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Ultimate strength analysis of composite typical joints for ship structures

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ABSTRACT

In order to solve the damage failure problem of composite L-joints for ship structures, the failures and ultimate strength of the composite L-joints for ship structures are researched by using the progressive damage analysis method and experimental method. A number of studies have been carried out on the structural failure process and failure strength of the joints under compressive loading. The experimental and numerical results show the axial displacement of sandwich plates under axial compressive loading increases slowly before reaching the limit, but the bearing capacity of the structure decreases rapidly once the load exceeds the ultimate load, with the slow increment of axial displacement until the sandwich plate cracks. The major failure modes of sandwich L-joints are the delamination between core and skin, fiber failure, base shear failure and PVC failure. There is a good agreement between the numerical results and the test results, which offers a guide in designing the structure of sandwich composite joint.

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1. Introduction

As new kinds of functional materials, composites exhibit excellent performance such as high speed, low emission, long life and superior comfortability in the marine environment [1]. In addition, due to the lightweight and high specific strength, composites are gradually applied in ship building [2–5]. However, the anisotropic and brittle characteristics of composites make the stress distribution and failure modes of composite joints far more complex than metal structures [6]. Composite material failure is the process of the internal microscopic damage accumulation and material degradation. Due to the diversity of microscopic damages, the failure process is lack of regularity. Therefore, it is necessary to analyze the mechanical properties of the composite joint by experimental method.

Smith and Dow [7] predicted the ultimate strength of hat composite stiffened plate under axial compressive load, ignoring the stiffness reduction of stiffened plate. Dow [8] completed a series of ultimate strength experiments on composite laminated plates and stiffened laminated plates of ship structure. Chen, et al. [9] analyzed the longitudinal ultimate strength and reliability of composite hull with beam-column theory and Smith's method. Prusty [10] discussed the effect of reinforcement on the ultimate strength based on the first-order shear deformation theory and shear correction factor, but his research ignored the stiffness of destroyed layers within the elastic range. Tang, et al. [11,12] studied the compressive ultimate strength of stiffened laminated composite plates under axial load, then discussed the influence of layer, thickness on ultimate strength. However, only a few tests have been done to analyze the ultimate strength of sandwich composites.

Till now, the ultimate strength analysis of composite material structure is still in the stage of development, as material failure criterion is imperfect, the experimental data is not enough, and the progressive failure analysis method is flawed [13,14]. In fact, the failures of composite structures occur widely in practical engineering. During the initial loading, the weak part will be damaged first, which leads to stress redistribution. In fact, this kind of damage cannot be seen in macro. With the load increasing, the damage region will expand and the stiffness of structure will be degraded until the final failure happens. Considering the local failure and material degradation, progressive failure analysis method can better simulate the failure process and the ultimate failure load of composite material structure. Therefore, in this paper, experimental method and progressive damage analysis method will be compared to study the ultimate strength of sandwich L-joints in shipbuilding.

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2. Experiment analysis

Currently there is a wide range of naval structures being developed using composite materials. The applications examined included large patrol boats, hovercraft, mine countermeasure vessels and corvettes that are built completely of composite materials [15]. As shown in Fig. 1, the simplest type of plate girder structure consists of plates, stiffeners and brackets. Stress concentrations at these corners cause cracks initiate and propagate under static and cyclic loadings [16]. Therefore, several full scale sandwich L-joint were used in this paper to analyzed the ultimate strength in the corner. Schematic diagram of specimen sketches in Fig. 1, the corner is the stress concentration region when the hull is hogging or sagging.

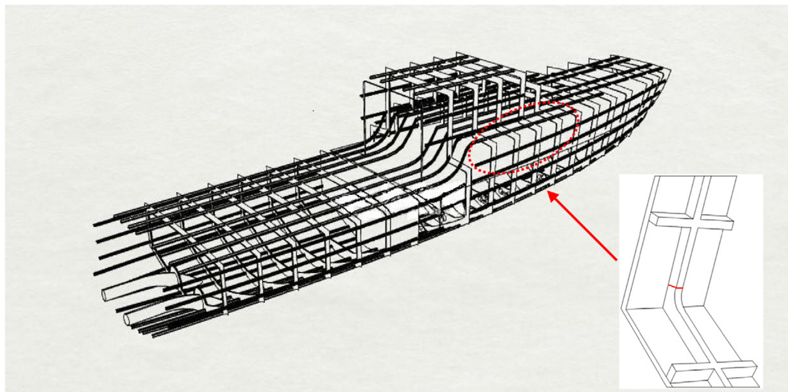

Fig. 1. Schematic of the framework for composite ships.

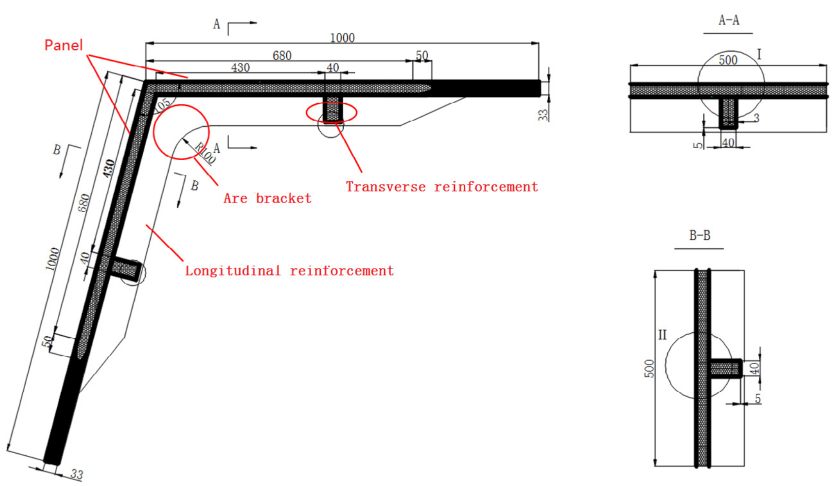

Fig. 2. Geometry parameter of L-joint.

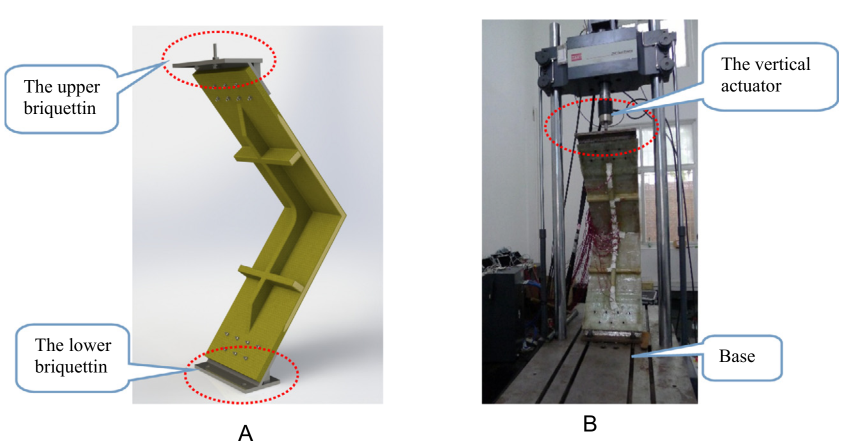

Fig. 3. Specimen and equipment: (a) specimen fixture; (b) test platform.

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