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DELAMINATION FAILURES IN GFRP MATERIAL BY FINITE ELEMENT SIMULATION

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Abstract:

The focus of this paper is on the modelling of progressive damage in GFRP materials of glass fibre reinforced laminae. A general review of modelling approaches to failure in the context of the finite element method is first presented, with an emphasis on models based on continuum damage mechanics. The way in which delamination and matrix splitting (that may or may not interact with fibre-tension damage) should be addressed in the framework of a commercial finite element code is considered next. It is shown that the finite element simulations can accurately represent the physical mechanisms controlling damage development and progression and reproduce a number of phenomena including delamination, laminate in-plane failure and behaviour at notches. The delamination phenomenon is undesirable and constitutes a major problem. In this paper, a study of delamination for glass fibre reinforced material is analysed. The composite plates were made using two manufacturing technologies, hand lay-up and compression hand lay-up process. The study found out the maximum value of the force where delamination occurs and the specific delamination resistance. Also, it's done a finite element simulation of delamination process at composite material under transverse loads. The propagation model of delamination was implemented in finite element ANSYS software. There are presented the used materials for samples, the manufacturing process, laboratory equipment and the experimental results.

Introduction:

GFRP materials commonly found in aerospace, automotive and civil engineering applications exhibit a distinctively nonlinear behaviour. This nonlinearity can arise in various ways. The heterogeneous nature of the material, which consists of fibres of one material (usually carbon or glass) in a matrix material makes the mechanical behaviour complex. This observation holds with respect to the force and time constitutive response, with directionally dependent properties, and to the failure behaviour, usually of a brittle type. In addition, since many GFRP materials consist of thin plates, they are likely to undergo large deflections. The interface between the materials plays an essential role in the mechanical behaviour. Impact, shocks, loadings or repeated cyclic stresses can cause the laminate to separate, forming a structure of separate layers, with significant loss of mechanical strength, a condition known as delamination [1].

The description of real composite behaviour is a challenge, either using experimental procedures, or numerical methods. In this respect, virtual tests for composite materials carried out by means of numerical modelling are increasingly replacing some mechanical and physical tests to predict and substantiate their structural performance and integrity due to recent developments in software-based nonlinear finite element analysis methods, particularly in composite-specific tools. This includes the computational advances in fracture modelling, especially the improvement of cohesive models of fracture and the formulation of hybrid stress-strain and traction-displacement models that combine continuum and discrete material damage representations in one single calculation.

Delamination is interlaminar damage and can be produced during production or exploitation of the composite structure. It is an insidious failure that's develops inside of the material, without being obvious on the surface. The core of the material is opaque, that's why it is difficult to evaluate the contact that was realized between the material layers during the manufacturing process, [2-4].

A finite element for modeling delamination in a composite beam has been developed by [5]. The delaminated beam is divided into two sublaminates, above and below of the delamination plane, and modeled with finite elements. A.M. Elmarakbi et. al. [6], study the delamination growth under transverse loads in laminated composite materials using finite element method. Some researchers developed a model for delamination propagation in laminated composites to permit the prediction of degradation in materials due to delamination process [7]. Interface elements and an interface damage law was used by [8,9] in finite element analysis of delamination for laminated composites. A.M. Girao et. al. [10] show that the physical mechanisms can be accurately represented through finite element method, such as delamination, laminate in plane failure and behaviour at notches. A failure criterion and damage properties are investigated to model delamination in composite parts by [11]. These presents a simulation of failures in laminated composite materials. Taking into consideration the previous researches in the field, the purpose of this study was to evaluate the delamination process for composite materials reinforced with unidirectional glass fibres matrix. A study on the delamination testing was done. The analysis found out the maximum value of the force where delamination occurs. There, also a finite element analysis of delamination for unidirectional composites was presented.

Experimental setup:

The strength of laminated fiber reinforced composite materials depends on the combination of the layer's orientations. The used materials for the composite plates were unsaturated (Lerpol TIX 3603/R) as matrix and for reinforced fiber glass materials (unidirectional fabric 225 g/m^2). They were obtained by hand lay-up process and compression hand lay-up process. The hand lay-up technology is the most used manufacturing process for the composite material parts. In order to show the pressure influence on mechanical properties at delamination tests, a pressure of 0.15 MPa was applying, on unidirectional composite plates made by compression hand lay-up process. After the layers of the composite have been obtained, before polymerization, the mold was compressed with a power-press, in order to homogenize the structure and to remove the surplus of the resin. The mold consists of two metal plates with dimensions of 200 x 200 mm. The manufacturing process was performed at ambient temperature of 20 °C. The experimental tests at delamination were done according to ASTM D 5528-01 [12], schematically represented in figure 1. The samples were cut from the obtained plates where the fiber orientation in the samples was at 30º. During the manufacturing process, at one end of the plate was inserted a polypropylene thin film of 30 µm with length a = 55 mm. It was considered that the number of layers to be equal to the one side and other of the film.

