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On using corrugated skins to carry shear in sandwich beams

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Abstract

A simplified approach is used to study the potential of using a corrugated skin in a sandwich to carry shear loads. Shear carrying capability is a major requirement for ship bottom panels, among other structures. The simplifications in the paper are quite major and in particular the corrugated skin is modeled as a conventional material with a homogenized stiffness. The goal of the paper is to point out some of the potentials as well as limitations of using a corrugated skin to carry shear loads. The major analysis tool was finite elements, although some analytical analyses were also performed. It was found that the introduction of a corrugated skin provided improved shear carrying capability and offered weight savings, particularly for heavily loaded sandwich beams. Alternative methods to increase shear strength were briefly reviewed.

Keywords: Composite sandwich; Corrugated; Finite element analysis; Structural optimization

1. Introduction

Lightweight composite structures often use sandwich construction with stiff and strong skins on either side of a light and relatively soft and weak core. In a traditional sandwich panel, in-plane loads and bending moments are carried as in-plane stresses in the skins, while transverse shear forces are carried by the core. In the type of sandwich presently considered, one or both skins are corrugated and can therefore carry some of the loads usually carried by the core. Investigating the potential of this load carrying mechanism is the main objective of this paper.

In a recent paper, Grenestedt and Reany [1] showed by analytical, numerical and experimental means that corrugated skins could substantially increase wrinkling strength of compression loaded sandwich specimens without increasing weight. Finite element (FE) models of sandwich panels with different kinds and depths of corrugations were analyzed and the results correlated well with carefully executed experiments. The strength increase was substantial, up to three or four times without increasing weight.

Sandwich panels with one flat and one corrugated skin were recently manufactured for a 16 ton test section of a steel/composite hybrid ship hull (Grenestedt et al., unpublished work). Two corrugated and six conventional sandwich panels were manufactured for this specimen. The corrugations were this time used mainly to reduce weight without sacrificing buckling strength under shear loads. The corrugated panels were approximately 20% lighter than the conventional sandwich panels.

The Appendix contains a simple analysis showing some of the potential benefits in terms of bending stiffness of a corrugated skin sandwich. However, the focus of the present paper is on utilizing one or both of the stiff and strong composite skins to carry shear load that otherwise would be carried by the lightweight and compliant sandwich core. For simplicity beams rather than panels were used for the study.

Preliminary work has recently been performed on using one deeply corrugated skin to carry shear loads in a short span fiber reinforced polymer (FRP) bridge (Grenestedt et al., unpublished work). In Fig. 1, an 890 mm long small scale version of such a bridge is shown. This specimen was made by 5-axis routing of a Divinycell foam core, on which E-glass fiber skins were vacuum infused with a vinyl ester

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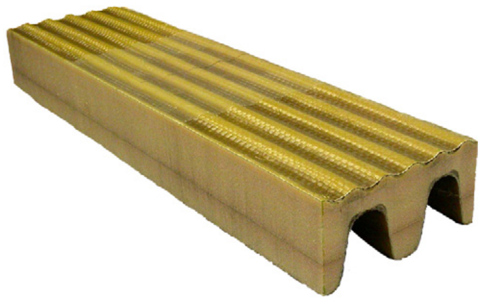

Fig. 1. A small scale corrugated bridge specimen.

resin. The specimen was tested to failure, which occurred at loads substantially higher than the failure loads of conventional sandwich specimens of otherwise similar construction. Both the conventional and the corrugated specimens failed due to core shear.

One application where high shear strength is of fundamental importance is in bottom panels of composite ships. The present design philosophy of simulating water loads with an evenly distributed pressure applied quasi-statically on a bottom panel leads to very high requirements on shear strength. For example, using the DNV regulations, the pressure on a bottom panel of a 70 m long surface combatant is on the order of 400 kPa. In the middle of a long and narrow panel, the behavior is similar to that of a beam. A sandwich beam of, say, one meter length loaded with a pressure of 400 kPa would require a Divinycell H250 core to be at least 133 mm thick, using a knock-down factor for shear strength of 3 (the knock-down for the core was used mainly to account for fatigue) and the material properties given in Table 1. However, plain fiberglass skins, with an in-plane tension and compression strength of 230 MPa, would only have to be 1.6 mm thick to carry the bending loads in this sandwich (using no knock-down factor). The core weight corresponds to 84% of the total weight of this sandwich, which is an excessively large fraction. The aim of the present work is to pave the way towards developing sandwich panels with corrugated skins, where the strong and stiff skins can help carry some of the shear load that traditionally is carried by the core.

It should be emphasized that for the present study, no connection between the two sandwich skins apart from the core will be considered. There are a number of reasons for this, including performance under shock loads where stiff connections between the skins tend to lead to localized failure. A compliant foam core can work as a "cushion" between the outer skin and the internal structure, whereas a stiff composite web between the skins in a sandwich can have the effect of a razor blade. Manufacturability of structures such as large ship hulls may be another reason to avoid internal structures. A number of studies have been performed on sandwich-like structures with internal load carrying members and there are commercial products available.

Table 1
Summary of finite element properties in the model

Material type	τ_{cr}^{foam} and σ_{cr}^{skin} (MPa)	E (MPa)	$\rho\left(\frac{kg}{m^3}\right)$
H80	1.0	80	80
H130	2.0	140	130
H160	2.6	170	160
H200	3.3	230	200
H250	4.5	300	250
Sandwich skin	230	23,000	1927

2. Review: optimal configuration of traditional sandwich beams

One of the main interests at present is for bottom panels of ships. These are traditionally designed using an evenly distributed quasi-static pressure. In longer rectangular bottom panels, the deformation is similar to that of a beam over an appreciable fraction of the panel. For simplicity, the present study concentrates on beams. In a traditional sandwich, the core carries the transverse load. Neglecting stress concentrations, the resulting shear stress in the core is

$$\tau^{core} = \frac{T}{wd} \tag{1}$$

where T is the transverse force, w is the width of the beam, and d is the thickness of the core. The skin stress is

$$\sigma^{skin} = \frac{M}{twd} \tag{2}$$

where M is the bending moment in the beam and t is the thickness of the skins. Both skins will be assumed to have the same thickness and to be much thinner than the core ($t \ll d$). Under uniform pressure p the transverse force is

$$T = \frac{pwL}{2}\left(2\frac{x}{L} - 1\right) \tag{3}$$

for both simply supported and clamped beams. The bending moment is

$$M = \frac{pwL^2}{2}\frac{x}{L}\left(\frac{x}{L} - 1\right) \tag{4}$$

for simply supported beams, and

$$M = \frac{pwL^2}{12}\left(1 - 6\frac{x}{L} + 6\left(\frac{x}{L}\right)^2\right) \tag{5}$$

for clamped beams. For a sandwich beam not to fail, $\tau^{core} \leqslant \tau_{cr}^{core}$ and $\sigma^{skin} \leqslant \sigma_{cr}^{skin}$ are required. For a simply supported beam, this requires that

$$\begin{aligned} \frac{d}{L} &\geqslant \frac{1}{2}\frac{p}{\tau_{cr}^{core}} \\ \frac{t}{L}\frac{d}{L} &\geqslant \frac{1}{8}\frac{p}{\sigma_{cr}^{skin}} \end{aligned} \tag{6}$$

The (normalized) mass of the sandwich beam is

$$\frac{m}{\rho_{skin}L^2 w} = \frac{d}{L}\frac{\rho_{core}}{\rho_{skin}} + 2\frac{t}{L} \tag{7}$$