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A methodology for improving shear performance of marine grade sandwich composites: Sandwich composite panel with shear key

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ABSTRACT

Researchers have developed several measures to improve shear resistance capacity of sandwich structures composed of thin composite face sheets of Eglass/epoxy and low density PVC foam core, but these methodologies are either costly or result in damage to the sandwich composites before being placed for production. A novel, innovative cost-effective methodology of introducing fiberglass shear keys attached to face skins to improve the stiffness and strength of the sandwich composite panel is being proposed in this manuscript. Manufacturing of the sandwich composite panels along with experimental and numerical investigations have been performed in this manuscript to demonstrate the potential of the proposed simple methodology which can be utilized for shear-sensitive design and analysis of sandwich composite structures and/or components. A parametric study has also been carried out to determine the effect of change in shape, size, spacing and material of the shear keys on the sandwich composite panel global response.

1. Introduction

Sandwich panels represents a special form of laminated composite material in which a relatively thick, lightweight and complaint core material separates thin and strong face sheets. Typically for marine applications, the face sheets are made of laminated polymer based composite materials, such as glass fiber reinforced polymer or carbon fiber reinforced polymer; the cores are typically made of balsa wood or foam materials such polyethylene, poly-vinyl-chloride or polyurethane foams. The faces and core are joined by adhesive bonding with epoxy or vinyl-ester resins. The potential benefits of incorporation of sandwich composites in construction of marine and naval vessels are innumerable. In comparison to conventional metallic structural components, sandwich composites have high strength to weight ratio (which results in increase of military payload, provides greater range and/or reduced fuel consumption), extended operational life, lower maintenance cost (due to less corrosion, and resistance to marine boring organisms), as well as a range of integrated functions, such as thermal and sound insulation, excellent signature properties, fire safety, good energy absorption, directional properties of the face sheets enabling optimized design and production of complex and smooth hydrodynamic surfaces. Thereby, over the past few decades, sandwich composite structures have found wide use in marine industry [1,2]. Examples of sandwich composite construction include ship hulls of patrol boats (e.g. KNM Skjøld of Royal Norwegian Navy); mine-counter-measure vehicles (MCMV) (e.g. Landsort class MCMV by Royal Swedish Navy); Visby Corvettes (e.g. NGPV class of Royal Swedish Navy); Superstructure of naval boats (e.g. La Fayette class frigates of French Navy); Advanced Enclosed Mast/Sensor (AEM/S) for the US Navy; propellers, propulsors and propulsion shafts along with secondary structures, machinery and fittings for numerous naval vessels.

Inspite of innumerable advantages of using composite sandwich panels as a structural material, these structures are notoriously sensitive to failure by shear load. Shear strength is one of the primary design criterion in application of these structures for marine environment. An example application area is the bottom of large high speed ships subjected to high sea pressures which might result in shearing of the bottom along its perimeter.

2. Previous research efforts

A number of research ideas have been briefly presented which dealt with improving the shear properties of sandwich composite panels. It is to be noted that there have been research articles, within the perspective of material science, on improving the properties of the core using functionally graded materials [3]. However, these research within the perspective of material science have not been considered in this manuscript and only those research articles which presents a structural solution of improving the properties of the sandwich composite panels have been presented.

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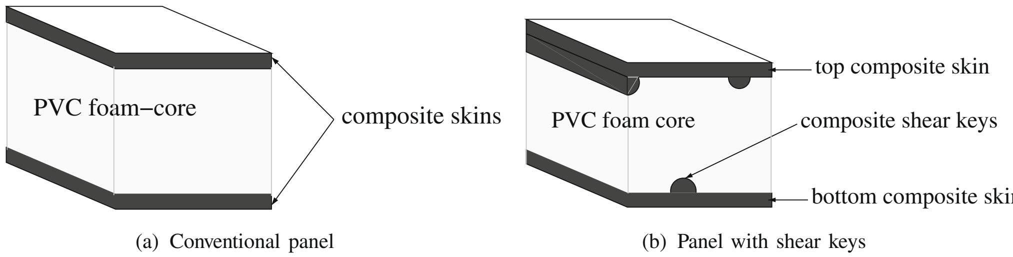

Fig. 1. Sandwich composite panels.

End grain balsa sheets have been utilized as a structural alternative to using foam materials as the core material in sandwich composites. In fact, a typical end grain balsa core, with a density around 155 kg/m^3, possesses a slightly higher quasi-static shear strength in comparison to a PVC foam core of the same density. However, the typical end grain arrangement does not fully utilize the anisotropy of balsa wood for the benefit of shear properties. A new arrangement of balsa blocks in a sandwich core was developed and numerically analyzed to obtain superior shear stiffness [4].

