A Brief Review on Corrugated Composite Sandwich Structure

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Abstract -- Fibre composite sandwich has become the new generation of material used in civil infrastructure in the last decade. A structural sandwich is a special form of a laminated composite fabricated by attaching two thin but stiff skins to the lightweight but thick core. Because of this special feature, the sectional area is increased and consequently an increase in its flexural rigidity. The strength of this type of construction results from the combination of properties from the skin, core and interface. In a sandwich structure, the strong and stiff skins carry most of the in-plane and bending loads while the core mainly bears the transverse shear and normal loads.

Keywords -- Composite Sandwich Structure, Corrugated Sandwich Structure.

I. INTRODUCTION

Sandwich structures are commonly used in aerospace and automobile structures, since they offer great energy absorption potential and increase the flexural inertia without significant weight penalties. The purpose of the core is to maintain the distance between the laminates and to sustain shear deformations. By varying the core, the thickness and the material of the face sheet of the sandwich structures, it is possible to obtain various properties and desired performance. Examples of widely used laminate materials are glass reinforced plastic (GRP) and carbon fiber. There are many wide varieties of core materials currently in use. Among them, honeycomb, foam, balsa and corrugated cores are the most widely used. Usually honeycomb cores are made of aluminum or of composite materials: Nomex, glass thermoplastic or glass-phenolic.

The other most commonly used core materials are expanded foams, which are often thermoset to achieve reasonably high thermal tolerance, though thermoplastic foams and aluminum foam are also used. For the bonding of laminate and core materials, normally two types of adhesive bonding are commonly employed in sandwich construction, i.e., co-curing and secondary bonding. Characterization of sandwich materials has been carried out in detail in scientific literature. The determination of the sandwich material behavior under crushing loads and the measurements of the ductile fracture limits is normally done with the help of compression tests. Typically, cores are the weakest part of sandwich structures and they fail due to shear. Understanding the shear strength properties of sandwich core plays an important role in the design of sandwich structures subjected to flexural loading. Most of the research work done is on sandwich structures are on metallic foam core honeycomb structure PVC foam core and corrugated paper boards and metal corrugate structures, the works are focused on the behavior of the sandwich structure on due to impact loading. Less research works are done on the composite corrugate structures made by using fibers as reinforcement and polymers as matrix.

There is no any standardized method proposed for the fabrication of test specimens. Limited research work is done on the impact behavior of corrugated structure, the effect of change in geometry like thickness and profile of the core made from glass fiber reinforced composite, on the load carrying capacity under different loading condition is studied to a less extent. Corrugated structures have good crashworthiness properties hence they find applications in aerospace and automobiles. One of the key factors preventing the widespread use of corrugated composites structures is the absence of specialized test methods for the characterization of specific energy absorption (SEA).

II. LITERATURE SURVEY

Fibre composites are now commonly used for the top and bottom skins due to its high mechanical performance and low density. On the other hand, the core provides a sandwich construction with high flexural stiffness and strength with a relatively lightweight structure [1]. The interaction of the inherent properties of these constituent materials makes composite sandwich construction an efficient structural system. Over the last few years, the development in fibre reinforced polymer (FRP) composite sandwich structures has been very exciting in volumes as well as in applications. Their usage is mainly in the aerospace, aircraft and marine industries because of their fuel efficiency in transportation vehicles. The evolution of sandwich structures with enhanced material systems provided an opportunity to expand the application of this material in civil infrastructure.

At present, there is a strong interest in the development and applications of fibre composite sandwich structures for civil engineering and
construction. The light weight of sandwich composites facilitates handling during assembly, and reduces installation and transportation costs. They also offer corrosion resistant structures requiring less maintenance. In Australia, fibre composite sandwich structures are now being used as structural panels in residential and industrial buildings, boardwalks, bridge decks, and timber replacement girder in a number of infrastructure projects. Its application for a railway sleeper is also now trialled. This paper presents an overview of the recent developments and initiatives on fibre composite sandwich structures, which have been evolving and have become a viable construction material in civil engineering and construction. The on-going research, development and applications of a novel composite sandwich panel made up of glass fibre reinforced polymer skins and a modified phenolic core material at the Centre of Excellence in Engineered Fibre Composites (CEEFC) at the University of Southern Queensland (USQ) are also highlighted.

