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ORIGINAL ARTICLE

The influence of stiffeners on axial crushing of glass-fabric-reinforced epoxy composite shells

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Abstract A generic static and impact experimental procedure has been developed in this work aimed at improving the stability of glass fabric reinforced epoxy shell structures by bonding with axial stiffeners. Crashworthy structures fabricated from composite laminate with stiffeners would offer energy absorption superior to metallic structures under compressive loading situations. An experimental material characterisation of the glass fabric reinforced epoxy composite under uni-axial tension has been carried out in this study. This work provides a numerical simulation procedure to describe the static and dynamic response of unstiffened glass fabric reinforced epoxy composite shell (without stiffeners) and stiffened glass fabric reinforced epoxy composite shell (with axial stiffeners) under static and impact loading using the Finite Element Method. The finite element calculation for the present study was made with ANSYS®-LS-DYNA® software. Based upon the experimental and numerical investigations, it has been asserted that glass fabric reinforced epoxy shells stiffened with GFRP stiffeners are better than unstiffened glass fabric reinforced epoxy shell and glass fabric reinforced epoxy shell stiffened with aluminium stiffeners. The failure surfaces of the glass fabric reinforced epoxy composite shell structures tested under impact were examined by SEM.

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1. Introduction

Fiber-reinforced plastics (FRP) have recently been put into practice by the aerospace and automotive industries, due to their high specific strength and specific stiffness. Fabric reinforced or Textile composites (Naik and Ganesh, 2000; Sundaram and Shembekar, 2000; Vasiliev and Morozov, 2007) become more applicable to many applications such as aerospace structures, re-entry of vehicles and civil structures owing to low cost

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Nomenclature

ASTM	American Society for Testing and Materials	h_s	height of hemisphere (mm)
ASTS	Automatic Surface to Surface	m	striking mass (kg)
d_b	bottom diameter of the cone (mm)	P	axial compression (kN)
d_t	top diameter of the cone (mm)	SEM	scanning electron microscope
E	energy absorption due to static load (kNmm)	t	thickness of shell (mm)
E_L	elastic modulus along longitudinal direction (GPa)	UTS	ultimate tensile strength (MPa)
FEM	Finite Element Method	v	impact velocity (m/s)
F_{Lc}	longitudinal compressive strength (MPa)	α	semi cone angle
GFRP	Glass Fabric Reinforced Plastic	δ	axial extension (mm)
G_{ms}	shear strength (GPa)	ρ	density (g/cm^3)
H	drop height (mm)	υ_{LT}	Poisson's ratio
h_c	height of cone (mm)		

processing. However fabric composites tend to involve many microscopic damages including stiffness reduction due to buckling which often leads to catastrophic failure.

Thin-walled Glass Fabric Reinforced Plastic (GFRP) shell structures have been widely used in aircrafts, space applications and automotive applications because of the weight saving of the principal structural components. Nevertheless, the buckling and loss of stability of shell structures are the significant and critical failure phenomena of such structures. Thin-walled composite shell structures stiffened (Bhaskaran and Lalmoni, 2007; Gangadhara Prusty, 2003) with longitudinal stiffeners are widely used in launch vehicles, aircrafts, marine and satellite structures because of their high energy absorbing capabilities. Stiffeners (Jones, 1999) are finding increasing applications in aircraft wings (Wiggenraad and Arendsen, 1998), fuselage structures, and civil structures for increasing the buckling loads.

Many authors have extensively studied the buckling of thin-walled composite shell structures. In spite of much research in buckling of thin-walled shell structures over the past 50 years, very few researchers have studied a method for increasing the stability of axi-symmetric fabric composite shell structures under axial compression. Calladine (1995) has addressed the imperfection-sensitive buckling behaviour of shells. A detailed experimental study on impact behaviour of woven fabric composites has been presented by Naik et al. (2002). An optimum laminate configuration for the maximum buckling load of laminated conical shells was investigated by Goldfeld et al. (2005). The stability of stiffened conical shells with axial stiffeners and the influence of stiffeners on the buckling behaviour of conical shells were studied by Jabareen and Sheinman (2009). The experimental investigations of collapse behaviour of thin spherical shells under impact loading were studied by Gupta et al. (2007). The numerical simulation of collapse behaviours of thin spherical shells under dynamic loading condition using commercial nonlinear finite element software package LS-DYNA® was also considered in Gupta et al. (2007). Recently, Buragohain and Velmurugan (2011) have shown a method to study the stability of grid-stiffened composite shell structures. Stiffened composite shell structures would provide increase in the buckling load as well as specific buckling load indicating a net increase in the efficiency under axial compression were also considered in Buragohain and Velmurugan (2011). The effect of the number of helical ribs and grid shapes on the buckling of thin-walled GFRP stiffened shells under axial loading was investigated by Yazdani and Rahimi, 2010. Yazdani and Rahimi, 2011 also conducted an experimental study on the behaviour of stiffened GFRP shells under cyclic axial loading.

The study prescribed in this work would be useful in the design of structural shell components in the case of aircraft and spacecraft structures for crashworthy applications. This work concerns with a combined geometry of frustum of conical shell and spherical shell, fabricated with glass fabric reinforced epoxy composite with longitudinal stiffeners. The scope of the present work is to study the influence of stiffeners on the axial compression of thin-walled glass fabric reinforced epoxy composite shells. The Finite Element Method (FEM) has been employed in the present work for generating the numerical results with ANSYS®-LS-DYNA® software. The present study carried out deals with the following phases of work:

- Firstly, the facility for axial compression experiments as well as numerical methodology to study the static, and dynamic behaviour of the thin-walled glass fabric reinforced epoxy composite shells (unstiffened GFRP shell) has been developed. The material characterisation of glass fabric reinforced epoxy composite along with Scanning Electron Microscope (SEM) observations has been also carried out in this phase.
- Secondly, the fabrication of glass fabric reinforced epoxy composite shells with longitudinal stiffeners has been developed. Both experimental and numerical impact studies on static and dynamic responses of glass fabric reinforced epoxy composite shells with axial stiffeners (stiffened GFRP shell) were carried out. Both metallic and composite stiffener configurations were taken into account in this phase.

2. Experimental procedures

2.1. Materials

The specimens in the present study were made by hand lay-up operation using commercially available bidirectional plain