Extended Layerwise method of laminated composite shells

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PII: S0263-8223(15)00947-2
DOI: http://dx.doi.org/10.1016/j.compstruct.2015.08.141
Reference: COST 6924

To appear in: *Composite Structures*

Extended Layerwise method of laminated composite shells☆

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Abstract

This paper deals with the accurate description of the multiple delaminations and transverse cracks in double-curved laminated composite shells by using the extended finite element method (XFEM) and layerwise theory (LWT), and develops an extended layerwise method (XLWM) which had been applied to the laminated beams in our previous work [1]. In the displacement assumption of XLWM, the discontinuous function along the thickness direction is adopted to simulate the displacement discontinuous resulted from multiple delaminations. While the transverse cracks are modeled in in-plane displacements discretization by XFEM. The level set method (LSM) is employed in the present method to track the interfaces resulted from the transverse cracks. The interaction integral method and maximum circumferential tensile criterion are used to calculate the stress intensity factor (SIF) and crack growth angle, respectively. In order to ensure the accuracy of Gauss integral when certain nodes are very close to the crack surface as the crack grows, a local remeshing scheme is developed to shift these nodes without scarifying the mesh quality. In the numerical examples, spherical shells, cylindrical shells and plates with/without multiple delaminations and/or transverse crack are considered to the problems of static responses analysis, SIF calculation and transverse crack arbitrary growth.

Keywords: Laminated composite shells; Layerwise theory; Multiple delamination; Transverse crack.

1. Introduction

Composite shells are common structural elements in many engineering structures, such as pressure vessels, submarine hulls, wings and fuselages of aircrafts, pipes, exteriors of rockets, concrete roofs, and many other structures. Many investigations have been reported to research the static and dynamic analysis of composite shells [2–8]. Due to the layered and orthotropic characteristics, composite shells would appear various failure modes under impact loading conditions, such as, delaminations, matrix cracking, fibre breakage and fibre/matrix debonding. Whilst the first two modes are dominating for the low-velocity impact because of the high tensile strength of the fiber. For the laminated composite structures with delaminations or matrix cracks although, there are a lot of investigations on the static response, free vibration and buckling, only a few them consider multiple delaminations and matrix cracks.

For the delamination problems, Chattopadhyay and Gu [9,10] developed a new higher-order deformation theory for modeling delamination buckling and postbuckling of laminated composite plates and cylindrical shells. In both lower and higher order terms of displacement field, delaminations are simulated by the jumb discontinuity conditions at the delaminated interfaces. Oh et. al [11] presented a geometrically exact shell theory by a higher order zig-zag theory and Heaviside function for arbitrary shaped multiple delaminations without the thin shell assumption. General free-form surfaces were also considered by employing general tensor expressions in the displacement field. Lee and Chung [12] developed a finite element formulation based on the Sanders higher order shell theory [13,14] and equivalent transformation matrix [15] for the free vibration of laminated spherical shell panels with delamination around quadrilateral cutouts. The equivalent transformation matrix is used to combine the upper and lower elements in the delamination region with the single elements along boundary of delamination region. Yang and Fu [16] derived the postbuckling governing equations for the laminated cylindrical shells with delamination by the variational principle of moving boundary, together with the corresponding boundary and matching conditions. The formulas of energy release rate along the delamination front are obtained based on the Griffith criterion. Liu and Yu [17] established a novel approach for modeling the delamination of

☆Supported by the "Blue Sky Young Scholar" plan of Civil Aviation University of China (205003110307)
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