

# A review in design and manufacturing of stainless steel sandwich panels

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## 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 summarised by Romanoff and Kujala (2003).

## SANDWICH STRUCTURES

The most common type of sandwich structure consists of two thin, stiff and strong sheets of dense material separated by a low density material which have a lower stiffness and strength compared to the materials used as top and bottom faces. As a rough guide to

the proportions, an efficient sandwich is obtained when the weight of the core is close to the combined weight of the both faces.

Sandwich panels having both the top and bottom plates as well as the core made of steel are called steel sandwich panels or steel sandwich structures. Steel sandwich panels can be divided according to the core structures: I-core with straight webs, O-core with rectangular beams as a core, Vf/V-core with hat or corrugated sheets as a core and X-core with two hats as a core, Fig. 1. Other types of the profiles such as C, U or Z can also be used as a core. By using sandwich structures, it is possible to obtain high strength to weight ratio, i.e. the sandwich structures were found to be 30 – 50 % lighter than the conventional steel applications (Kujala et al, 2003).

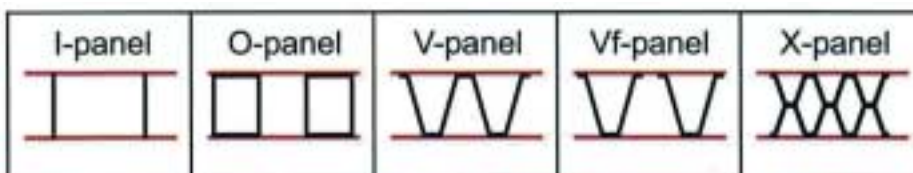


Figure 1. Five different core geometries suited for steel sandwich structures.




	Structural stiffness	Bending strength	Weight
	1.0	1.0	1.0
	7.0	3.5	1.03
	37.0	9.2	1.06

Figure 2. A comparison of the strength to weight ratio of sandwich panels and a solid plate with equal structural properties by prof. Dan Zenkert 1998

### DESIGN PRINCIPLES

Engineering materials have characteristic range of values to be used in designing. The performance of the structure is maximized and in load-bearing component this means maximum stiffness to strength ratio for a given weight. The performance of a structure depends on the type of loading (tension, compression, bending, torsion or a combination of them), on the shape of the section (solid, tubular, I-section, etc.) as well as on the properties of the material (modulus, strength, toughness, etc.).

The design formulations for steel sandwich panels are presented in the report "Formulations for the strength analysis of all steel sandwich panels" (Kujala and Romanov, 2002). The panel geometries considered in this report were I-core panel, O-panel and Vf/V-core panel. A brief description of how to design formulations of all steel sandwich panels was also given. Some comparison between the calculations, strength tests and 3-dimensional finite element models were also presented in that paper.

The strength, fire-resistance, fatigue etc. properties of the metallic sandwich panels can be considerably improved by implementing filling materials such as PU-foams, metallic foams, light concrete or mineral wool. The type of filling material used in an application largely depends on the desired properties, fabrication method and price.

The correct design of sandwich panel constructions has similar importance as the analysis of deflections, stresses and buckling loads. Furthermore designing the joint of one sandwich panel to another or to other structures is one of the key elements in the practical applications of these structures.

### DESIGN TOOLS

A Finnish company Componeering Inc. ([www.componeering.com](http://www.componeering.com)) provides a software application for analysis and design of metal sandwich panels. The ESAComp software, originally developed for the analysis and design of composite structures, has recently been enhanced with an add-on module for metal sandwiches. The theoretical input for this develop-

ment has been provided by the Ship Laboratory of Helsinki University of Technology. The work has been conducted as part of a technology programme supported by the Finnish Technology Agency TEKES and within the "Advanced Composite Sandwich Steel Structures" project supported by the European Commission.

ESAComp 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 analysed.

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. ESAComp 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 ESAComp brings the details of the metal sandwich behaviour into the analysis loop.

ESAComp software has an easy to use graphical user interface that allows definition of metal sandwich configurations, Fig. 3. The results of a plate analysis can be viewed as contour plots indicating critical areas of the plate.

