Review of joining methods of sandwich panels in ship construction

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Abstract

Lightweight sandwich panels are regarded as innovative structures, which could be widely applied in ship constructions. Herein some methods for joining panels are presented. Some of those methods are looked at as promising in shipbuilding technology.

1 Introduction

Progress in manufacturing methods, especially in the laser welding of thin plates, enables fabrication of advanced structural elements, which satisfy more strict strength requirements, retaining the same weight or, in many cases, reducing them. Sandwich panels fulfil these requirements in a great extend.

Examples of the application of lightweight sandwich panels in shipbuilding have been known [5, 8, 9, 16, 17, 18, 19, 28]. Assembling panels is especially interesting from a technical point of view. It requires elaboration of effective methods for achieving durable connections.

2 Types of sandwich panels

A typical sandwich panel consists of two surface plates and the core. The panels are made mainly from synthetic materials (composites) or metals (aluminium, steel). The structure of sandwiches can differ depending on the type of core elements and the method of joining them to surface plates. Some examples of the structure of sandwich panel are presented in Figures 1 and 2.

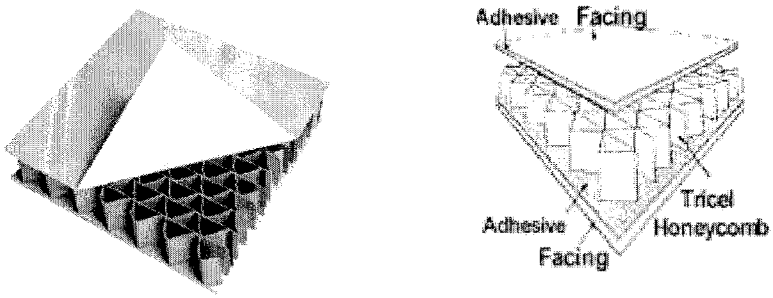

Figure 1: Honeycomb composite material panel, [34].

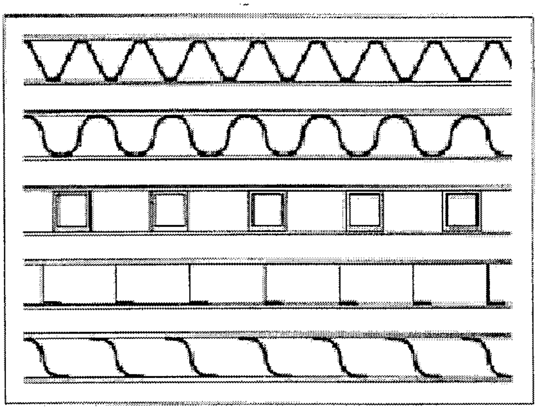

Figure 2: Various types of the steel core of sandwich panels, [17].

3 Application of sandwich panels in shipbuilding

Initially the sandwich structures have been used in light constructions, e.g. aircraft fuselages. In shipbuilding and in the construction of marine facilities (superstructures of rigs) these constructions have been introduced as certain parts of a hull and equipment, i.e. aircraft carrier hangar bay division door, enclosed mast structure, carrier elevator platform, helicopter landing deck, escape trunk, structural transverse bulkhead, deck of passenger ship, deck of superstructure.

The application of lightweight steel structures instead of conventional systems, consisting of skin plate and stiffeners, is relatively a new solution in the construction of ship hulls. The progress in the laser welding technology has enabled manufacturing sandwich panels, which fulfil the requirements important for building merchant vessels, [4, 10, 11, 12, 13, 14, 15, 19, 20, 28, 33].

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Favourable properties of sandwich panels have been approved in laboratory tests, i.e.:

- high strength-to-weight ratio,
- high stiffness-to-weight ratio,
- modular offsite construction,
- easy treatment,
- easy installation into the primary structure,
- minimum distortion – no alignment work,
- small distortion when welded into position,
- load-span parameters which could by available in a tabular form.

The first three properties allow making structures by 40 % lighter in comparison with the conventional ones [23].

4 Methods of connecting sandwich panels

Some several methods of joining the sandwich panels with other panels and with a traditional ship structural elements can be applied, i.e. bolting, riveting, clamp joining, clinching, pressure welding, welding and bonding.

4.1 Bolting

Bolting is the ideal assembling method when frequent, easy disassembly is required, and it usually is very reliable. Under some circumstances, however, bolts can work loose and should be secured, [19, 27].

4.2 Riveting

Riveting is the most popular mechanical connection technology in shipbuilding, in many aspects even more efficient than welding. Riveting applies especially to thin-walled constructions, where heat transfer should be kept to minimum due to thermal deformations, and also to connecting elements made from various materials (steel, aluminium, plastics), [19, 21, 22, 24, 26, 30, 32].

