Review On First Ply And Progressive Failure Of Composite Plates And Shells

Shibaditya Dey[a] and Dipankar Chakravorty[b]

[a]Research Scholar, Civil Engineering Department, Jadavpur University, Kolkata – 700032, India

[b]Professor, Civil Engineering Department, Jadavpur University, Kolkata – 700032, India

1. INTRODUCTION & OBJECTIVE

Laminated composite plates and shells are being widely used in civil engineering cladding units nowadays and such application started form the second half of the century. The researchers started with free vibration analysis of composite units and gradually the other aspects like forced vibration, failure initiation and progress started being taken up. The composite materials are advantageous in terms of their specific strength and stiffness and also due to the fact that these properties can be varied directionally depending on practical requirements. Despite having numbers of advantages, this material being weak in transverse shear exhibit failure initiation which often remains confined within the inner lamina of laminates and hence cannot be detected by visual inspection. This necessitates research work to evaluate first ply load of the composite plates and shells of different laminates, boundary conditions and subjected to different load cases.

This paper attempts to present systematically the current status of failure analysis of composite plates and shells by analyzing meticulously the papers that have been reported in last 30 years. The studied literature in analyzed from different angles in terms of surface geometry, curvature, linearity or non-linearity of strain components and also reports both technical and experimental research papers.

2. METHOD OF ANALYSIS

The reviewed literature has been characterized to provide a clear understanding of failure analysis in laminated composites. The first level of classification differentiates between composite plates and shell as the curvature introduces notable differences in stress distributions and failure initiation. The second classification is based on the strain assumptions: majority of the previous works used linear stain and small deformation theories while the recent works has included nonlinear stain. The third classification is based on the validation scenario, as majorly of the studies are purely theoretical with sparse experimental works. The final classification is based on the failure modes of laminated composites: most consider solely first-ply failure , and a smaller number of references deal with progressive failure.

3. CRITICAL DISCUSSION

- The research on curved surfaces and shell structures is still very limited whereas research of plates is common among the research works.
- Most studies rely on linear strain and small deformation assumptions, which reduce the accuracy while analyzing curved laminates or shell structures with nonlinear responses.
- Many studies on composite laminates lack sufficient experimental validation, reducing the assurance in numerical predictions.
- In most of the research woks the environmental effects, manufacturing defects, and complex loads are rarely considered.

- Most works focus on first ply failure, with limited treatment of progressive damage, stiffness degradation, and ultimate failure, which are necessary for accurate predictions for lifetime and residual strength.
- Research on non-linear first ply and progressive failure of composite shells is rare. The effect of non-uniform loading on curved surfaces is largely unaddressed in most of the works.
- The aspect of sensitivity analysis is largely missing in existing works, leaving uncertainties in material behavior, geometry, and loading effects unquantified.

4. CONCLUSIONS

This review emphasizes the need of a balanced strategy in composite failure analyses. Valid structural laminate design needs coupling of nonlinear analysis, progressive damage mechanics, and experimental verification. A shift of emphasis toward shell geometries, commonly applied in civil and aerospace structures, will fill current gaps and enhance prediction capability. Development of these directions will lead to safer, more efficient uses of composite plates and shells in engineering practice.

5. REFERENCES

[1] Y. S. N. Reddy, C. M. D. Moorthy, and J. N. Reddy, “Non-linear progressive failure analysis of laminated composite plates,” *International Journal of Non-Linear Mechanics*, vol. 30, no. 5, pp. 629–649, Sep. 1995, doi: 10.1016/0020-7462(94)00041-8.

[2] T. Y. Kam and H. F. Sher, “Nonlinear and First-Ply Failure Analyses of Laminated Composite Cross-Ply Plates,” *Journal of Composite Materials*, vol. 29, no. 4, pp. 463–482, 1995, doi: 10.1177/002199839502900403.

[3] G. S. Padhi, R. A. Shenoi, S. S. J. Moy, and G. L. Hawkins, “Progressive failure and ultimate collapse of laminated composite plates in bending,” *Composite Structures*, vol. 40, no. 3–4, pp. 277–291, Dec. 1997, doi: 10.1016/S0263-8223(98)00030-0.

[4] L. N. B. Gummadi and A. N. Palazotto, “Progressive failure analysis of composite cylindrical shells considering large rotations,” *Composites Part B: Engineering*, vol. 29, no. 5, pp. 547–563, Sep. 1998, doi: 10.1016/S1359-8368(98)00010-9.

[5] S. M. Spottswood and A. N. Palazotto, “Progressive failure analysis of a composite shell,” *Composite Structures*, vol. 53, no. 1, pp. 117–131, Jul. 2001, doi: 10.1016/S0263-8223(00)00183-5.

[6] C. S. Lopes, P. P. Camanho, Z. Gürdal, and B. F. Tatting, “Progressive failure analysis of tow-placed, variable-stiffness composite panels,” *International Journal of Solids and Structures*, vol. 44, no. 25–26, pp. 8493–8516, Dec. 2007, doi: 10.1016/J.IJSOLSTR.2007.06.029.

[7] K. Bakshi and D. Chakravorty, “First ply failure study of thin composite conoidal shells subjected to uniformly distributed load,” *Thin-Walled Structures*, vol. 76, pp. 1–7, Mar. 2014, doi: 10.1016/J.TWS.2013.10.021.

[8] K. Bakshi and D. Chakravorty, “First Ply Failure Loads of Composite Conoidal Shell Roofs with Varying Lamination,” *Mechanics of Advanced Materials and Structures*, vol. 22, no. 12, pp. 978–987, Dec. 2015, doi: 10.1080/15376494.2014.884660.

[9] A. Ghosh and D. Chakravorty, “First ply failure analysis of laminated composite thin hypar shells using nonlinear finite element approach,” *Thin-Walled Structures*, vol. 131, pp. 736–745, Oct. 2018, doi: 10.1016/J.TWS.2018.07.046.

[10] G. F. O. Ferreira, J. H. S. Almeida, M. L. Ribeiro, A. J. M. Ferreira, and V. Tita, “A finite element unified formulation for composite laminates in bending considering progressive damage,” *Thin-Walled Structures*, vol. 172, p. 108864, Mar. 2022, doi: 10.1016/J.TWS.2021.108864.

[11] S. Choudhury, A. Ghosh, D. C.-I. C. on, and undefined 2024, “Nonlinear First Ply Failure Characteristics of Clamped Composite Cross Ply Cylindrical Panels Under Non-uniform Load,” *Springer*, pp. 713–724, 2025, doi: 10.1007/978-981-97-6667-3_54.