The samples have 12 layers and were cut from the composite plates using a diamond disc at 20x3x135 mm dimensions. At the end of the samples, where the film has been inserted, two steel metal profiles by 28 x 28 mm were glued, to be fixed it in the tensile test machine grips. There were used hinge formed from two-piece articulated on an axle, to remove any undesirable additional stresses which may occur during the sample tests. The unidirectional ply is an orthotropic material whose planes of symmetry are parallel and transverse to the fibre direction. The material coordinate axes are quite often designated as 1, 2 and 3, see Fig. 2

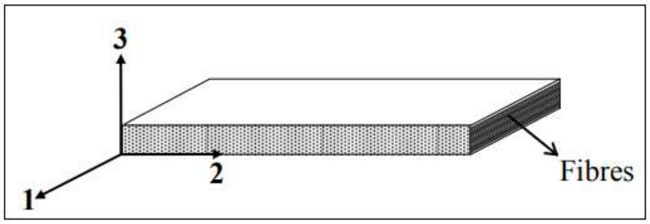


Fig. 1 Ply coordinate system

- Axis-1 runs parallel to the direction of the fibres (longitudinal direction).
- Axis-2 runs normal to axis-1 in the plane of the ply (in-plane transverse direction).
- Axis-3 runs normal to the plane of the ply (through-thickness direction).

The shape assumption of the curve completes the cohesive law. Although a variety of geometric shapes have been proposed (e.g., Tvergaard and Hutchinson [24], Xu and Needleman [25], who proposed trapezoidal and exponential laws, respectively), the simple bi-linear curve representation (e.g., Mi et al. [8], Camanho et al. [26], Jiang et al. [14]) is usually implemented for modelling the cohesive behaviour. Finally, a clear distinction between the possible failure modes of the interface (see Fig. 3), opening (mode I), sliding has to be made as each mode is associated with distinct values for strength and fracture toughness.

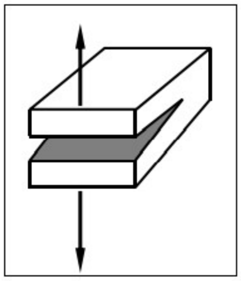


Fig. 2 Modes of delamination failure

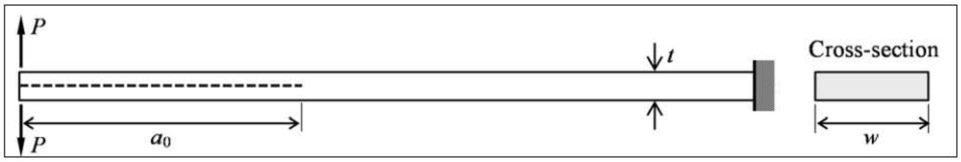


Fig 3 GFRP benchmark test coupon geometry (nominal dimensions)

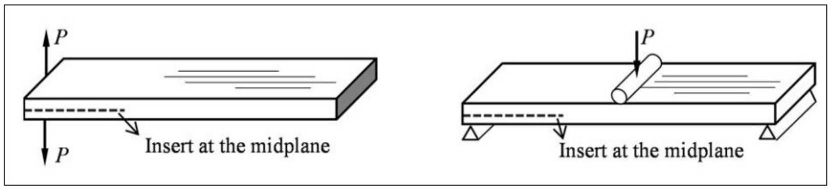


Fig 4: GFRP specimens

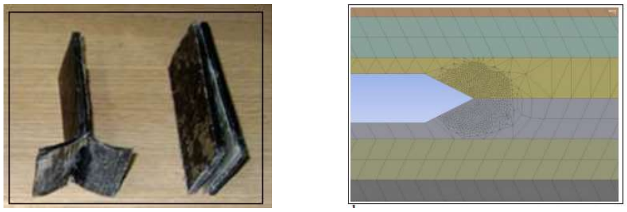
As a pure mode I problem, a glass fibre unidirectional composite GFRP specimen is analysed under displacement control. The experimental setup of Davidson and Waas [69] is simulated. The geometry of the specimen and the boundary conditions are illustrated in Fig.4. Although the nominal cantilever thickness t is 2.5 mm, the measured thickness values varied from a minimum of 2.5 to 2.9 mm. The initial length of the crack a_0 is 55 mm. The material data assumed for the finite element model are given in Table 1. For the laminate, Davidson and Waas [69] give elastic constants E1 and ν12.

