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A Review Paper on Study of Progressive Damage of Composite Structure under Tri Axial Loading by Using Micromechanical based Failure Theories

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ABSTRACT
Paper reviewed laminate failure occurred by various means under tri axial loadings by using various micromechanics based failure theories applied under static loading conditions. Experimental data shows that the mechanical behaviour and progressive damage of composite laminates may be different under multi axial loading than under uniaxial loading conditions. The proposed failure model by various authors is an extension of the strain energy failure theory for tri axial loading conditions. The paper summarizes laminate failure which includes initial failure, progressive damage, and final failure for laminate composite designed with different ply and material configurations. The paper also reviewed the structure failure due to stress concentration effects arrive due to edging effects. The aim of paper is to present failure of complex composite geometries/laminate under complex loading conditions.

Keywords: *Composite laminate, failure, Strain energy model, progressive damage etc*

1. INTRODUCTION

Composite material is combination of two phases designed for better engineering properties. Composite materials used in design of structures such as mud and straw, now days they are continue to be used in concrete. Fiber is stiff member which is embedded in matrix and exhibits more load sustaining capacity. Load on structure received by matrix and transferred to fiber. Fibers are oriented in different directions to enable to achieve desired property configuration and strength. Fiber can be woven braided or separately placed apart. Fiber may be continuous or discontinuous and decision will be taken based on sort of property configuration needed. Matrix may consist of polymer, ceramics or metal. Fiber and matrix forms the lamina structure which would have definite width, length and thickness, when several such laminas placed one above the other (The lamina fiber either may have same or different orientation) the resultant structure would be called as laminate. The property configuration of lamina and laminate is different from each other, and despite made of same material the ultimate load sustaining capacity and loading behavior is not same. The failure initiates from lamina and reach to laminate which leads ultimate structure failure.

The broad application of fiber-reinforced composite laminates has led to a large amount of research into their progressive damage and failure, and many authors have devoted their work in similar context. There are numerous progressive and failure models that predict mechanical response of structure which includes all loading configurations, boundary conditions, lay-ups, and thicknesses of composite laminates. Categorizing the existing failure theories is expected to highlight with regards to composite laminate progressive damage and failure where existing literature may be sparse. Existing failure criteria are classified as micromechanics or macro mechanics based, the structure failure analysed at lamina constituent level is recognized micromechanical approach where failure analysis at lamina level recognised as macro mechanical approach.

The failure analysis of composite structure is an important aspect to understand to enhance its utility and scope both. While trying in similar context the failure theories (Micromechanical based) are discussed throughout paper which project light on nature of loading, factors responsible in failure, and lamina behaviour before occurrence of ultimate failure, and thus knowledge of such few responsible parameters would enables the technical fellow to design robust structure to serve said application in desired manner.

2. Authors and failure investigation work based on Micromechanical failure theories:

Micromechanics Model		
Sr. No.	**Author & Year**	**Research conclusion**
1	Chamis & Sendeckys (1968)	Ply is macroscopically homogeneous, elastic and orthotropic
2	Bolotin (1965)	Strength of fiber greater than matrix
3	Bolotin (1966)	Macroscopic homogeneity of composite and not valid under few circumstances
4	Mccartney (2002)	Final lamina failure is accumulation of many cracks. The failure parameters can be considered mainly are, stress at crack tip, bridging effect of fiber and crack interaction etc. Compressive strength of fiber is greater than tensile strength.
5	Aboudi (1989)	Behavior of composite is function of cell repetition
6	Mallick (2008)	Crack initiation, propagation when stress intensity reaches to its peak value, further prorogation in crack leads structure failure, but there is no fixed pattern of crack propagation as every investigation had ever surface out different one.
7	Harris & Morris (1985)	Calculated stress intensity factor by graphical method which promotes crack propagation. Strain energy release also adopted fracture growth resistance
8	Bai (2011)	Mechanism determines fracture mode is not suited for all types of failure. Micromechanics model used fracture mechanics principle to model failure of material structure
9	Aveston (1971)	Fiber holds in matrix by means shear force.
10	Marshall & Cox (1985)	Predicts fracture toughness. Use stress intensity approach to predict matrix failure by means cracking
11	Budianky (1986)	Studied the propagation of matrix crack.
12	Hutchinson & Jensen (1990)	Studied fiber debonding and energy release, the stress magnitude responsible in generation of debonding crack
13	Nairan H V (1992)	Studied variation analysis of stresses and thus formation of outer ply crack
14	Mecartney (1998)	Cracking of transverse plies under the uni-axial and bi-axial loadings applied independently
15	Budiansty (1995)	Tensile strength of composite with first crack, author also studied tensile strength of ceramics composite.
16	Crack Zok (1997)	Line spring representation of crack as a result of fiber bridging
17	Pagano (1998)	Presented debonding modes of failure in matrix
18	Gonazelez-Chi &Young (1998)	Investigates failure of Polyethylene fiber, inline to the same study author has also studied axial stress distribution, shear stress at de bonded transition, debonding process in terms of interfacial fracture energy criterion etc.
19	Cox (1952)	Developed shear log model which depicts failure load redistribution on lamina, where fiber carries tensile load and matrix as shear, the stiffness of fiber would be more than matrix stiffness.
20	Peter Amaya	Stress filed using CLT & FEA combined with strain energy based criteria investigates progressive failure of laminate under uniaxial and multi-axial loadings.