Composite sandwich structure has been identified as a very interesting alternative to traditional construction materials. Consequently, several researchers have contributed towards the research and development of composite sandwich for structural and construction purposes. Daniel and Abot [2] suggested that the desired stiffness and strength of a composite sandwich structure can be modified by varying the materials for the skin and the core. It is also indicated that the nature of the core material system greatly influences the behaviour of sandwich structures. In recent years, there have been considerable attempts to improve the performance of core materials for composite sandwich structure. Marsh suggested that cellular manipulation can be made to achieve a high strength core.

Accordingly, Daniel and Abot filled the cells of a honeycomb core with epoxy to prevent premature shear failure at the load application. In another study, Mahfuz et al. improved the performance of a sandwich structure under flexure by infusing titanium dioxide (TiO2) nanoparticles into the parent polyethylene foam material. A 53% and 26% increase in the flexural stiffness and strength, respectively was attained by infusing 3% loading of TiO2 nanoparticles in the core compared to neat polyurethane foam. Another approach to improve the performance of sandwich structure is to reinforce the core with fibre composites. Karlsson and Astrom suggested that three-dimensional reinforcing fabrics that integrate the faces and the core have the potential of significantly improving structural integrity of composite sandwich structures. Lascoup et al. found out that stitching the top and bottom skins of the composite sandwich panels with glass fibres prevented the delamination failure and enhanced the mechanical performance. Reis and Rizkalla developed a 3-D fibre reinforced polymer sandwich panel with the top and bottom skins connected with through-the-thickness unidirectional glass fibres to overcome delamination problem. Increasing the quantity of 3-D fibres resulted in a significant increase in the shear modulus and compressive strength of the panel.

However, there was a decrease in the tensile strength due to the waviness created by the stitched fibres. Kampner and Grenestedt [3] found that the introduction of corrugated skin improves the shear capacity and offered weight savings in a composite sandwich structure. The corrugated skins also increase the wrinkling strength in compression and make the panels weigh 10-20% lighter than their plain counterparts.

### III. CORRUGATED COMPOSITE SANDWICH STRUCTURE

Some researches about mechanical properties of corrugated sandwich structures have been studied. Ellefiori F et. Al [4] devoted to study the effect of corrugation geometry on the crushing behavior, energy absorption, failure mechanism, and failure mode of woven roving glass fiber/epoxy laminated composite tubes. They carried out a comprehensive experimental program on two geometrically different types of composite tubes subjected to axial compressive loading conditions. Their experimental results showed that the initial failure was dominated by interfacial failure, while a folded zone grows progressively down in a form of mushrooming failure.

The results also showed that radial corrugated composite tube (RCCT) exhibited good energy absorption capability than circular composite tube (CCT). Wang Dongmei studied on Cushioning Properties of Multi-layer Corrugated Sandwich Structures and concluded that the energy absorption of multi-layer corrugated sandwich structures is significantly higher than that of the monolayer ones and the multi-layer ones have the capability to resist more shocks. L. Torre & J.M Kenny studied Impact testing and simulation of composite sandwich structures for civil transportation.

They developed two different sandwich structures and analyzed them, the first type is a classical structure composed by a glass fiber-polyester matrix-composite skin and a foam core. The second one, specifically developed for their research, consisted of skins made from a glass fiber-phenolic matrix composite laminate and a core formed by an internal corrugated structure of the same laminate used for the faces filled by phenolic foam. LU et. al [5] studied Compressive Behaviors of Corrugated Board Panels. According to their study the
compressive responses and failure mechanisms of corrugated sandwich panels subjected to uniform lateral compression are examined by a combined theoretical and experimental study. Tomas Nordstrand has done Analysis and testing of corrugated board panels into the post-buckling regime the result showed that corrugated board panels show consistent buckling behavior. Enrico Armentain, et. al have done the FE Analyses of Stability of Single and Double Corrugated Boards. The results they obtained from FE analysis were consistent with the experiment results.