Riveting offers many advantages:

- the ability to connect various construction materials (e.g. metals with plastics);
- riveting does not require any heating which would introduce thermal stress;
- modern riveting techniques allow one-side access assembly process;
- riveting joint allows micro-movements of joined elements, which decreases local stresses coming from structure twisting and bending;
- in case of electrochemical corrosion exposure (e.g. steel and aluminium) it is possible to use insulation spacers and rivets of specially selected alloys;
- it is possible to dismantle a rivet joint and reassemble it again using the same holes.

There are also disadvantages of riveting, i.e.:

- overlaps of joined elements are required (an increase of the hull weight);
- holes for rivets have to be drilled, weakening the joined elements;
- rivet holes increase the danger of corrosion.

4.3 Clamp joining

Bending the edges of element plates makes clamp joints. Several bends are required to obtain a reliable connection, Figure 3. This technology is used for materials revealing a good plasticity (small radius bending required).

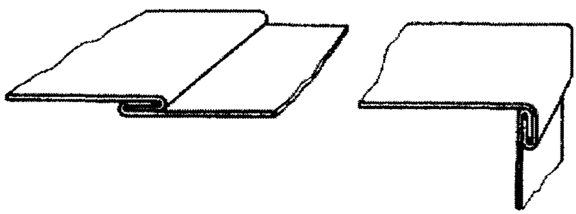

Figure 3: Examples of clamp joints, [19].

4.4 Clinching

Clinching is difficult to apply in assembling the large constructions, because of limited access of clinching tool to all parts of construction, [19].

4.5 Pressure welding

In a pressure welding process heat is introduced to joint spots only, which causes small deformation of joined elements, [2, 5].

4.5.1 Electric resistance welding

Electric resistance welding is a process where a permanent connection is obtained by heating the contact area between two elements using the electrical current and pressing them together with an appropriate force. Resistance welding may be carried out in a number of ways depending on the geometry of joined elements and the desired shape of a joint, i.e.: flash and upset welding, spot, projection and line welding, high frequency current welding, [2, 5].

Flash and upset welding are used for butt joints. Spot, projection and line welding require overlaps, which make them more suitable to connect thin-walled plates of sandwich panels. High frequency current welding may be carried out on both secured and continually moved elements. Static welding can be used for butt, overlap and back joints, while continuous welding is mainly used for butt and overlap joints, and T-joints.

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4.5.2 Ultrasonic pressure welding

Ultrasonic welding is a solid state welding process, where the joint is made by a local introduction of high-frequency mechanical vibration under pressure. It may be used in overlap joints, muff joints, edge joints. However, overlap joints are most commonly used, [2, 5].

4.6 Welding

Fusion welding is presently a dominating technology for joining ship hull elements. There are the following advantages of fusion welding: good mechanical properties of joint, low joint weight, good tightness, feasibility of automation.

The following welding technologies may be used to join elements of a few mm thickness: arc welding in gas shields using consumable or non-consumable electrodes, plasma arc welding, electron beam welding, laser beam welding, [2, 5].

4.6.1 Gas-shielded arc welding

Gas Tungsten Arc (GTA) welding is used mainly for joining thin plates (up to 2.0 - 3.0 mm) or making root passes on thick welding joints, which are then welded with a more efficient method.

Gas Metal Arc (GMA) welding provides deep penetration and easy adjustment of arc linear energy, allowing for joining construction elements made of carbon steel, alloy steel, stainless steel, aluminium, magnesium, copper, titanium and alloys of these metals, in a wide range of thicknesses (0.5 to 300 mm), giving a low content of parent material in the joint.

4.6.2 Plasma arc welding

Due to its specific properties the GTA plasma arc welding can be used for welding plates of thicknesses ranging from 0,025 mm up to 50 mm. Practically all metals and alloys presently used as construction materials are suitable for the plasma arc welding.

GMA plasma arc welding is used to join constructions made of low carbon steel, low alloy steels, stainless steel, aluminium and its alloys, copper and its alloys.

4.6.3 Electron beam welding

Electron beam welding allows making single-pass joints on any type of metal or alloy, for thicknesses of up to 250-450 mm in any welding position. Butt joints or spot joints are available. Fillet welds are only possible when additional material is introduced.

Electron beam welding is a high-speed and high-quality process, which can be used to join elements made from low carbon steels, low alloy and alloy steels, and alloys of aluminium, magnesium, copper and nickel (also these metals themselves). Electron beam welding allows also joining metals and alloys, which have significantly differing physical properties and which cannot be welded using conventional arc welding methods.