Fig 5: Optical image of delamination test sample and test setup.

The delamination tests of the samples were performed on the universal testing machine type Zwick/Roell Z150, equipped with a process computer having the possibility to draw variation diagrams of force during application, Figure 2. Test speed was of 2.5 mm/min to determine the specific resistance at delamination (σ_d) has been reported the maximum force at sectional aria required, using the relation:

$$\boxed{\sigma_{\mathrm{d}} = \frac{F_{\max}}{b} \ \text{[N/mm]}}$$

where: Fmax- maximum force necessary to cause delamination between the sample layers, [N]; b - sample width, [mm]. The results of the maximum force F at delamination tests, corresponding to the displacement and delamination resistance for the both manufacturing process of unidirectional fiber composite plates, are presented in table 1



(a) (b)

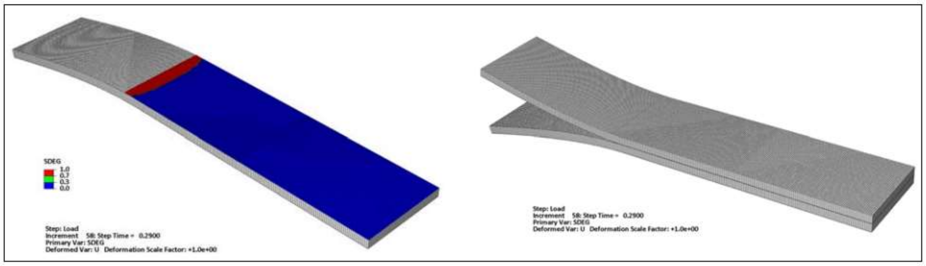
Fig 6: a, b detail of the mesh density in the area of crack initiation.

Table 1. Experimental results at delamination tests

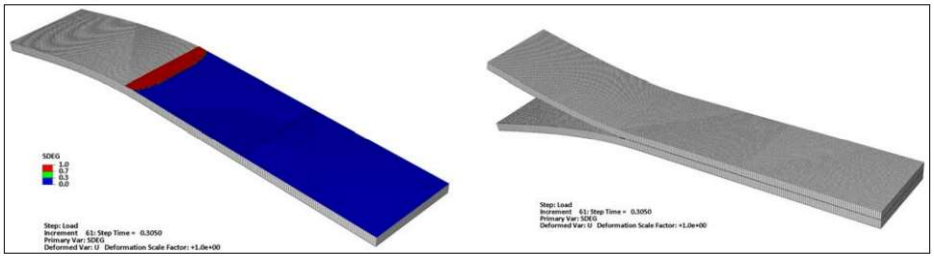
Manufacturing process	**Maximum force F [N]**	**Average maximum force**	**Average specific resistance**
		Fmax med [N]	**$\sigma_{d\ med}$ [N/mm]**
Hand lay-up	49.5		
	52.4		
	47.5	50.184	2.87
	50.2		
	51.32		
Compression hand lay-up	28.8		
	30		
	32.5	31.2	1.29
	30.9		
	33.8		

By compression hand lay-up process, a 18.984 % less force value at delamination was obtained than in the case of the simple hand lay- up process, due to phenomena that occur at the interface between fibre and matrix and resin variation volume. The important role is played by the matrix, the force at delamination being taken by the resin.

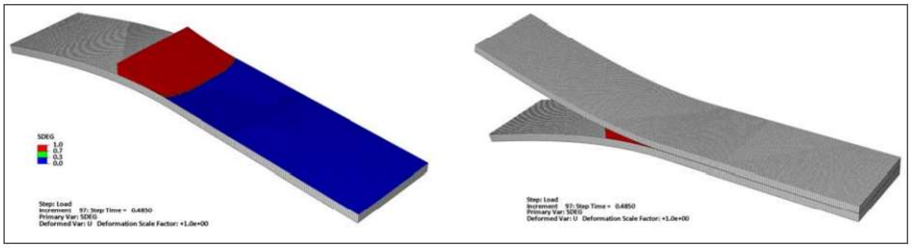
Simulation on delamination:



(a)



(b)



(c)

🟥 Completely damaged 🟩 Partially damaged 🟦 Undamaged

Fig 7: Evolution of mode I delamination zone in the GFRP test specimen

For this research the ANSYS 16.0 Software was used. The proposed objective was to analyse and to determine the force at delamination for unidirectional fiber glass polyester composites samples during the experimental tests. Figure 12. shows the mesh distribution in the samples where the mesh size was 0.25 mm. In this simulation case, a mesh with 21959 nodes and 14413 elements has been generated. The mesh density in the area of crack initiation, presented in Fig 12 was 0.065 mm.

