Delamination Analysis and Testing of composite plates for Aerospace Applications

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Abstract

Advanced lightweight laminated composites are increasingly being used in modern Aerospace structures, for enhancing their structural efficiency and performance. one of the most common failure modes for composite structures is delamination. The remote loading applied to the composite components are typically resolved into interlaminar tension and shear stresses at discontinuities that create a mixed mode I ,II ,and III delaminations.

The concept of filament wound composite structures for defense applications is relatively new and such structures have been designed in the recent past by researchers and engineers by adopting different manufacturing processes. Given this context, the objectives of this paper is, the composite rocket motor casing will be made by carbon fiber reinforced prepreg, The delaminations mostly occur in CRMC is between fabric to fabric layer on dome portion as well as skirt locations. To study the behaviour and also determining the fracture toughness of a material between the fabric and fabric layer. The model is considered as a composite plate, by creating the delamination in between the fabric and fabric layer ,is used to carried out the fracture toughness, buckling analysis and testing of composite plate by varying delamination sizes using carbon fabric prepreg by hand lay-up process. Investigation was carried out on composite plates by varying delaminations, when plates are loaded in axial compression.

In this paper, FEM and experimental study on buckling and fracture behavior of carbon fiber reinforced plastic (CFRP) layered composite plates under axial compression, is carried out to characterize the GI, GII and GIII. VCCT technique is employed to study the effect of crack length and compared the FEM results with test data.

1. Introduction

Composites are ideal candidates for making composite rocket motor casing (CRMC) which are essentially cylindrical pressure vessels comprising two tapered-end domes, and end-fittings terms as polar bosses and skirts. Polar bosses have features for connecting the igniter and the nozzle of the missile to the casting and the skirts for transfer of loads to interfacing systems. The RMC generally has different sizes for the two end openings due to varied interfacing parts. This presents a challenge for filament winding technology. That has to be non geodesic in nature, which successfully nets the fibre in tension. The optimum composites RMC need to have high specific strength and light weight and needs to with stand high internal pressure. The composite generally includes carbon and aramid fibers. Advanced carbon fibre composite rocket motor casings for propulsion stages and such CRMCs have been fabricated indigenously.

Filament winders can expect greater fiber placement control due to increased tack of the TowPreg, leading to increased design freedom and more accurate burst pressure predictions. Other benefits include: faster winding speeds due to exceptional fiber placement control, eliminating resin bath limitations, cleaner operations, and eliminated resin waste. Additionally, the material may be stored at room temperature for up to three months, simplifying logistics and facility requirements.

Composites being orthotropic materials can be tailored to give properties as desired in specific load directions. This advantage also causes complications in design and analysis, for, the directional material property changes have to be taken into consideration. Therefore, design of composites with optimum thickness and sufficient factor of safety requires detailed study and analysis.

The delaminations mostly occur in CRMC between fabric to fabric layer on dome portion as well as skirt locations. To study the behaviour and also determining the fracture toughness of a material between the fabric and fabric layer. The model is considered as a composite plate ,by creating the delamination in between the fabric and fabric layer ,is used to carried out the fracture toughness, buckling analysis and testing of composite plate by varying delamination sizes using carbon fabric prepreg by hand lay-up process.

. When we compare the several experimental results from the literature [3-6] it can be found that the fracture toughness has increased with increase in the percentage of the additive materials like glass beads [3], particulate [4], poly ether imide [5], tyre rubber [6].

In the current study we carried out the delamination analysis of composite plate to find out the load bearing capability with different size of patches. And composite plates were fabricated with patch and load tested to find out the failure behaviour.

2. Background

In this study an investigation on the utilization of delamination models based on plate theories and interface technique for analyzing 3D delamination problems is presented. The proposed method analyses the laminated structures as composed by first-order shear deformable plate elements interconnected by interfaces, whose constitutive relationships are based on fracture and contact mechanics. Delamination is simulated by reducing to zero interface stiffnesses, which otherwise perfectly connect the plate models by considering them as penalty parameters. Lagrange and penalty methods are adopted in order to simulate interactions between layers. The influence of plate and interface quantities on the interface fracture problem is investigated by means of closed form expressions for energy release rates, developed in terms of interface strains and of plate stress resultant discontinuities. At first, a simple two-dimensional delamination problem is considered in order to highlight the main characteristics of the model. Then, numerical results for the energy release rate distributions are given for typical three-dimensional mixed mode delamination problems by implementing the method in a 2D finite element analysis. Comparisons with 3D finite element models show the accuracy and the computational efficiency of the proposed procedure. Some applications are proposed to point out the convergence of the mode partition procedure as the delamination front element size decreases, also when oscillatory singularities exist.

