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Applications of Sandwich Plate System for Ship Structures

[1]KVRamakrishnan, [2]Dr P GSunil Kumar
[1]*Naval Architect, kvrk@aimri.in*
[2]*Managing Director, researchguide@aimri.in*
Aries International Maritime Research Institute, Sharjah, UAE

Abstract: *Sandwich Plate System (SPS) is an alternative to conventional stiffened plate construction. Sandwich plate system is a lightweight material that consists of two metal plates separated by a core. Plates, usually made of steel, are joined via perimeter bars on the edges of the plate. Polyurethane elastomer core transfers shear and bending forces between plates and dissipates strain energy over a large area, reducing load concentrations and the possibility for permanent deformations. Sandwich plate system eliminates the need for secondary stiffeners, making the structure less complex and flush. Considering the high strength to weight ratio, ease of construction, blast and ballistic properties of the material, availability of a flush surface etc., SPS has been widely used in building bridges, stadiums, floors, blast walls etc. SPS panels have also been used in ship repair as an overlay on existing structures, converting them conventional steel to sandwich plates. The concept of complete hull structure made of SPS is a big challenge. At present, no thorough study over complete ship bull sandwich structure is available, mainly due to the non-availability of design tools for the SPS concept. However, the introduction of Class rules has brought in the use of sandwich structures in marine construction. It is roughly estimated that weight reduction possibilities of SPS over the conventional structure varies from 10 to 70%. In this paper, the advantages of SPS are examined. The scope for SPS panels in shipbuilding, and various areas where further research and progress could be made is also recommended.*

Keywords: *Composite Structures, Honeycomb Structures, Lightship, Sandwich Plate System, Ship Building Structures, Ship Repair, Steel Sandwich Panels.*

I. Introduction

Structural sandwich construction is one of the first forms of composite structures to have attained broad acceptance and usage. Sandwich structures are widely used in helicopters and airplanes including military aircraft and space vehicles. In recent years, most commercial space vehicles have also adopted this technology for many components. In addition to air and space vehicles, the system is commonly used in the manufacture of cargo containers, relocatable shelters, and air field surfacing, navy ship interiors, small boats and yachts, and production parts in the automobile, recreational vehicle industry and a great many items.

Although the employment of sandwich design is to produce lightweight structures, it is found to have originated as early as 1820. However the commercial use of this idea did not occur until late into the 20th century. The sudden acceptance of these type of structures was due to the successful commercial production of structural adhesives. The adhesives and the core materials used in sandwich structures have evolved over the years and have resulted in a revolution in bonding technology. Many further developments followed which included improved cleaning methods for metal skins, low weight, high strength honeycomb materials, glass fabrics, high peel adhesives requiring lower cure temperatures and pressures etc.

SPS has been used for shipbuilding and ship repair as well. A lot of existing structures have been replaced using the overlay process. By avoiding stiffeners, SPS repair makes the process much simpler than the traditional practice. In order to improve competitiveness with other modes of transport, inland vessel's cargo carrying capacity has to be increased. Considering river dimensional limitations and the fact that more cargo leads to increased weight and draft of the vessel, feasibility of new lighter structures are being explored. This is the primary reason why sandwich structures have found their way into the shipbuilding industry.

However, no thorough study over complete ship hull sandwich structure is available. The main reason for this is the lack of tools for establishing the full equivalence in strength requirements between conventional structures and SPS, when applied in a model as complex as a ship's hull. This was overcometo a great extent bythe introduction of Provisional rules for the Application of Sandwich Panel Construction to Ship Structure, by Lloyds Register, in 2006.

The rules introduced a set of explicit calculating procedures for new building hull structure scantlings and thus allows a weight comparison between conventional and sandwich type ship. Such a comparison is carried out in this paper, and the results and conclusions are drawn.

II. Sandwich Plate System

A Sandwich plate system unit is formed by injecting a two-part thermosetting liquid elastomer into a cavity formed by two face plates. The face plates may be made of any type of metal including steel (mild, high tensile or stainless) or Aluminum. The core is typically made of solid polyurethane elastomer. The elastomer provides strengthening support via bonding to the plates thereby removing the need for stiffeners. It is bounded by perimeter bars, on the other four sides. The core bonds to the prepared steel surfaces, acts as a web and provides continuous support to the faces precluding local plate buckling and closely spacedstiffeners needed for a single plate steel structure. The stiffness and strength are tailored as required by using the appropriate thicknesses for the sandwich elements.