Like boundary conditions, the end of the right side of the sample is rigid fixed, and the left side has imposed displacements on both sides of the sample. Figure 4 shows the force values at delamination obtained during the finite element simulation. The maximum force at delamination was 310.24 Mpa.

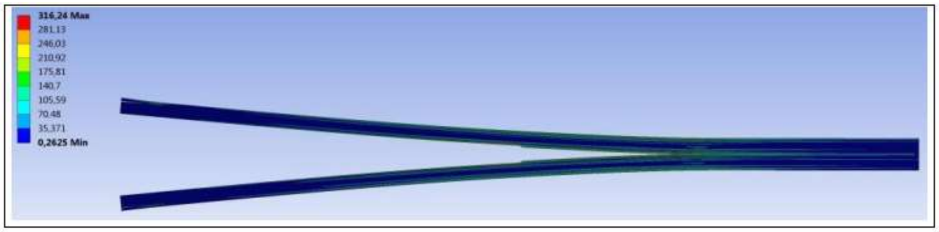


Fig. 8. Finite element simulation at delamination on GFRP sample

Table 2. Delamination values of force reaction vs. time for hand lay-up

Time[s]	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Force[N]	12.56	19.76	28.65	32.62	38.15	41.18	45.43	48.16	50.42

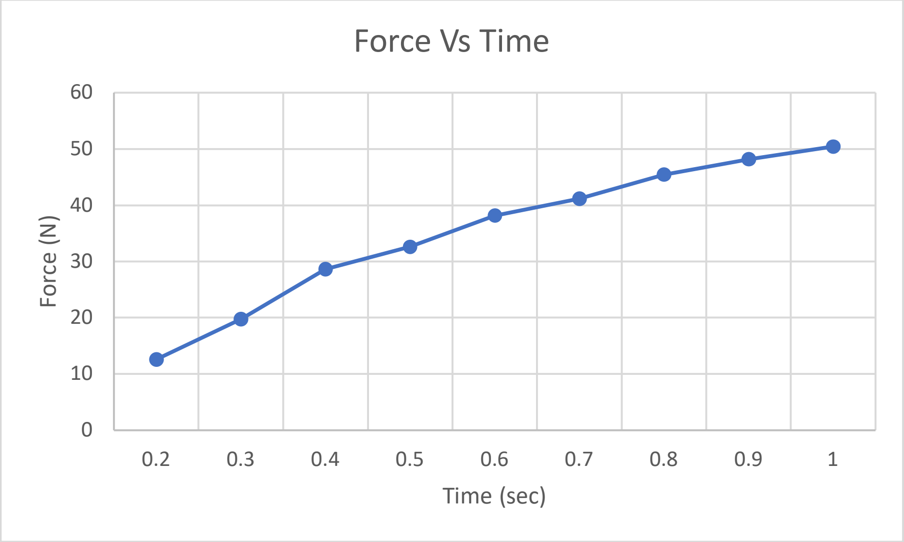


Fig.9: Graph between force vs. time w. r .t FEA

Table 3: Delamination values of force reaction vs. time for compression lay-up

Time [s]	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2
Force[N]	51.8	53.58	52.73	51.67	50.31	50.98	49.98	49.54	48.15

The accuracy of the results can be considered acceptable. It is observed that the results obtained from finite element analysis are very similar to the test results. We can conclude that the proposed model simulates very well delamination defects within composite structures. There were obtained very close values for the results of force reaction in cases studied, experimental part and FEA simulation. The finite element analysis is confirmed by the test results.

Conclusion:

This paper presents the results obtained both by experimental research and finite element simulations. The manufacturing technologies used were hand lay-up process and compression hand lay-up process for the composite plates. In order to show the pressure influence on mechanical properties at delamination tests, the plates were compressed at 0.15 MPa pressure. The used materials were unidirectional fabric 225 g/m^2 and polyester resin Lerpol TIX 3603/R. The experiments consist in delamination tests, to find out the maximum value of the force when delamination occurs and the specific resistance at delamination. By compression hand lay-up process, a 18.984 % less force value at delamination was obtained than in the case of the simple hand lay-up process. In this case, we can conclude that the important role is played by the matrix, the force at delamination being taken by the resin. This paper analysed the delamination process at polymeric composite materials under transverse loads using the ANSYS 16.0 Software. The analysis proposed to determine the maximum force at delamination during transverse loads. We can observe that the results obtained from finite element analysis are very similar to the test results. The finite element analysis is confirmed by the test results and shows a good prediction of interlaminar failure.

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