Interlaminar fracture mechanics has proven useful for characterizing the onset of delaminations in composites and has been used with limited success primarily to investigate onset in fracture toughness specimens and laboratory size coupon type specimens. Future acceptance of the methodology by industry and certification authorities however, requires the successful demonstration of the methodology on the structural level. In this paper, the state-of-the-art in fracture toughness characterization, and interlaminar fracture mechanics analysis tools are described. To demonstrate the application on the structural level, a panel was selected which is reinforced with stringers. Full implementation of interlaminar fracture mechanics in design however remains a challenge and requires a continuing development effort of codes to calculate energy release rates and advancements in delamination onset and growth criteria under mixed mode conditions

3. Model Considered

The composite plate model having a size of length 200 mm and 50 mm wide is considered for a design load of 500kg. The composite plate is given in Fig.1.The models used were analysed in ANSYS 13, manufactured with CFRP options given below. The CFRP materials exploited and property details are tabulated below in table-No.1. The FEM model of thickness 4 mm was generated and delamination is located at the centre of the laminate. The delamination sizes considered are 5x5 mm, 25x25 mm, and 50X25 mm. Buckling factor and fracture toughness of a material by varying delamination sizes are studied. Ply sequence was finalized as [0&90]s for equal thickness of 0.33 mm in each layer.

Table1:- Material Properties

Property	Value
Young's modulus,(E1) (GPa)	110
Young's modulus,(E2) (GPa)	8
Young's modulus,(E3) (GPa)	8
Poison's ratio,ν12	0.25
Poison's ratio,ν23	0.32
Poison's ratio,ν13	0.25
Shear modulus,(G12) (Gpa)	3.58
Shear modulus,(G23) (Gpa)	4.50
Shear modulus,(G13) (Gpa)	3.58

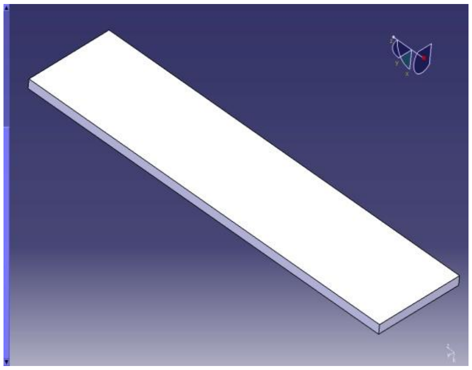

Fig.1- Composite plate

4. Fe Analysis

4.1 Buckling Analysis

A complete 3D model was built incorporating the ply sequence. Finite element mesh is generated using 8 node SOLID 46 in ANSYS software. SOLID 46 is a layered version of the 8-node structural solid designed to model layered thick shells or solids. The element has three degrees of freedom at each node: translations in the nodal x, y, and z directions. The FE model is shown in Fig.2. It was ensured to simulate exact boundary condition of practical test. The results of FEA are shown from Fig 3 to Fig.4.

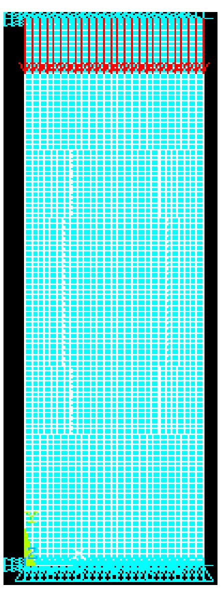

Fig.2-Fe Model

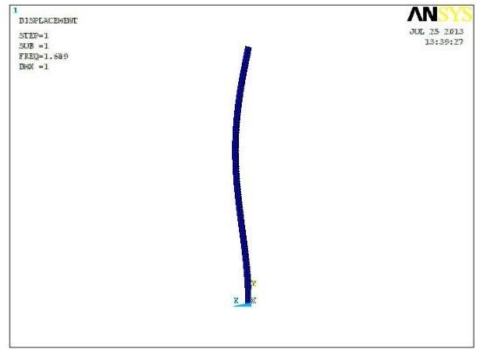

Fig3: WithOut delamination

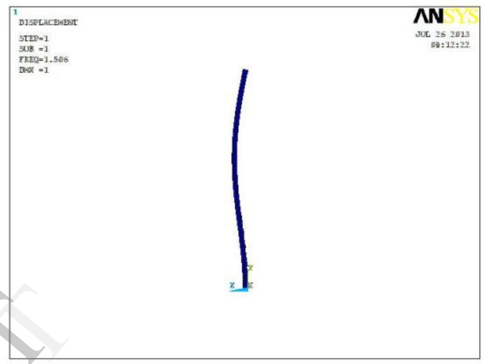

Fig4: With delamination of 5x5mm

Table2:

Type of plate	Buckling factor	Final buckling factor after knockdown (0.8)	Buckling load (kN)
Without delamination	1.689	1.35	6.75
With delamination(5 X5mm)	1.506	1.204	6.02
With delamination(2 5X25mm)	1.504	1.203	6.01
With delamination(5 0X25mm)	1.494	1.195	5.97

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4.2 Fracture analysis:

Finite element mesh is generated using 8 node SOLID 46 in ANSYS software. SOLID 46 is a layered version of the 8-node structural solid designed to model layered thick shells or solids. The element has three degrees of freedom at each node: translations in the nodal x, y, and z directions. The FE model is shown in Fig.1. It was ensured to simulate exact boundary condition of practical test. The results of FEA are shown from table3.

