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Investigation on a novel bolted joint scheme for foam inserted top-hat stiffened composite plates

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ABSTRACT

Joint schemes are very important in the design of bolted joints in huge composite structures. This article describes the scheme, manufacturing method, performance testing and simulation of a novel bolted joint configuration for top-hat stiffened composite plates. Firstly, a bolted joint scheme is proposed for use in top-hat stiffened composite plates, after which the manufacturing method of the joint scheme is presented, as is the fabrication of test specimens and their bending performance are tested. Then, a numerical method is proposed to analyze the performance of these specimens. Drawing on experimental and simulated results, seven failure modes are summarized with varied geometrical parameter. We change the angle of top clamp θ and the length of the foam block L_x, and discuss the relationship between the mutative design parameters and bending performance. Suitable design parameters are obtained and suggestions for the joint scheme are offered. It is found that good mechanical performances can be achieved with the proposed scheme through suitable parameter design, and it is also found the simulated result agrees the experiment well, which provides a useful method for the bolted joint design of foam inserted top-hat stiffened composite plates.

1. Introduction

Fiber-reinforced polymer matrix composites have gained substantial attention as structural engineering materials in shipbuilding due to their outstanding mechanical properties, such as high durability, thermal expansion, lack of magnetism, high load-bearing capability and relatively low density. Foam inserted top-hat stiffened composite plates are effective structure form in composite shipbuilding. Bolted joints are often used to assemble larger composite structures, especially in composite shipbuilding. Joint schemes have been proven very important in the design of bolted joint, which affect the structural performances and durability obviously [1]. Some studies [2–5] have been conducted on bolted joints, covering such topics as composite bolted joint failure modes, analytical methods and the geometrical parameter design of bolted joints. Researchers have also investigated various joint configurations and design schemes in recent years. Turaga et al. [6] proposed a configuration with attachments that transferred the load to strengthen single-lap joints. Li et al. [7,8] studied various composite joint configurations with different attachments and proposed a butt joint configuration to improve the structural performance. Bella et al. [9] designed and improved composite T-joints for use in composite watertight bulkhead connections. Bai and Yang [10] developed several novel joint configurations for assembling all-composite space truss structures. Löbel et al. [11] proposed a mechanical joint scheme using staple-like pins, and analyzed and validated the tensile performance of this joint configuration. G.Lamanna et al. [12] proposed a hybrid joint scheme and investigated the tensile performance of the scheme experimentally. Turvey and Cerutti [13] proposed a splice joint scheme for use in bolted joints in pultruded composite wide flange beams. Dhôte et al. [14] investigated liquid shim for aerospace bolted joints. Arun et al. [15] studied the influence of the bolt configuration and filler content on the strength of composite joints. Caccese et al. [16] developed and compared many novel joint concepts, including Bolted Close-Out, Co-cured Metallic Insert, Metallic Extension with Secondary Bond, and Integral Fit (Mechanical Locking). Diler E.A et al. [17] investigated six types T-joint configuration used in GRP/PVC sandwich structures. These investigations indicated that joint configuration affects the mechanical performance of structures, and that an outstanding joint configuration should fulfill the following criteria,

- Provide outstanding mechanical performance and structural integrity.
- Reduce the stress concentration attributable to the joint geometry and abrupt changes in material stiffness.
- Be simple to manufacture and maintain.

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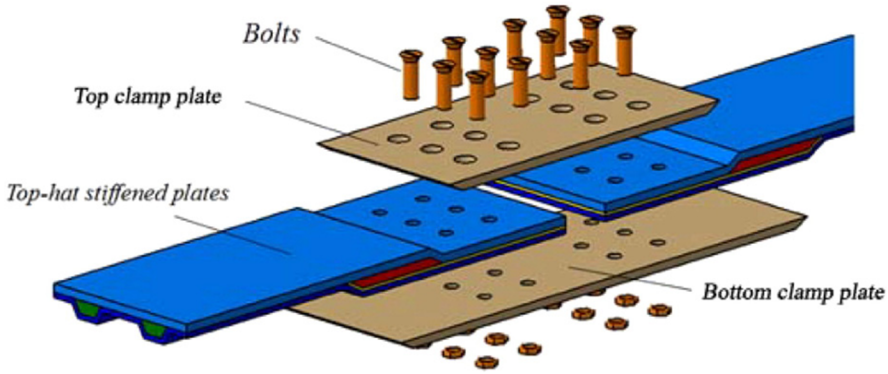

Fig. 1. The joint scheme of foam inserted top-hat stiffened composite plates.