Sandwich panels in general can be classified as composite sandwich and metallic sandwich panels. Composite sandwich panels consist of non-metallic components such as FRP, PU foam etc. and are typically applied as load carrying structures in naval vessels and leisure yachts, and mainly as non-load carrying elements on merchant and large cruise ships. For metallic sandwich panels there are basically two types of panels: panels with metallic face plates and bonded core such as SPS panels and panels with both metallic face plates and core welded together.

SPS was initially designed to provide impact resistance plating for offshore structures-working in severe environmental conditions. SPS has approvals from major ship classification societies and regulatory authorities for the use of SPS panels in new builds and repair works. SPS replaces conventional stiffened metal plates in marine structures providing benefits in fabrication, performance, cost and safety for both civilian and military applications.

A. Terminology

1) *A Steel Sandwich Panel* consists of three layers. Two external layers of steel and an internal core layer, see Fig.1.

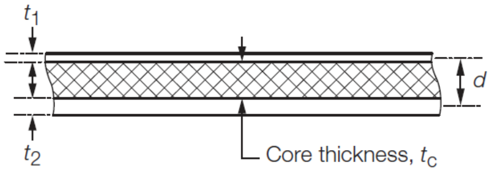

Fig. 1Steel Sandwich Panel Scantling Definition [1].

2) *Core* applies to the layer between the steel plates. The core is injected in between the top and between steel plates and bonds mechanically directly to the steel surfaces.
3) *Bottom Plate* applies to the steel plating to which primary members are attached.
4) *Top plate* applies to the steel plating exposed to sea, weather or cargo.
5) *Cavity* is defines as the space enclosed by the top and bottom steel plates and perimeter bars.
6) *Panel* is defined as the sandwich panel enclosed by the primary members.

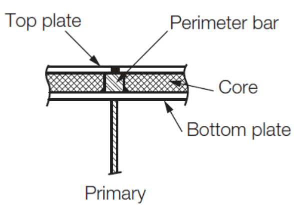

Fig. 2Typical Primary Member, Perimeter bar Arrangement [1].

7) *Spacer* applies to the square or round block made of elastomer or steel secured to the bottom plate. The spacer is intended to maintain the required distance between the top and bottom plates.

B. Core Materials

1) Wood

The oldest of materials used as a sandwich core is wood, which continues to be used in many applications. End-grain balsa has broad acceptance in boat hulls and is used in the replacement flooring. The traditional advantage of the lower cost of wood has progressively eroded with the passage of time. However, the ease of use and excellent durability of the end product has led to substantial increased usage, particularly of the carefully selected grades of balsa for boat hulls. Balsa's closed-cell structures consist of elongated, prismatic cells with a length that is approximately sixteen times the diameter. Withdensities between 0.1 and 0.25 g/cm^3, the material exhibits excellent stiffness and bond strength. The static strength of balsa panels will generally be higher than PVC foams, impact energy is however lower. Local Impact resistance is good, because stress is effectively transmitted between the sandwich skins.

2) Foams

The use of foam as a structural core is extensive. Recent developments in the technology of foam injection have sharply increased the use of these materials. Foams also provide special properties such as insulation or radar transparency, when used with appropriate facing materials.

Foamed plastics such as cellular cellulose acetate (CCA), polystyrene, and polyurethane are very light (about 2 lbs/ft^3) and resist water, fungi and decay. These materials have very low mechanical properties and polystyrene will be attacked by polyester resin. These foams will not conform to complex curves. Use is generally limited to buoyancy rather than structural applications. Polyurethane is often foamed in-place when used as a buoyancy material.

3) Honeycomb

Honeycomb types in common usage include products made from uncoated and resin impregnated Kraft paper, various aluminum alloys, aramid paper and glass or carbon fiber reinforced plastic in a number of weaves and resin systems. Honeycombs based on titanium, stainless steel and many others have been used in lesser quantities. Most honeycomb cores are constructed by adhesively bonding strips of thin material together.

C. Adhesive Materials

Adhesives used in sandwich panels must have these important properties. They are good Bonding Pressure, Fillet Forming, Adaptability, Bond line control and toughness. The typical materials used in adhesives are the following:

1) Phenolic blended with Vinyl rubbers or Epoxy
2) Epoxies modified with Nylon or other polyamide Polymers
3) Nitrile Rubber modified epoxies
4) Urethanes
5) Other Polyimides, Thermoplastics and Highly Specialized adhesives.