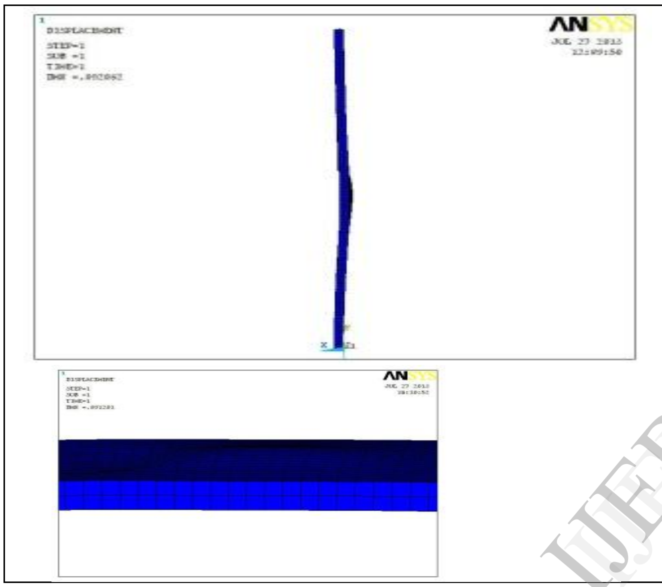

Fig5: Deformed model of a plate with delamination size of 25X25mm

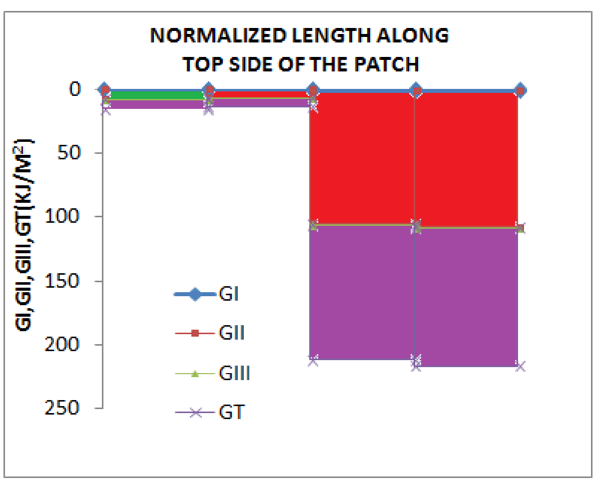

Fig5:GI,GII,GIII,GT and normalized cracklength on the topside of the patch

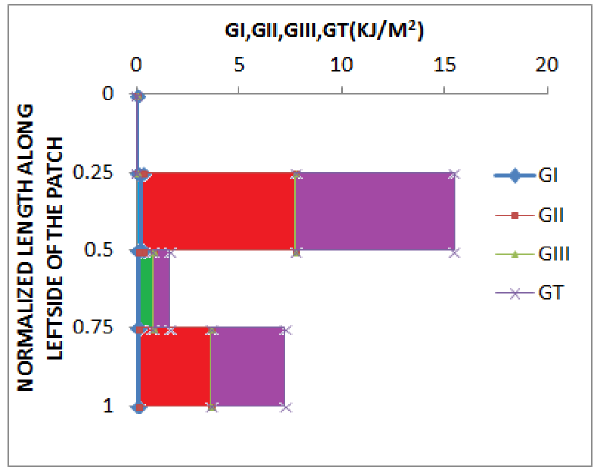

Fig6:GI,GII,GIII and normalized cracklength on the left side of the patch

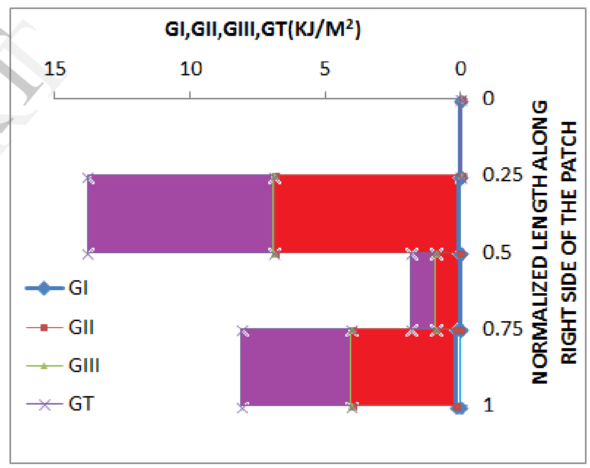

Fig7:GI,GII,GIII and normalized cracklength on the right side of the patch

5. Experimental Investigation

To validate the results obtained from finite element analysis, the plate was carried out with the three different delamination sizes being studied. Composite plates were manufactured and confirmed to be devoid of any defects by ultrasonic inspection. The process details are given in Fig.8. A test fixture was designed to simulate the axial compressive loading .Load was gradually applied in increments and strain data was recorded using strain data acquisition system. The plates were tested un-till failure. The test set up is shown below in Fig 9, and failure mode of each plate is shown in Fig 10.