Z-pinning [5–9] is another established methodology of improving the shear properties of composite sandwich. This process refers to insertion of metallic or fibrous pins/rods (which can be of carbon and glass fiber, titanium, stainless steel, aluminum, etc.) through the thickness of the uncured laminate using an ultrasonic insertion technique. A extensive literature review on manufacture, mechanical performance advantages and disadvantages of introducing Z-pins are presented in the review paper by Mouritz [10]. Studies have also been performed on the failure mechanism of sandwich composites with Z-pins [11]. Above presented manuscripts on Z-pinning and the references cited within them have demonstrated, through experimental and numerical simulations, that significant gain can be obtained in the mechanical performance of sandwich composites with Z-pinning.

The method of *Stitching* of sandwich materials have also been developed quite recently and represents another alternative methodology of improving the shear properties of the composite sandwich. As the name suggests, this process is one of the techniques for composites fabrication, which basically involves sewing high-tensile-strength yarn (e.g. glass, carbon or Kevlar), through a sandwich composite using an industrial sewing machine. An extensive literature review [12] is presented on the in-plane performance of stitching of composite laminate structures in which the researchers indicated that stitching affects strength, stiffness, and fatigue performance of a laminate. A number of researchers have reported significant gains in mechanical performance of these structures [13–17]. Research and parameter studies have also been performed to demonstrate improvements in performance of angled stitched sandwich composites in comparison to vertical stitched sandwich composites [18,19]. Above presented manuscripts on stitching of sandwich composites and the references cited within them have demonstrated, through experimental and numerical simulations, that significant gain can be obtained in the mechanical performance of sandwich composites with stitching.

Even though research on the above mentioned methodologies have reported significant gains in mechanical performance, specially shear strength, in comparison to the conventional sandwich composites; these processes have their own disadvantages. It has been pointed out that the process of Z-pinning is a slow and expensive process [17] and has thereby been primarily limited to the aerospace market and probably not a cost-effective solution to the naval industry. Moreover introduction of Z-pins results in initial damage to the structure and may result in the mechanical performance being compromised [10]. For the stitching methodology, it has been reported that the load bearing fibers may be distorted or damaged while weaving due to the repeated action of abrasion and bending as the yarns are fed through a loom. It has been reported that the tensile strength of carbon yarns are reduced by up to 12% due to abrasion and bending [20]. Fibers are also distorted and crimped during weaving, and this can lead to significant in-plane tow waviness in 3D woven composites [21,22]. The combined effects of fiber damage and tow waviness have an adverse effect on the in-plane mechanical properties of 3D woven composites.

Thereby, the objective of this research has been to present an alternative novel cost-effective methodology of improving the shear properties of composite sandwich panels without inducing significant initial damage to the panels.

3. Sandwich composites with shear keys: proposed novel methodology

Sandwich composites with shear keys have been proposed as an alternative to using the above discussed methodologies for increasing the shear properties of composite sandwich panels. This novel mechanism of increasing the shear performance of sandwich composite panels is based on introduction of a new concept of inserting shear keys in the PVC core. The cross section of both conventional sandwich composite panel and panel designed based on the novel concept of sandwich composites with shear keys are shown in Fig. 1a and b respectively. The shear-key inserts in the foam core may be of any shape, size and of any material. The spacing in between the shear keys can also be varied in a specimen.

The shear-key inserts would typically improve the shear resistance of the sandwich panel by improving the bonding between the fiberglass face sheets with the core. The superior strength and stiffness of these shear-key inserts in comparison to the foam core would also result in increase in shear strength and stiffness of the sandwich composite. With introduction of glass fiber shear-key inserts, the face sheet also contributes to resistance in shear in addition to the conventional concept of foam core resisting shear. This new design methodology would also prevent propagation of delamination cracks between the face plates and the core, similar to the proposed “peel-stopper” mechanism [23,24]. However, the effectiveness of this new methodology to prevent propagation of delamination between the face plates and the core is beyond the scope of this manuscript. This topic is currently being researched by the authors and would be discussed in future publications.

The proposed novel methodology would be cost-effective in comparison to the costly process of Z-pinning. Moreover, in comparison to the stitching methodology, the sandwich composites manufactured based on this novel methodology would be free from initial damage being introduced into the material due to abrasion and bending during the process of stitching. Thereby, this methodology represents a viable alternative for increasing the shear properties of sandwich composites. It should also be mentioned at this point, that the proposed methodology is compara-