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Experimental and numerical study of hybrid steel-FRP balcony overhang of ships under shear and bending

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ABSTRACT

A model of a composite-to-steel hybrid balcony overhang is tested to find its strength and stiffness under imposed shear and bending loads. The configuration tested is representative of a solution being considered for the balconies of cruise ships, where the substitution of steel by composites aims at weight saving. The steel component is a channel type of structure made of two plates that serve as external supports of the sandwich plate. A finite element model is used to compare with the experimental results and to predict the critical regions of stress concentration. The results include load-deflection and load-strain curves with the maximum value of the shear and bending loads. The critical locations and failure loads have been investigated too.

1. Introduction

In ship structures, there are many applications for composites, including the current and potential use in hulls and superstructures, decks, bulkheads, advanced mast systems, propellers and other equipment [1]. There are many benefits to use composites, including reductions of weight, flatness for stealth requirements, and increased resistance to corrosion. A number of ships are wholly constructed of composite sandwich with foam or Balsa cores and glass or carbon fiber reinforced skins. This combines high strength and rigidity with low weight, good shock resistance, low radar and magnetic signatures [2].

The current research concentrates on a hybrid ship part, consisting of a steel support, to which a composite material plate (a sandwich panel) is attached. Such a structure will require a strong joint between the composite and the steel part. Some of the difficulties with joining composites and metal are related to the large difference in mechanical properties especially stiffness. The stiffness mismatch generally leads to debonding and accordingly weak joints.

Many papers, dealing with steel-to-composite joints, have been published already. Clifford et al. [3] examined the mechanical response of a prototype joint between a glass-fiber reinforced polymer superstructure and a steel hull formed via a resin infusion process and subsequently modified to improve performance through a combined program of modeling and mechanical testing. Cao et al. [4] replicated the joint design type A from Clifford et al. [3], with different glass fiber, vinylester and core material. The joint was then redesigned by moving the steel edge away from an area of high stress concentrations. Specimens of both the original and new designs were made and tested. The new joint was lighter, and the limited number of tests suggests that it was stronger as well. Kharghani et al. [5] performed a numerical analysis of a composite to steel joint in order to determine the stress distributions on the joint as a function of the imposed bending and torsional loads. The steel component was a channel type of structure made of two plates that serve as external supports of the sandwich plate. The attachment of the steel joint to the structure was supported by a bracket. Finite element analysis was conducted with 3D models in order to determine the most highly stressed zones where failure

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can be expected. Analysis of the results shew the most suitable values of the design parameters and the estimation of the maximum load that can be exerted on the specimen. These results served as the basis to design test specimens and to plan the current experimental investigation.

Xiaowen Li et al. [6] examined the mechanical response of the joint between a glass-fiber reinforced polymer (GRP) superstructure and a steel hull formed and subsequently modified to improve performance through a combined program of modeling and testing. Jiang et al. [7] studied the adhesively-bonded joint under shear loading experimentally and numerically. Also they [8] focused on mechanical behavior of adhesively-bonded joints between FRP sandwich decks and steel girders. A specific tensile–shear loading device was designed with the capacity to provide the combination of tensile and shear loads in six different ratios. Ultimate failure loads, load-deformation behaviors and failure modes of adhesively-bonded joints were investigated experimentally and compared regarding to different loading angles.

Hentinen et al. [9] presented several joint elements developed for joining large FRP sandwich panels to ships. Metal profiles were adhesively bonded to the panels in the prefabrication phase of the sandwich. This made it possible to weld the FRP part directly to the metal structure in the shipyard. Boyd et al. [10] proposed parametric variation and optimization using genetic algorithms employing single and multi-objective functions for the optimization of a structural steel/composite connection. Cao and Grenestedt [11] concentrated on hybrid ships, consisting of an advanced double hull stainless steel center section, to which a composite material bow and/or stern was attached. Two concepts of joints, a bonded-bolted joint and a co-infused perforated joint, were evaluated. Also Cao et al. [12] investigated a hybrid ship hull made of a steel truss and composite sandwich skins experimentally and numerically. A 6-m model was tested under hogging loads, after having previous been subjected to sagging loads. Kotsidis et al. [13] studied an adhesively bonded butt-joint, comprised of a double lap steel-GFRP joint and a GFRP sandwich composite part. In order to simulate the mechanical behavior of the joint subjected to tensile and bending loading, a two-dimensional finite element model was developed. Various design parameters were examined in order to evaluate their effects on the joint load bearing capacity and stiffness.

Guedes Soares et al. [14] presented an experimental and numerical study on the investigation of the behavior of a glass fiber reinforced plastic box girder under pure bending. The box was fabricated using the WR/polyester glass reinforced plastic and the experiment was performed by a four-point bending of a beam which was composed of two symmetric supporting parts and the box girder specimen in the middle. A nonlinear finite element code was used to predict the responses of the box. Mantari et al. [15,16] presented bending and free vibration analysis of multilayered plates and shells by using a new accurate higher order shear deformation theory (HSDT).

Regarding to the necessity of investigation steel-composite bonding strength in a more realistic condition for an industrial marine structure, a hybrid steel-FRP balcony overhang is studied numerically and experimentally in the current paper. Firstly the behavior of the structure is predicted by ANSYS 15 finite element software and the contours of stresses and displacements are obtained to identify the critical regions and deflections. Then large-scale experiments are carried out to analyze the behavior of the structure in a more real situation even after the failure.

2. Experimental approach

2.1. Specimens

Three specimens were tested with the given unique identities: Sp1, Sp2 and Sp3. The steel component of the specimens is a channel type of structure made of two plates that serve as external supports of the sandwich plate. The attachment of the steel joint to the structure is supported by two brackets (see Fig. 1). The technical drawing of the joint is presented in Figs. 2 and 3 and it is the result of a previous initial numerical 3D parametric study [5]. The thicknesses of the core, steel and skins are 30, 6 and 2.5 mm, respectively. The thickness of the steel base-plate is 20 mm (see Fig. 3), whereas the angles of the steel brackets are 45° and the width of all specimens is equal to 750 mm. Finally, the overlap length between the steel parts and the sandwich panels are 404 mm for all of the specimens (see Fig. 2).

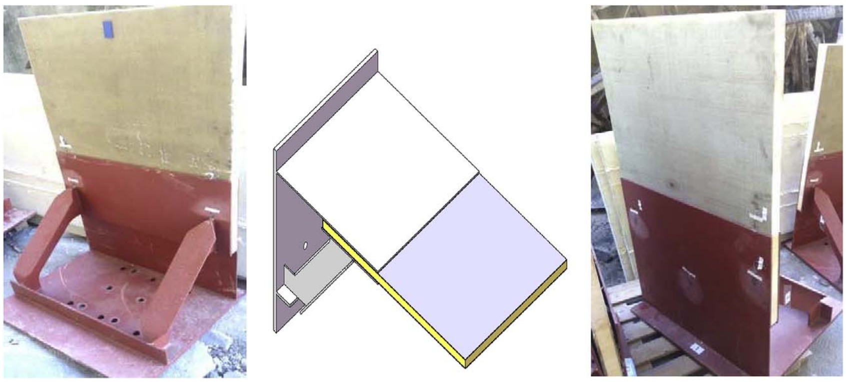

Fig. 1. 3D view of the specimen.