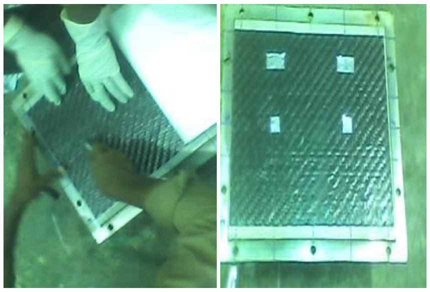
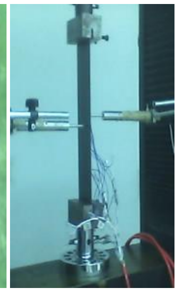

Fig8: Laminate preparation Fig9: Test setup

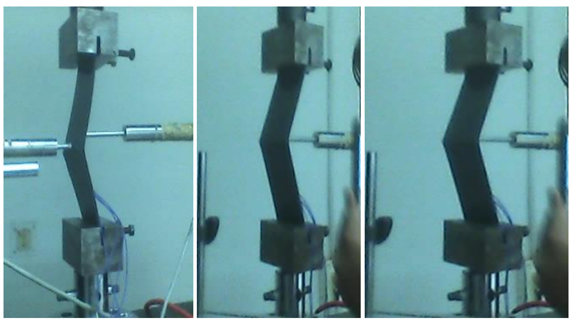

Fig10: Buckling Failure of plates with and without delamination

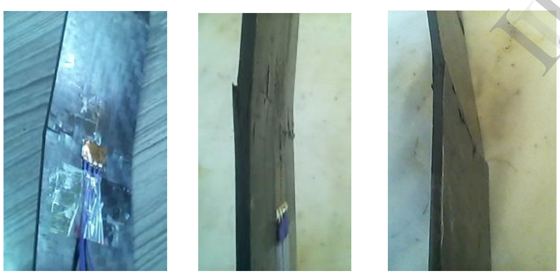

Fig11: TestedPlates

6. Results and Discussion

The buckling load results for Layered-46 element type and from practical test are listed below in table-3. To cater to the manufacturing defects knock down factor of 0.8 is considered and critical buckling load estimated. It is observed that increase in material stiffness is directly proportional to buckling load. The failure strains to be considered for each material type could be estimated from the test conducted.

Table4: Summary of Buckling analysis

Type of plate	Buckling factor	Buckling factor after knock down(0.8)	Buckling load (kN)	Tested data (kN)
Without delamination	**1.689**	**1.35**	**6.75**	**6.83**
Delamination -5x5mm	**1.506**	**1.204**	**6.02**	**6.16**
Delamination-25x25mm	**1.504**	**1.203**	**6.01**	**6.10**
Delamination-50x25mm	**1.494**	**1.195**	**5.97**	**6.07**

Table5:critical load at all sides of the patch

Type of plate	Top side (KN)	Bottom side (KN)	Left side (KN)	Right side (KN)
Delamination-5X5mm	2.43	6.02	2.54	2.73
Delamination-25X25mm	2.44	6.01	4.69	4.18
Delamination -50X25mm	2.46	5.97	4.65	4.24

7. Conclusion:

FEM and experimental study on buckling and fracture behavior of carbon fiber reinforced plastic (CFRP) layered composite plates under axial compression, is carried out to characterized the GI, GII and GIII. The VCCT technique is employed to study the effect of crack length in composite plate. To studied the fracture behaviour, the model is considered as a composite plate, by creating the delamination in between the fabric and fabric layer.

Investigation was carried out on composite plates by varying delaminations, when plates are loaded in axial compression. Composite plates were fabricated by varying delamination sizes using carbon fabric prepreg by hand lay-up process and tested in Instron machine. During the load test, the growth was observed at 2.43 kN and subsequently plate was buckled at

6.07kN. Based on the test results, it was observed, mode-II is critical in compressive loading conditions. Also observed that the crack length increases, the load bearing capability will decrease. Therefore, the analytical values are matching to the test data.

The fracture analysis approach with VCCT technique can be applied in delamination analysis of CRMCs for aerospace applications.

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