A Review on Design and Analysis of Stainless Steel Sandwich Structure

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Abstract— The demand for bigger, faster and lighter moving vehicles, such as ships, trains, trucks and buses has increased the importance of efficient structural arrangements. In principle two approaches exist to develop efficient structures: either application of new materials or the use of new structural design. A proven and well-established solution is the use of composite materials and sandwich structures. In this way high strength to weight ratio and minimum weight can be obtained. The sandwich structures have potential to offer a wide range of attractive design solutions. In addition to the obtained weight reduction, these solutions can often bring space savings, fire resistance, noise control and improved heating and cooling performance. Laser-welded metallic sandwich panels offer a number of outstanding properties allowing the designer to develop light and efficient structural configurations for a large variety of applications. These panels have been under active investigations during the last 15 years in the world. Outokumpu has been participating in several collaborative projects in this area. In Finland the research related to all steel sandwich panels was initiated in 1988 in the Ship Laboratory of Helsinki University of Technology.

Key words: Design Optimization, Hoist able Car deck, Laser Welding, Shipbuilding Structures, Steel

I. INTRODUCTION

The demand for bigger, faster and lighter moving vehicles, such as ships, trains, trucks and buses has increased the importance of efficient structural arrangements. In principle two approaches exist to develop efficient structures: either application of new materials or the use of new structural design. A proven and well-established solution is the use of composite materials and sandwich structures. In this way high strength to weight ratio and minimum weight can be obtained. The sandwich structures have potential to offer a wide range of attractive design solutions. In addition to the obtained weight reduction, these solutions can often bring space savings, fire resistance, noise control and improved heating and cooling performance. Laser-welded metallic sandwich panels offer a number of outstanding properties allowing the designer to develop light and efficient structural configurations for a large variety of applications. These panels have been under active investigations during the last 15 years in the world. Outokumpu has been participating in several collaborative projects in this area. In Finland the research related to all steel sandwich panels was initiated in 1988 in the Ship Laboratory of Helsinki University of Technology.

The first study focused on the application of sandwich panels in the shell structures of an icebreaker. Since then in a considerable number of research projects in Finland, such as Shipyard 2000, Weld 2000 and the Kenno – Light Structures Technology Program, manufacturing, design and optimization of steel sandwich panels have been investigated. The work is based on several R&D projects driven jointly with VTT Industrial Systems, technical universities in Finland, stainless steel manufacturer Outokumpu Stainless Oy as well as Finnish sandwich panel manufacturers. In this article the results of the earlier mentioned R&D work in steel sandwich structures and applications is summarized from the stainless steel material point of view. The research related to design and design optimization of steel sandwich panels has been summarized by Romanoff and Kujala.

A. *Steel sandwich panels: types, benefits and production*

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. The metal material can be either regular, high tensile or stainless steel, or aluminum alloys. This paper focuses on steel sandwich panels welded by laser. The steel sandwich panels can be constructed with various types of cores as summarized in Figure 1. The choice of the core depends on the application under consideration. The standard cores such as Z-, tube- and hat profiles are easier to get and they are typically accurate enough for the demanding laser welding process. The special cores, such as corrugated core (V-type panel) and I-core, need specific equipment for production, but they usually result with the lightest panels. Naturally, during the production process or after welding of faceplates plates and core together, the steel sandwich panels can also be filled with some polymer, mineral or rock wool, concrete etc. to improve the behavior for specific targets. All kinds of sandwich panels have a number of common benefits, like good weight to stiffness ratio, high pre-manufacturing accuracy etc. and problems, e.g. integration in a ship structure, while the various variants also show a number of specific advantages and disadvantages. Steel sandwich is relatively light and the total costs are very competitive to other light structures solutions. Typically, normal strength steel is used with steel sandwich panels as buckling or displacement is the dominating failure criteria, therefore high strength steel does not usually give any major benefits. For areas with high demands for corrosion protection or easy maintenance stainless steel can be also applied. Laser welding require relatively high investment costs, therefore the price of the panels is strongly related to the volume of the production. However, as the material costs are smaller due to the decreased weight, typically the price of the steel sandwich panels/unit area is about the same magnitude as that of conventionally stiffened steel panels.