21	Mallick (2008)	Fiber occupied larger volume and takes major part of loadings.
22	Mallick (2008)	Proved that, carbon fiber have varying tensile modulus under different loading conditions
23	Mallick (2008)	Low viscosity of epoxies allowed to proceed them for matrix manufacturing
24	Mallick (2008)	Void formed tends to invent micro crack which tends to propagates with respect to increase in load magnitude.
25	Gordon (1964)	Magnitude of In Plane Shear stress and Transverse shear stress reach maximum at crack tip which tends to propagate the crack.
26	Pagano (1970)	Magnitude of inter laminar shear depends on fiber orientation, for 0 and 90 degrees fiber it is noted null and highest for fiber oriented +35 or -35 degrees
27	Waddoups (1969)	Lamina shows nonlinear behaviour for shear loading, and laminate has nonlinear stress-strain curve as a result of this lamina degradation is limited to that respective lamina and let not transferred to adjacent lamina.
28	Chiu (1969)	Analyze orthotropic material failure in one direction
29	Hill (1950)	Mode of failure determined from individual layer strain, the maximum value of strain induced was limited to ultimate strain of laminate
30	Foge (1973)	Investigates behaviour of lamina and came to predict nonlinear relationship between transverse normal stress and shear stress
31	Sandhu (1974)	Degraded lamina due to transverse and shear load still can sustain longitudinal load, the stress-strain behavior is found non linear
32	Brown (1976)	Lamina failed in longitudinal direction can sustain load in transverse direction and vice versa
33	Yeow & Brinjon (1977)	Symmetric laminates with off axis fiber orientation, subjected to uni-axial loadings. Laminate configuration [0/30/-30/0], the failure occurred to 30 and -30 degree laminas
34	Pack-Forster (1970)	Transverse and shear failure associated with matrix failure, the theory also used to predict start of yielding
35	Nahas (1986)	Amount of load carried by failed lamina modeled by exponential degradation method. The rate of modulus degradation after first ply failure/post initial failure will be exponential and instantaneous
	Load distribution Model	
36	Nairn (1988)	Stiffness of fiber is more than matrix, fiber caries tensile load and matrix as shear.
37	Mishnaevsky & Brondsted (2009)	Analyze fiber failure and load distribution among remaining intact fiber's
38	Mishnaevsky & Brondsted (2009)	Author has modeled interaction between multiple fiber breaks, state of stress around single fiber break and used to model stress distribution in composite with multiple fiber break.
39	Daniel (1945)	Bundle of similar fiber with same elastic properties subjected to tensile load accounts the progressive damage of each other Progressive damage in brittle fiber leads ductile behavior of composite
	Micro buckling model	
40	Kyriakides (1995)	Predicted reduced shear modules to avoid overestimation of strength by using theory of plasticity
41	Argon (1972)	Fiber reinforced has region of misalignment causes shear stress concentration and reduces value of shear modulus.
42	Argon (1972)	Buckling stress is inversely proportional to fiber misalignment angle

43	Weaver & Williams (1975)	Composite with low fiber volume subjected to compression and hydrostatic loading leads kinking/kink band
44	Budiansky (1983)	Kink band formation is function of axial stress, shear strain and fiber misalignment angle with principal axis
45	Pimenta (2009)	Kink band formation is function of fiber misalignment angle which laterally supported by elasto-plastic matrix
46	Yerramallis & was (2003)	Compression and shear loading initiate composite failure in terms of spitting
47	Aboudi (1989)	Effective moduli's, fatigue strength and coefficient of thermal expansion are the functions of interaction between adjacent cells. Each such cell has sub cell which is occupied by fiber and matrix. The cell methods also used to predict macroscopic failure and local phenomenon such as fiber rotation, crack initiation etc.
48	Hage (2009)	Combines cell method and FEA to predict three dimensional engineering elastic properties.
49	Ha (2010)	Modeled unit cell of microstructure to derive ply properties from constituents.
50	Bednarcyk (2010)	Material nonlinearity is function of material damage. Author also investigates progressive damage of lamina
Rule of mixture and multi continuum approach		
51	Suresh & Mortenson (1998)	Reviewed rule of mixture and possible progressive failure of composite
52	Ashkenazi (1965)	Author proved normal strength is twice the shear. Further investigations determined interaction coefficient between fiber and matrix for 45 degree fiber
53	Hashim & Rotem (1973)	Proposed several equation describing fiber and matrix failure
54	Hashin (1980)	Distinguished tensile and compressive failure for fiber and matrix

Conclusion

- Prediction of mechanical response of laminates under different loading condition can be done by using progressive damage and failure model suggested by various authors who are dealing over the years in context behavior and failure analysis of lamina and laminate composite under complex sets of loading.
- Use of classical lamination theory is recommended to model uniform stress filed which otherwise impossible to invent.
- Predicted behavior of undamaged lamina by means of CLT (Classical Lamination Theory) agreed with experimental results.
- Initial, intermediate, and final failures of the unidirectional and multidirectional laminate tubular specimens can be predicted adequately by the strain energy theory combined with CLT.
- Stress concentration occurs at free edge leading to exhibit highest stress at respective location.
- Matrix failure at the 0 degree plies occurred at center.
- Load transfer from damaged lamina to undamaged lamina depends on ply layup.
- In plane and out of plane shear do not increases in 0 degree ply after occurrence of initial failure.

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