deviation between the numerical prediction and the actual experimental value of the maximum force applied on the specimen was 9%. In Figure 3 we see a typical comparison between experimental (black) and numerical (red) force – deflection curves, where the very good coincidence of both bending stiffness and maximum force is obvious. In addition, in Figure 4 we can see the buckling of the upper sub-laminate of the C-200 specimens (200 mm length, delamination at 0.75t from the tension side). The numerical model was proved capable of predicting this particular behaviour.

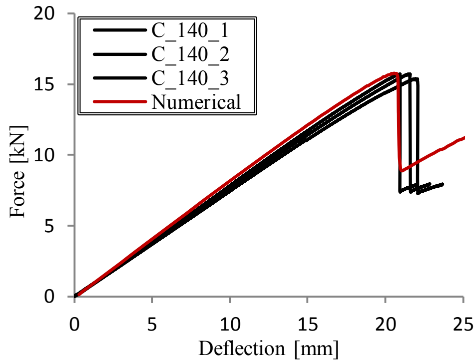

Figure 3. Comparative Force – Deflection curve for C_140 specimens

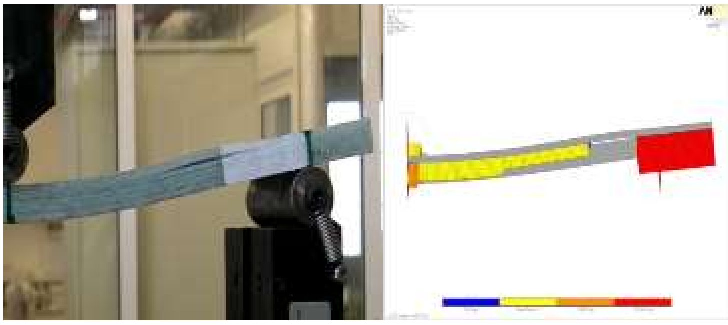

Figure 4. Buckling of upper sub-laminate in C-200 specimens, experimental and numerical comparison

4. CONCLUSIONS

The experimental and numerical results obtained are in accordance with each other. The basic conclusions arising from this study are the following:

- The strength and the bending stiffness of the beam decrease as the delamination length increases.
- The case where the delamination position is at mid-thickness (position B) has the most adverse effect on the beams' load bearing capacity, as shown in Figure 5, where the experimental maximum loads for all cases are summarized.
- For small delaminations up to 30% of the beam span located at the sub-laminate in tension, the failure is local; for delaminations in the order of 50% of the span located at mid-thickness or at the sub-laminate in compression, the failure occurs due to delamination propagation.
- For large delaminations in the order of 70% of the beam span located at the sub-laminate in compression, buckling of this sub-laminate may occur.

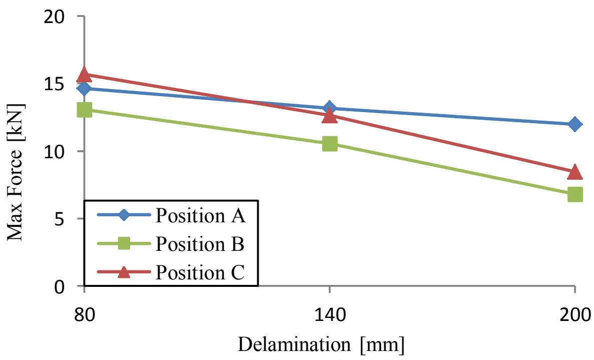

Figure 5. Summary of maximum force for all cases examined

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