III. Honeycomb Cores

Physical and Mechanical properties of the honeycomb cores materials are strongly influenced by the properties of the materials from which they are manufactured. Some of these differences like obvious in the thermal conductivity. However, several significant properties of honeycomb are peculiar to the materials and should be separately noted.

A. Properties

1) Cell Shape

All honeycomb structures are anisotropic and the result directional properties should be adapted to the loads anticipated. The cell shape variations may be either furnished to specification by the core manufacturer, or in certain materials such as aluminum, shapes may be intentionally or inadvertently altered by the core-user.

2) *Density*

All mechanical properties increase with higher density.

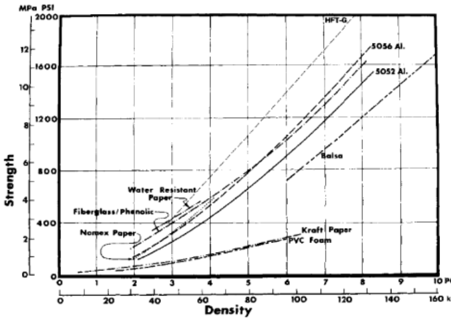

Fig. 3 Typical Stabilized Compressive Strengths [2].

3) *Cell Size*

Although cell size tends to be secondary variable for most mechanical properties of core materials, it is primary in fixing the strength level of the core-to-face attachment and in determining stress levels at which intracellular buckling or face dimpling of facing occurs.

4) *Thickness*

The shear and compressive properties noted for a specific core type can only be realized when test methods are carefully specified and controlled and the correct thickness of core is tested.

5) *Specimen Geometry and Test Method*

Like thickness, these must be specified and carefully controlled in order to obtain comparability with test values obtained by others.

B. Honeycomb Types

The following are some of the major types of Honeycomb structures used in various applications. The difference in each of these is the core material. The chemical composition and the mechanicalproperties of each type can be found in various published literature [2].

1) *Paper Honeycomb*
2) *Aluminum Honeycomb*
3) *GFRP Honeycomb*
4) *Aramid Paper Honeycomb*
5) *Carbon Fiber Honeycomb*
6) *Kevlar Honeycomb*
7) *Kevlar Paper Honeycomb*

IV. Advantages Of Sps Panels

The immediate advantages of SPS over conventional stiffened steel plates are as follows:

1) *Simplified fabrication:* In SPS fabrication, there are fewer parts, fewer intersections, less welding, fewer stiffeners to be handled and a reduced surface area.
2) *Better design features*: The SPS design will remove the sources of stress concentrations and will reduce the effects of initiations of cracks and fatigues, which directly impacts the future cost of maintenance and through life ownership.
3) *Effects of details*: The SPS design is less sensitive to poor design details and inadequate workmanship during construction or repair.
4) *Weight*: For new builds, the weight of an SPS arrangement is less than a conventional structural arrangement.
5) *Cost*: The overall SPS arrangement has lower build and operational costs than the equivalent conventional stiffened plate arrangement for reasons mentioned previously.

Other advantages of Sandwich Panels include:

1) *Damping characteristics:* An attractive feature of elastomer is its damping property and its presence in SPS has enhanced its damping response. Vibration and impact tests have shown the response amplitude function for SPS is much less than steel and the damping coefficient is 4 to 5 times greater than steel. The effect of these SPS damping characteristics is that there would be less vibration on the deck of a ship constructed from SPS or repair using the SPS concept. In addition, slamming loads would be less likely to be transmitted inside the hull due to the presence of the core, thereby allowing high speed craft to maintain their speed in higher sea states.

2) *Operational performance:* Design simplification enables SPS arrangements to eliminate corrosion prone details and sharp edges. Flat surfaces also allow better quality coatings to be applied. The damping property and design approach will also increase the fatigue resistance of SPS.

3) *Extreme loads*: SPS provides enhanced performance for extreme intentional or accidental loads including ballistics, blast and impact, e.g. from collisions or groundings.