M. Winkler and G. Kress’s work determines the maximal possible deformations of a corrugated sheet where the corrugation pattern consists of two circular segments. The influence of the lay-up of cross-ply laminates and the influence of the geometry was investigated. The calculations were based on considerations of layer wise strains that are calculated with the help of an analytical singly-curved shell model. For the evaluation of the influence of geometric nonlinearities according finite element simulations are performed and compared to the linear strain limit calculations. The influence of scalable geometry parameters were also investigated. Matthew Kampner et al used a simplified approach to study the potential of using a corrugated skin in a sandwich to carry shear loads. Their work was focused to show some of the potentials as well as limitations of using a corrugated skin to carry shear loads. They found that the introduction of a corrugated skin provided improved shear carrying capability and offered weight savings, particularly for heavily loaded sandwich beams[6].

Sandwich structures, as many other structural materials are characterized by a mechanical behavior that is strongly dependent on the loading rate. In fact, they can have a ductile behavior in case of static loading, but may behave in a brittle manner and fail catastrophically when subjected to impact loads. Generally, when a sandwich structure is subjected to an impact, part of the energy associated to the impact is used for the elastic deformation of the material and returned back by the system. The energy in excess is dissipated through several mechanisms, such as fibers breaking, fiber-matrix deboning and delamination in the skins; while the core dissipates energy by crushing and shears deformation. The energy absorption capability of glass-epoxy composites is influenced by the factors such as fibers reinforcement type, type of structure, geometry and shape of specimens, orientation of fibers in a layer and stacking sequence of layers. Damage tolerance can be referred to the capability of a structure to carry load after different types of impacts, e.g. things dropped, projectile hits, rough seas and foundering. It can also refer to the capability of the same structure to absorb the energy from, and stop, impacting objects such as projectiles or shrapnel from explosions.

Because of its composition a composite sandwich can show a magnitude of failure modes. Hildebrand has identified a number of different failure modes which are Face crushing, where the face fails in through-thickness compression, Face shear, where the face fails in interlaminar shear at the edges of the impacting body, In-plane face failure, where the face fails in in-plane tension or compression near the edges of the impacting body, Flexural face failure, where the face fails in bending near the edges of the impacting body, Core crushing, where the core is damaged in out-of-plane compression, Core shear failure, where the core fails in shear near the impactor, or is sheared out as a plug, Face/core deboning, where the impacting body tears the face from the core[7].

IV. COMPONENTS IN CORRUGATED SANDWICH STRUCTURE.

1) Core -- The core may be made from a foamed polymer, folded sheet or corrugated web. Regardless of the core design, it should be stiff and strong in directions out-of-plane in order to keep the faces separated and parallel at the correct distance under in-plane and transverse normal loadings. The density of the core controls the impact behavior of the structure. In order to obtain a sandwich structure with improved energy absorbing performance the core must be of high density. In case of a core made out of foam it increases moment of inertia and improves the bending stiffness without increasing the weight. Hence the foam core does not have excellent mechanical properties and its function is limited. Corrugated cores have high energy absorbing capacity since stable crushing occurs instead of catastrophic failure at relatively high loads. The types of corrugations used are shown in Fig. 1.

![Fig. 1 Various types of Corrugated sandwich structures](image-url)

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2) Skin -- The skin or the face sheets are thin, most of the out-of-plane shear load is carried by the core, and it therefore should be stiff and strong in shear. The skin may be made of aluminum, steel, woven glass fiber or carbon fiber with polymer such as epoxy or polyester. If a sandwich panel is bent downward, the part of the sandwich above the neutral axis will stretch, and the part below the neutral axis will compress. Although the skin and core stretch and compress evenly at the location of the bond, the core and the skins have different material properties, and will in turn act differently to this bending. Glass fiber – epoxy, Glass fiber – polyester have a low density and high specific strength hence they are widely used for skin in a sandwich structure which are bonded to the core using a strong adhesive.

