Experimental and numerical study on the strength of sandwich L-joints in ship structure

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ABSTRACT

This paper presented results on the strength of composite sandwich L-joints subjected to bending load. Both experiment and FE simulation were carried out for fillet and corner connection L-joints. By taking failures of skin, core and adhesive into consideration, FE analysis were able to reveal damage evolution and failure mode. FE analysis showed that skin failure and foam core failure always existed in the loading process and there was no failure in adhesive. Experimental results and FE simulation both demonstrated the differences between different connection types. Stiffness, failure load and damage evolution were all affected by the connection types.

KEY WORDS: sandwich L-joint; failure load; damage evolution; FE analysis; connection type

INTRODUCTION

Composite materials have emerged as competitive candidates in various filed. In comparison with conventional metallic materials such as steel and aluminum, composites possess some unique advantages such as high relative stiffness and strength to weight ratios, resistance to corrosion and electromagnetism. Therefore they have been gradually employed in both commercial ships and naval vessels, which can be seen in (Chen and Guedes Soares, 2007; Di Bella and Calabrese and Borsellino, 2012; Mouritz and Gellert and Burchill and Chalil, 2001).

For the purpose of lightweight design of ships, sandwich composites are increasingly used, which consist of two thin face sheets with high strength separated by a thick core. This configure maximize the advantages of composite face sheets, however leads to the complexity in failure analysis on the other hand.

In general, failures of sandwich composite structures can be classified into three modes, which are core failure, face sheets failure and adhesive failure. Progressive failure model (PFM) enables better understanding of the damage propagation and acquirement of failure load with higher accuracy. Proper failure criterion is used to evaluate whether damage occurs based on the calculated results of stress and/or strain. Although local damage results in the degeneration of structural performance, the whole structure still remains the capacity to carry load. Stiffness degradation model is expected in the following analysis.

Various composite material strength criteria have been presented since 1960s, which can be split into two categories depending on whether failure modes involved. Maximum stress/strain criterion, Tsai-Wu theory and Hoffman criterion only give the conditions under which failure happens and take no account of the failure mechanism. However, Hashin (1980) proposed standards to evaluate the in-plane damage modes of laminates. Shokrieh (1997) took stresses between layers into consideration and extended the failure modes into seven types.

Stiffness degradation can be an effective method to reduce the stress of areas with local damage. The degradation coefficient \( k \) is introduced and \( 0 < k < 1 \). Researches by Chang (1987) and Camanho and Matthews, (1999) are of great significance for the development of PFM.

Joints of ship structures always inevitably compromise in performance, and accurate prediction of their strength is of great value to assure the economic and safety benefits brought by composites. Generally, adhesive joints, mechanical joints and hybrid joints cover all the types used in composite structures. The adhesive joint contributes to lower structural weight and avoids performance loss caused by cutting of fibers, compared to bolted and riveted joints. Banea and Silva (2009) presented a comprehensive review on adhesively bonded joints, in which factors that affect joint behavior and methods to analysis stress and predict failure were discussed. Contrast to the in-plane load carrying requirements for lap joints and step joints, corner joints are expected to transfer flexural, tensile and shear loads, which results in different failure models. For ship structures, bulkhead and hull sections are jointed together, which is the typical T-joint and can be seen in (Dharmawan and Thomson and Li and Herszberg and Gellert, 2004; Di Bella and Borsellino and Pollicino and Ruisi, 2010; Guo and Morishima, 2011; Khalili and Ghaznavi, 2011). The connection of deck and side plate is L-joint, which has been extensively used in ship structure. Failure prediction of single-L joint structures under tensile and bending has been conducted in (Feih and Shercliff, 2005a; Feih and Shercliff, 2005b). Referring to previous works published by related