4) *Fire resistance properties*: SPS has exceptional resistance to fire and can eliminate the need for the installation of thermal insulation. It is an extremely effective barrier to heat, flame, smoke and toxic gases. It will contain a fire and prevent it from spreading to adjacent compartments, greatly limiting the growth of a fire throughout a structure. The elastomer core has excellent insulation properties. Full-scale deck panel and bulkhead tests conducted in laboratories under International Maritime Organization (IMO) A60 Class (A60 Bulkheads are those which withstand a standard fire test for a period of one hour, with the temperature on the unexposed side not rising more than 180° above the original temperature) [9]specified conditions have shown that the temperature increase at the unexposed surface of SPS was +5°C with insulation (on exposed side) and +38°C without insulation. The comparable temperature changes for steel stiffened plate are +192°C and +710°C respectively.

V. Sps In Shipbuilding

From the stand point of hull design, the ideal ship is one which has the following characteristics:

1) Has a structure which is not complicated in terms of construction – simple and easy to build.
2) Requires minimumthrough-life maintenance.
3) Improved Corrosion resistance.
4) Has a minimum of breakdown in coatings.
5) Immunity from cracking or other structural problems.
6) Does not unduly vibrate.

SPS, in some way has achieved these challenges and ship operators are keen to take advantages of the benefits in improved lifetime performance, reduced maintenance and structural simplicity. The use of sandwich panels in various marine application has helped accentuate this fact. They are also being used in specific applications, where unique properties such as fire protection and noise damping are exploited.

VI. Sps In Ship Repair

SPS Overlay is the repair application of SPS and works by incorporating the plating of the existing structure into a composite formed by a new top plate and an elastomer core that is injected in-situ.

One of the most disruptive and risk laden activities in a repair or conversion project is structural modifications using crop and replace(hot work)methods. This requires the original structure to be taken out and replaced by new plating.

The main steps with respect to repairing a plate on a ship are:

1) Piping, electrical services and insulation in the vicinity of the repair are disconnected and removed.
2) The existing plates are removed from the stiffeners in small sections by gas cutting.
3) The new plates are installed and welded to the existing stiffening.
4) Insulation, pipe racks and cable trays are re-installed and service runs re-connected and tested.

Regardless of the circumstances, this is a disruptive, time consuming, uncertain, and inherently dangerous operation.

SPS Overlay overcomes the operational difficulties of conventional repair techniques by retaining the existing structure. As a consequence, an SPS Overlay repair is extremely fast, safe, non-disruptive, and from a scheduling perspective, predictable. Although deck reinstatement is taken to illustrate the process, SPS Overlay is applicable to any flat surface whether it is horizontal or vertical. The technology can be used to reinstate the structure to its original load bearing capability or to accommodate heavier loading conditions. Intelligent engineering has also developed non-welded solutions using advanced adhesives to create the steel cavities in circumstances where hot work is a problem.

Hence the entire process of overlay can be summarized as follows:

1) The process is very straightforward and no special skills are required for the steelwork.
2) The process is safer by virtue of the structure remaining intact and because of the convenient access and reduced hot work.
3) The reduced work content of SPS Overlay effectively reduces the cost.
4) The resulting repaired structure will not have any misalignments and the potential build-up of locked-in stresses and fatigue concentrations is avoided.
5) The time taken to repair is typically four or five times faster than crop and replace and time savings are further enhanced as there is no need to detach and re-attach piped and electrical services and insulation.
6) SPS Overlay embodies the same characteristics of the new build composite structure, e.g. high impact resistance, built- in fire protection, noise and vibration attenuation and reduced fatigue stresses.
7) Plating that has corroded beyond conventional limits can be repaired by the SPS Overlay concept to the satisfaction of the Classification Societies

VII. Design Principles

Using SPS in ship structures requires a fresh view on design, especially in areas of structural intersections.

Basic longitudinal strength is assessed in a similar way to current established methods, using classical naval architecture theory and standard hull section property calculations. With SPS structures, the continuous inner and outer face plates of the composite sandwich are included in the section properties, but the elastomer core is not included in the calculation. Depending on local strength requirements, a portion of the steel area, about the neutral axis, may be redistributed to the deck and outer hull to maintain the section modulus while reducing overall weight.

The scantlings of SPS plating are generally in the range of 3mm to 8mm for the steel face plates and 20mm to 50mm for the core thickness. The required scantlings are a function of the loads and spacing of the supporting framing, and are currently determined by direct design calculations, using normal stress criteria for yield and shear modes of failure. Corrosion margins are added to the face plates, as required.