4.6.4 Laser beam welding

Laser beam welding (already used in sandwich manufacturing) can be used for welding elements of a wide range of thickness (from 0,0025 mm to 25 – 32 mm), making all types and shapes of joints in any welding position. Butt, overlap and back joints are the most commonly made connections. Narrow joint and heat-affected zone ensure significantly better properties in comparison to arc-welded joints. Heat cracking is also significantly reduced.

4.7 Chemical assembly - bonding

Bonding extends production scope by offering many advantages, [1, 6, 19, 23, 25, 29, 31], i. e:

- joining materials of various properties and shapes;
- even stress distribution, elimination of stress concentrations near drilled holes or welding path;
- no structural changes: the properties of the materials are not affected, as they can be with welding;
- no distortion: since parts are not heated, as it is the case in welding; components with different weights and dimensions can easily be assembled;
- combinations of different materials: these permit designers to select and combine materials so that the properties of each are used to best effect;
- seal joints: adhesives also work as seals;
- insulation: metals with different electrochemical properties can be joined; corrosion, frictional erosion and fretting are avoided;
- less components: pins, bolts, rivets, clamps, etc.

An adhesive facilitates the joining of irregularly shaped surfaces. However, the adhesive must be a perfect match for the surfaces it is to be applied on, be compatible with production methods, transmit anticipated service loads and endure operational environment. The adhesive selected for a particular application must be able to resist these loads and stresses not only initially but also after sustained exposure to the most severe environmental factors which will be encountered during the life of the adhesive joint. Heat and humidity are usually the most damaging environmental factors for the majority of bonded joints.

5 Case study

Labour intensity in manufacturing ship hull sections has been compared, [3]. Three sections were investigated, i.e.:

- no 1 of conventional structure, transverse frames, flat plate,
- no 2 of conventional structure, transverse frames, bent plate,
- no 3 of flat sandwich panel structure (SPS).

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Similar technology of joining elements of sections was applied (welding).

The following parameters were measured and calculated for each section:

- weight of section, [kg],
- labour, [man-hour],
- labour indicator, [man-hour/kg].

The results presented in Figure 4 do confirm, that SPS section despite of the labour intensity requires more labour input than conventional flat section, because of its bigger weight.

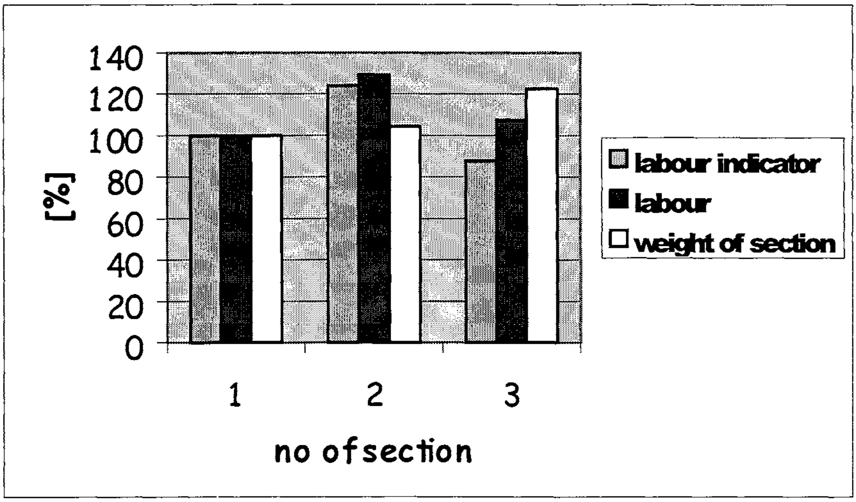

Figure 4: Comparison of parameters for 3 sections of a ship hull, [3]. The value of 100 % is assumed for section no 1.

Summary

Authors have analysed the joining technologies, which could be implemented in the fabrication of the thin-walled constructions made from metals and plastics.

The most common method of joining constructions used in shipbuilding is the classical fusion welding which is suitable for a very wide range of thickness. That method is hard to apply when welded elements are very thin due to thermal deformations, which may cause deformations of a whole construction.

The case study shows, that using sandwich panels in ship construction, applying traditional methods of joining elements, is not the best solution from an economical point of view. There is a necessity to develop other methods of joining leading to more effective fabrication process.

The promising methods of joining the thin plate construction are as follows:

- bolting – a well-known method to join certain parts of construction made of various materials, e.g. elements of a superstructure;
- riveting – a well-known technology but presently very rare in shipbuilding; especially promising in joining thin elements;
- pressure welding – up to now not used in building the ship strength structure;
- bonding – presently very rare in shipbuilding; the advantages of this method make it very attractive in case of joining elements made from various materials and with diverse thickness.

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