V. MODE OF FAILURE
The modes of failure in sandwich structures depicted can be divided into two main categories, the point load related damages and the structural response related damages. The point load damages occur as a direct result of something hitting the sandwich structure. Structural response related damages occur because the hitting object forces the structure to deflect too much, resulting in damages. V Crupi et al. studied the comparison of the impact strength between polymeric and aluminum sandwich structures. They performed Impact tests by a drop test machine in order to investigate the structural response of PVC foam sandwiches and AFS panels. The failure mode and damage were investigated using two experimental techniques: thermography and 3D Computed Tomography. V.L. Tagarielli et al. measured the dynamic response of glass fiber – vinylester composite beams by impacting the beams at mid-span with metal foam projectiles. The beams exist in composite monolithic form, and in sandwich configuration with composite face sheets and a core made from PVC foam or end-grain balsa wood. They used high-speed photography to measure the transient transverse deflection of the beams and to record the dynamic modes of deformation and failure. The dynamic strength of the beams was quantified by them by the maximum transient transverse deflection at mid-span of the beams as a function of projectile momentum. They also demonstrated that sandwich beams can outperform monolithic beams of equal mass. The trade-off between core strength and core thickness is such that a low density PVC foam core outperforms a higher density PVC foam core. End-grain balsa wood has a superior stiffness and strength to that of PVC foam in compression and in shear.

Consequently, sandwich beams with a balsa core outperform beams with a PVC foam core for projectiles of low momentum. The order reverses at high values of projectile momentum: the sandwich beams with a balsa wood core fail prematurely in longitudinal shear by splitting along the grain. Beams under three-point bending and end-loaded cantilever beams are subjected to both bending moment and shear. It is assumed that the core and facings in the vicinity of the applied load are locally reinforced to suppress any possible indentation failure. The bending moment is primarily carried by the facings and the shear by the core. Excluding indentation, possible failure modes include core shear failure, core failure under combined shear and compression, facing wrinkling and facing compressive failure. Sandwich structures also fail due to delamination. Shear at the interface between matrix and fibers, Separation of the fibers from the matrix, Deboning of the skin and core and also the fibers may fail when the load exceeds its tolerance leading to material failure.

Buckling analysis of stiffened and unstiffened corrugated panels was dealt with via a mesh free Galerkin method. Peterson presented the buckling strength of corrugated shear webs by analyses and tests, in which the edge rotations of the web along lines of support ranging from unrestrained to completely restrained were considered. Formulations presented in paper provide the capability to represent a corrugated panel with sinusoidal profile as an equivalent anisotropic plate.

The work presented in deals with the prediction of shear buckling loads of composite panels having sinusoidal or hat type corrugation. The given panel is idealized as a homogeneous orthotropic plate whose equivalent properties are determined from the given parameters of the panel. Two opposite edges of the panel in one direction are assumed to be simply supported and the panel is assumed to be very long in the other direction. By proper choice of lamination, significant increases in buckling loads can be achieved compared to the quasi-isotropic case. Corrugated sheet always has a better shear load carrying ability before buckling compared to a flat sheet. Having the corrugation plane normal to the shorter side is significantly better than having the corrugation plane normal to the longer side.

VI. CONCLUSION
This research work is limited to corrugated structure sandwich structures which have great potential on offshore oil and gas platforms, where weight is at a premium, this can be particularly advantageous and corrugated panels often form part of their blast mitigation systems. These corrugated structures, referred to as blast walls, provide a safety barrier for personnel and critical equipment against accidental explosions and consequently the blast walls are designed to be efficient energy absorbing systems.
References