Proposals for the construction of sandwich-like components were made in different industrial branches as early as the 1950's. However, the application of laser welding started to be increasingly discussed only after the high power laser sources became available on the market at more affordable prices. Due to its high energy intensity resulting in a low heat input and a deep penetration effect, laser welding offers a number of benefits for the production of all-metal and hybrid-metal sandwich panels. High pre-fabrication accuracy of the components, high welding speed and the possibility to connect internal stiffeners with the face sheets from outside have led to a wide application of laser welding in the construction of metal sandwich panels. In the 1980s the United States Navy led the development of laser welded sandwich panels with a robot system at the Navy Joining Centre at Pennsylvania State University. The development resulted in some prototype panels, first strength tests and first limited applications, such as antenna platforms on the US Navy ships. Between the late 1980's and early 90's Europe took over the lead in research related to laser welded sandwich panels. Research was initiated especially in Britain, Germany and Finland. In Britain the strength of spot welded steel sandwich panels was studied by the School of Civil Engineering at the University of Manchester. They performed both theoretical and experimental investigations on the behavior of steel sandwich panels under various loading and boundary conditions. A large German project [10] conducted by Meyer Werft between 1994 and 1999 investigated both the production and application of sandwich panels in cruise vessels. This led to the development of the I-Core panels.

In Finland the research related to all steel sandwich panels was initiated in 1988 in the Ship Laboratory of Helsinki University of Technology. The first study focused on the application of sandwich panels in the shell structures of an icebreaker. Since then a considerable number of research projects in Finland, such as Shipyard 2000, Weld 2000 and Kenno – Light Structures Technology Program, investigated manufacturing, design and design optimization of steel sandwich panels. The European research project SANDWICH joined forces between the main actors in Europe and continued the development based on previous national projects. The project aimed at enlarging the field of applications of sandwich panels in various surface transport sectors, by further improving the sandwich panel properties by implementing local filling material into the panels, developing and validating reliable design formulations within the design tool. One very important outcome of the project was the first DNV guidelines for the classification of these panels in marine applications.

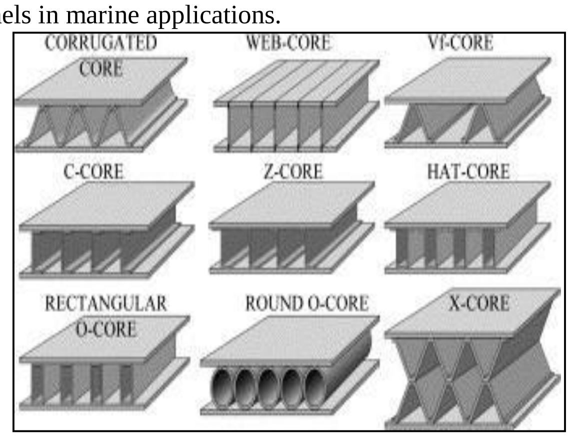

Fig. 1: Different steel sandwich structure with various cores

II. LITERATURE REVIEW

The study of design and analysis of sandwich structure are given by various researchers are as follows.

Noor, Burton and Bert state that the concept of sandwich construction dates back to Fairbairn in England in 1849. Also in England, sandwich construction was first used in the Mosquito night bomber of World War II which employed plywood sandwich construction. Feichtinger states also that during World War II, the concept of sandwich Construction in the United States originated with the faces made of reinforced plastic and low density core. In 1951, Billiard studied sandwich optimization for the case of a given ratio between core depth and face thickness as well as for a given thickness [1] Various analyses on sandwich structure are Kevin J. Doherty investigate sandwich panels of metallic face sheets and a pyramidal truss core subjected to panel bending and in plane compression testing to explore the effects of relative core density and process parameters.[2].

Aydıncak, İlke made a design and analysis of honeycomb structures to develop an equivalent orthotropic material model that is substitute for the actual honeycomb core.[3] Jukka Säynäjäkangas make a review in design and manufacturing of stainless steel sandwich panels and conclude an efficient sandwich is obtained when the weight of the core is close to the combined weight of the both faces[4]. Tomas Nordstrand made an analysis on corrugated board in three-pointbending and evaluation of the bending stiffness and the transverse shear stiffness [5]. Pentti Kujala discussed that steel sandwich panels that are welded by laser can save 30- 50% weight compared to conventional steel structures [6]. Jani Romanoff presents a theory of bending of laser welded web core sandwich panels by considering factors that effect the total bending response of laser welded web core sandwich plates [7]. Pentti Kujala made analysis on metallic sandwich panels which are laser welded have excellent properties with light weight having more applications [8]. Narayan Pokharel determined local buckling behavior of fully profiled sandwich panels which are based on polyurstyrene foam and thinner and high strength steels [9]. Pentti kujala determined ultimate strength of all steel sandwich panels and numerical FEM analysis and development of design formulations for these panels. [10]