- Have a suitable geometrical outline without decreasing the functions of products.

Foam inserted top-hat stiffened plates are the most commonly used structural element in the construction of composite ships, and form the deck, hull, side shell and bulkhead. In this investigation, we compare many joint configurations found in the literature, and create a bolted joint scheme suitable for a top-hat stiffened ship hull. Finally, the manufacturing method, performance testing and simulation method of the bolted joint scheme are studied, and suitable geometrical parameters are also discussed.

2. Joint scheme, specimen manufacture and test

2.1. Scheme description

The bolted joint scheme is proposed for use in top-hat stiffened composite ship hulls and therefore must consider the following aspects: a) whether the one-sided geometrical shape should be streamlined or smooth, b) how to make a smooth transition between a top-hat stiffened composite plate and the joint area, and c) whether the stiffness of the stiffened composite plate should match the stiffness of the metal components. After consulting several studies [18–21], especially the scheme by Caccese [20], we proposed a scheme in which the joint area consists of two top-hat stiffened plates, a top metal clamp plate and a bottom metal clamp plate as shown in Fig. 1. To keep the external surface streamlined, the top clamp is designed to sink into the stiffened plate. To decrease the stress concentration and stiffness mismatch between the metal clamp and the top-hat stiffened composite plates, the two metal clamps are designed to have different lengths. Two foam blocks are used to smooth the top-surface of the joint area (red parts in Figs. 1–2). The thickness of the foam block is the same as that of the top metal clamp to ensure the top-surface smooth. A sketch of the form inserted top-hat stiffened plate manufacturing process is shown in Fig. 2. Firstly, the top metal clamp is laid onto the mold. Then, the top fiber layer, the foam block and the top-hat foam bars are laid on top. To strengthen the bolted joint area and to smooth the stiffness transition between the top-hat stiffened composite plate and top-hat stiffened composite plates, a specifical reinforced layer is used, as shown in yellow in Fig. 2, and finally the bottom fiber layers are laid.

2.2. Test specimens

After above manufacturing preparations, release films, resin flow mesh and vacuum bags are covered and sealed. With the help of vacuum extraction, resin is impregnated into the mold, which is vacuum assisted resin infusion (VARI) technique, shown as in Fig. 3. After resin curing, demoulding and assembling, test specimens are manufactured, as shown in Fig. 4. In the process of machining the holes, a PROXON-MB140s micro drilling machine was used, which was made by ATTON. After machining, we detected the holes by magnifying glass and did not find visible defects around hole.

The geometry of these test specimens is shown as in Fig. 5. The geometric parameters used are listed in Table 1. In the figure, the degree of the top clamp plate is the same as that of the inserted foam block, and the length of the bottom clamp plate L_2 equals the sum of L_1 and double L_x. Thus, when the parameters of the inserted foam block are changed, the parameters of the clamp plate vary accordingly. The height of top-hat stiffened rib, h_c, is set to be the sum of t_1 and t_r to smooth the lower surface of joint area. Based on our previous research [22], two geometrical parameters, the width to bolt diameter ratio (B/D) and

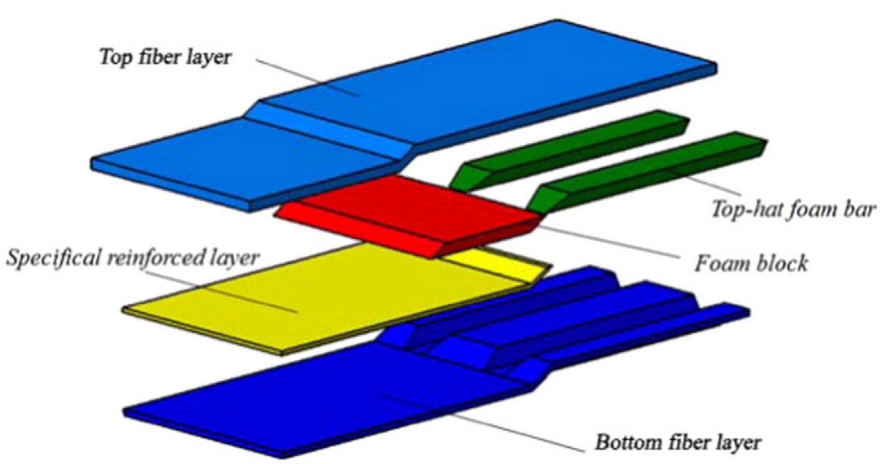

Fig. 2. The manufacture process of foam inserted top-hat stiffened composite plates.