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Buckling Response of Impact-Damaged Composite Panels

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ABSTRACT

In the marine industry, composites are being used more often compared to traditional materials due to their increased strength- and stiffness-to-weight ratios, corrosion resistance, ability to tailor properties, and improved stealth characteristics needed for military applications. However, one drawback with composites is the lack of robust damage models applicable to large composite structures capable of reliably predicting damage growth and ultimate failure loads. This is especially true when predicting delamination which can occur when composites are subjected to lateral impact or shock loads. The focus of this research is to examine the effects of low-velocity impact loading on the behavior of a composite panel. Seven panels were manufactured using a modified Vacuum Assisted Resin Transfer Molding (VARTM) technique. Each panel was 91.4-cm wide x 121.9-cm long x 1.9-cm thick and was made from 29 layers of 24oz. woven roving/8084 Dow Derakane vinyl ester. Impact testing on four panels was performed at the Naval Surface Warfare Center Carderock Division (NSWCCD). A total of three different impact energies were used. After impact was imparted, these damaged panels plus three baseline panels were subjected to in-plane compression to failure. Results from this testing are compared to determine the residual strength of the panels after impact.

KEY WORDS: Composites; shock; impact testing; delamination; damage; buckling.

INTRODUCTION

Composite materials have been used for several decades in the marine industry as an alternative to traditional construction materials (such as aluminum and steel). However, little work has been performed to gain an understanding of the detailed response to shock loading and the residual strength after a shock load. Delamination damage is a particularly common and serious damage mode resulting from a shock load, and if undetected, can lead to catastrophic failure. The ability to computationally model a structure under a potentially damaging load is increasingly sought after. The marine industry envisages full-scale modeling capabilities of its vessels and the ability to predict damage and survivability after a damaging load. However, there is limited research on in-plane testing, shock testing, and damage modeling of large-scale composite structures and little validation of current failure criteria in this area. In addition, the vast proportion of the work is carried out on aerospace composites, which are inherently different than common marine composites, such as glass reinforced polymers (GRP).

One relevant study on GRP materials was performed by Sutherland and Guedes Soares (2005). They tested a range of diameter-to-thickness ratios circular glass/polyester plates, ranging in size from 100 to 200 mm in diameter. The impact velocity was varied up to a maximum of 6.19 m/s. Matrix cracking, fiber failure, and delamination were examined together with the force-displacement and force-time response. The onset of delamination was described using a fracture mechanics model, and the impact force and incident energy were modeled using an energy balance approach.

Another study on low-velocity impact damage and residual strength of woven fabric glass/polyester laminates was carried out by Davies et al. (1996) who related the impact force and incident kinetic energy to identify damage initiation. These laminates were 100 to 500-mm long and up to 25-mm thick. A simple mode II fracture analysis was used to model a single circular delamination in an isotropic material, with the assumption that the woven fabric was not too far from isotropic. In another set of impact tests on glass/polyester specimens, Kuboki et al (2003) examined the relationship between the delamination resistance and the impact resistance. Static mode I and mode II delamination tests were used to characterize the delamination resistance. This study highlighted the problems currently existing in the relationship between the delamination resistance of GRP and its impact resistance.

An improved stress-based delamination criterion for laminated composite structures was developed by Hou et al (2001) and verified with low-velocity impact tests on plates (140x85x2.6 mm). The failure criteria were implemented in LS-DYNA3D using one solid element through the thickness and taking into consideration the out-of-plane stresses for damage initiation. Both influences of fiber failure and matrix cracking on delamination were modeled by reducing the