Laser welded stainless steel sandwich panels have big potential in wide range of attractive design solutions. The correct design of the details of the sandwich constructions is of great importance as well as the analysis of deflections, stresses and buckling loads. Joint of sandwich panel to other sandwich panels or to other structures is one of the key elements in the practical applications of these constructions. The results of the studies have indicated that austenitic stainless steel grade 1.4301 (AISI 304) can be used in laser welded sandwich panels offering good mechanical properties and corrosion resistance. The use of higher strength austenitic stainless steel as sandwich panels was shown to be reasonable when substantial weight reduction of load bearing structures is desired. In addition to laser welding the development of resistance and spot welding, adhesive bonding and weld-bonding processes will increase the variety of efficient techniques in manufacturing of stainless steel sandwich structures in the future. There has been a lot of research activities in Europe related to the development of laser welded steel sandwich panels. The work carried out includes the development of design formulations for the ultimate and impact strength, analysis of fatigue strength for the joints, and development of solutions to improve the behavior under fire and noise. New factories have been established to produce these types of panels, which enables larger scale implementations of the panels for various types of ships in the near future. Optimal design of steel sandwich panel applications in ships is a complex task, comprising many subtasks, such as load modeling, response calculations and optimization. Following this principle, a redesign of Hoistable Cardeck was performed, including the minimization of weight and cost of production. Two advanced sandwich alternatives were suggested instead of the traditional paneled structure and were then optimized. Paper gives evidence that the Hoistable Cardeck with sandwich paneling can now be designed in the preliminary faze without using the finite element methods. This seriously shortens the design time, which is of great importance to a designer. One optimization run, on a typical PC, took only couple of minutes, thus enabling the variability and offering more freedom to designer to explore new concepts [11]

Narayan Pokharel investigates the local buckling behaviour of foam supported steel plate elements. Appropriate finite element models were developed to simulate the behavior of foam-supported steel plate elements used in the laboratory experiments as well as sandwich panels used in various building structures. The finite element model was validated using experimental results and then used to review the current design rules. The results reveal the inadequacy of using the conventional effective width approach. It is concluded that for low *b/t* ratios (<100) current effective width design rules can be applied, but for slender plates these rules can not be extended in their present form. Based on the results from this study, an improved design equation has been developed considering the local buckling and post buckling behavior of sandwich panels for a large range of *b/t* ratios (<600) for design purposes [12]

Steel sandwich structure with stainless steel faces and mild steel core are joined by welding and compression test is conducted on Universal testing machine (UTM) and ultimate stress and deflection are studied. The in plane compression testing of sandwich structure was performed on universal testing machine (UTM) having capacity 400KN. The samples were placed between hardened end plates in order to protect the surface of the machine's platens. Load is applied uniformly and deflection and compression strength are noted. The work has been conducted as part of a technology programmed supported by the Finnish Technology Agency TEKES and within the "Advanced Composite Sandwich Steel Structures" project supported by the European Commission. ESA Comp software allows definition of metal sandwich cross sections having I, O, V, C, Z type web configuration. A filling material may also be included in the panel. The equivalent stiffness properties of a panel are computed using analytical approaches from which the structural components like beams and rectangular plates under given loads can be analyzed. Resulting panel stresses are taken back to the level of the face sheets and the web, thus allowing detailed failure assessment including modes like yield and local instability. ESA Comp further integrates with finite element (FE) software such as ABAQUS, ANSYS and NASTRAN. The analyses of the complex structures are possible with relatively simple shell based FE models as ESA Comp brings the details of the metal sandwich behavior into the analysis loop. ESA Comp software has an easy to use graphical user interface that allows definition of metal sandwich configurations [13].

III. Discussion

From the above literature survey by various surveyors following discussion is made.

A. *Design characteristics*

The basic text books for sandwich structures, give the basic design equations for these types of panels. However, these books concentrate mainly on composite panels. Special design formulations and tools for steel sandwich have been developed in the Finnish national research projects and in the EU-SANDWICH project, the formulations are summarized. The developed design formulations support calculations of response, fatigue, fire, corrosion, sound and vibration.