SPS panels are very stable, since the stiff elastomer core prevents local buckling effects. Semi-empirical equations have been developed to determine the in-plane load carrying capacity for any combination of transverse loads. These have been verified using full-scale tests and non-linear finite element analyses. Current design practice uses finite element analysis to check the in-plane load carrying capacity of SPS panels. This is achieved with models using solid or layered shell elements to account for both material and geometric non-linearity.

The maximum transverse framing should be in the range between 3.2 to 4.0m. SPS plating should have an aspect ratio between 1.4 and 1.7, to produce an economic plate with the maximum buckling strength. SPS panels should be arranged so that the largest dimension is aligned along the length of the ship.

SPS structures have a high inherent resistance to fatigue. The bond between the elastomer core and the face plates is virtually fatigue insensitive. Joints, between SPS panels and connections of SPS panels to supporting structure, have a good inherent resistance and may be checked using standard fatigue assessment techniques already used in the marine industry.

VIII. Estimation Of Lightship Weight

Lightship estimates of a ship when constructed using SPS panels, will give us a good idea about the savings in cost and time. To obtain such a conclusion, an existing dumb barge was considered. The principal particulars and the lightship weight of the barge are as given below.

TABLE I

PRINCIPAL PARTICULARS OF SAMPLE BARGE

LOA	70M
Breadth	20m
Depth	4.5m
Draft	3.5m
Lightship	673.5T
DWT	3897T

The barge had a longitudinal framing system, with a longitudinal bulkheadport and starboard. The same type of framing is considered for the SPS panel barge.

The design equations for calculating the thickness of plates for deck, other places and bulkheads can be found in the class rules [1]. The following flowchart gives the procedure for the actual design process.

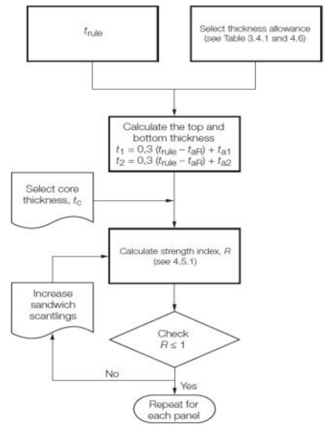

Fig. 4Flowchart for Calculating Plate and Core Thickness [1]

The lightship weight of the barge when the conventional steel structures were replaced by SPS panels was approximately 600T. The estimated reduction in lightship weight is approximately 11%. This is in concurrence with [3], where the reduction in lightship weight for ships using SPS panels is estimated between 8 to 15%.

IX. Conclusion

The Sandwich plate system is a proven and established technology with a lot of marine applications, especially in the field of repair. The growing need for lighter materials, and the continuous progress made with the classification societies will only ensure that new applications for SPS in the marine industry will continue to evolve. However, one has to consider the fact that even though SPS offers many advantages, it is now widely accepted for complete hulls for varied reasons. Though there are many estimates of weight reduction of up to 70%, various experiments [3], and the sample calculations conducted prove that the actual weight reduction is much lesser than the estimates.

With regard to structural analysis, distinct properties of dissimilar metals need to be taken into account. The difference in physical properties may initiate derivative interactions between those dissimilar parts inducing additional mechanical stressing or other adverse effects. Thermal expansion under altered ambient temperature and galvanic corrosion of the metal part in a seawater environment, attributable to the distinct electrode potential of dissimilar structural components, exemplify that issue.

One more behavioral distinction pertains to a potentially considerable difference in fatigue performance of the dissimilar parts of a material-transition structure. For this reason, a part that has superior load-bearing capability under a short-term loading may manifest inferior performance under long-term operation. This transition can be aggravated by different sensitivities of the dissimilar parts to environmental impacts. Due to these considerations, the weakest link may migrate over the material-transition structure undergoing alternating force-ambient loading exposure during a ship's operation.

Taking into consideration these points, though SPS is a viable alternative to conventional stiffened plates, there needs to further enhance before it can be used in the construction of a new ship. In the area of ship repair however, it is proven a lot useful and the numerous applications is a testament to the fact. It has also been successfully used in unique applications such as Ramps for Ro-Ro ships, Funnel casing etc. in addition to its fire protection and noise damping characteristics.

X. Acknowledgment

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