Formulations are intended for designers as well as for the use in optimization. One practical case engulfing some of these characteristics is described in the following chapter. The strength formulations cover the basic first principle design approaches. In these formulations, the effect of possible filling inside the panel, using e.g. balsa, polyurethane or concrete, is included to develop tailor made panels for specific application cases. Design tools such as ESA Comp MSE are available, although limitedly, which allows a shipyard designer to integrate sandwich structures into a global finite element model of a ship as well as to design optimal panels.

B. *Material*

The results of the studies have indicated that the austenitic stainless steel grade 1.4301 (AISI 304) can be used for laser welded sandwich panels with good mechanical and general corrosion behavior in different applications. To increase the corrosion resistance and to improve the resistance to pitting and crevice corrosion the austenitic stainless steel grade 1.4401 (AISI 316) can be used. The use of higher strength austenitic stainless steels like grade 1.4318 (AISI 301LN) or even hard cold rolled materials was shown to be good or reasonable when substantial weight reduction of load bearing structures is desired. Especially point loading resistance can be increased. The use of hard cold rolled stainless steels for sandwich panels is still under investigation.

C. *Modeling and Drafting*

1) *Triangular*

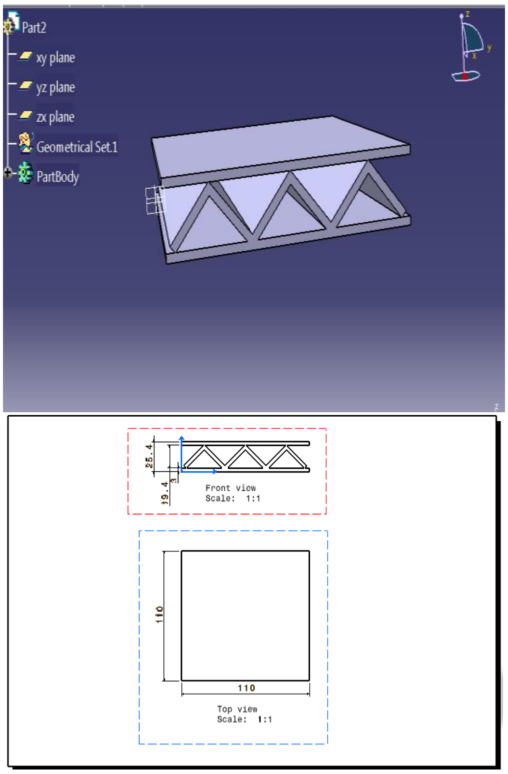

Fig. 1: Triangular

2) *Circular*

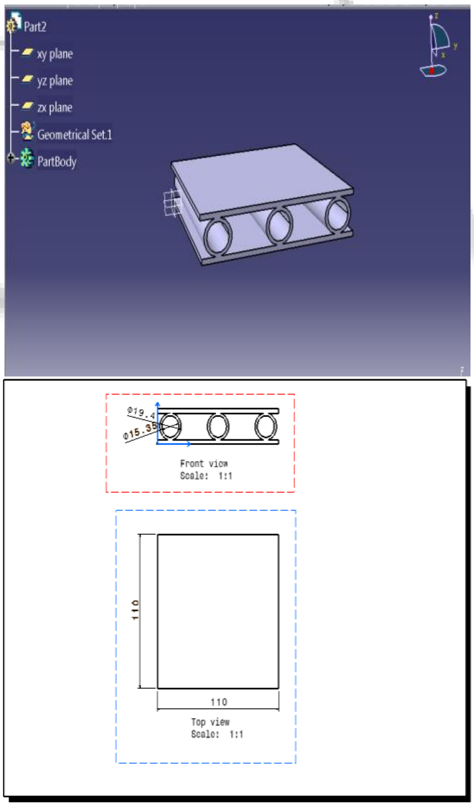

Fig. 2: Circular

D. ANSYS Workbench

ANSYS Work bench can be thought of as a software platform or framework where it performs analysis activities. In other words, workbench allows organizing all your related analysis files and databases under same frame work. This means it can use the same material property set for all analyses. Some of the applications that fit into the workbench framework are:

1) Fluent
2) Mechanical (simulation)
3) Design modeler
4) AUTODYN
5) CFX Mesh
6) FE Modeler

The ANSYS Workbench platform allows users to create new, faster processes and to efficiently interact with other tools like CAD systems. Those performing a structural simulation use a graphical interface (called the ANSYS Workbench Mechanical application) that employs a tree-like navigation structure to define all parts of their simulation: geometry, mesh, Setup, Solution and boundary conditions and results. By using ANSYS workbench user can save time in many of the tasks performed during simulation.

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