### MATERIALS

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 behaviour 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

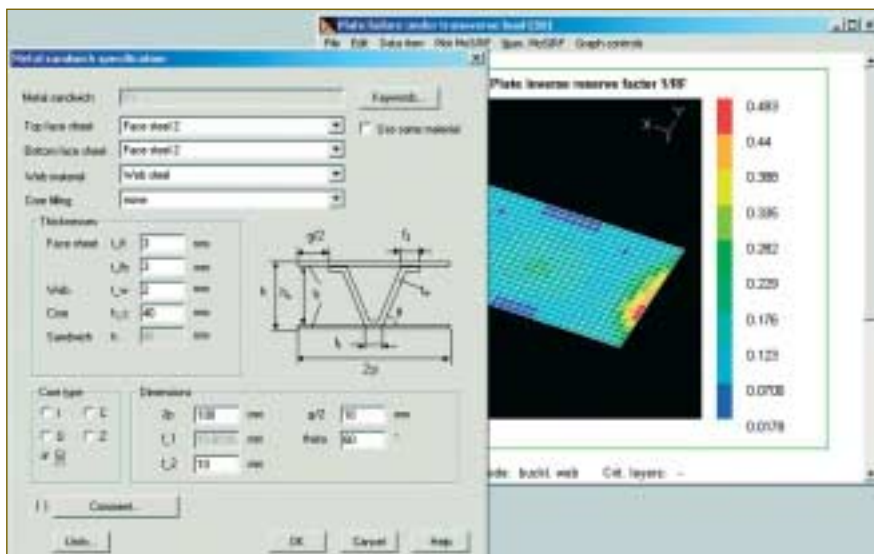


Figure 3. Views of ESAComp software

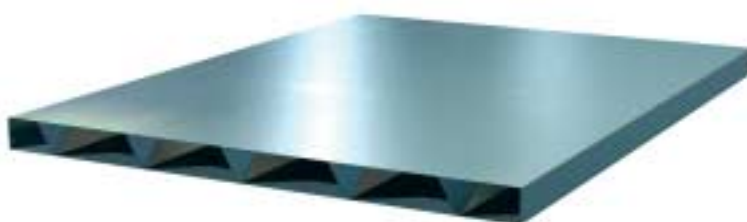


Figure 4. V-core stainless steel sandwich panel with hat sheets as a core. (Photo: Mizar Oy)

desired. Especially point loading resistance can be increased. The use of hard cold rolled stainless steels for sandwich panels is still under investigation.

### CORROSION

The corrosion resistance of welded stainless steels in salt spray chamber tests and road conditions has been studied in several projects (Alenius et al 2002). The salt spray chamber tests and the field tests consistently showed that the use of proper post-weld cleaning method is of great importance when subjecting welded stainless steel parts unprotected to de-icing salt environments. Pickling was demonstrated to be the most effective post-weld cleaning method. Other methods were clearly less effective.

Large laboratory and field corrosion test programs were performed in the ECSC funded project "Stainless steels in bus constructions" (Report EUR 20884 EN 2003) which was coordinated by Outokumpu Stainless Oy. These tests consisted different stainless steel grades and joint types.

The aim of the study was to compare the laboratory test results with the results of the field tests. Remarkable slighter corrosion took place in the field tests in Rome, Gibraltar and Madrid compared to the test results obtained in Helsinki where de-icing salt is used on the roads during the winter season. Corrosion resistance was classified in ascending order: 1.4003 (Cr12) - CrMn16-7 - 1.4301 (AISI 304) - 304sp (Mo-alloyed).

Grade 1.4301 (AISI 304) managed well in these tests and it could be stated as a preferred grade regarding corrosion resistance. Joints and crevices are stated as the critical points.

In general it can be said that a visual evaluation gives a good general view of the surface, but a closer microscopic examination is needed to check the severity of the corrosion. That is the case for example to identify existence of crevice corrosion.

### PRODUCTION PROCESS

Various manufacturing techniques, such as resistance and spot welding, weld-bonding and adhesive bonding are



**Figure 5.** In the special container for gravel truck the stainless steel sandwich panels as side walls are welded to wear resistant plates in the bottom of the structure. A Mo-alloyed stainless steel grade 1.4432 (AISI 316L) has been used. (Photo: Kennotech Oy)

applied for sandwich panels with metallic core. Laser welding combines high productivity and low heat input with excellent fatigue properties.

Austenitic stainless steel is ideally suited for laser welding thanks to the low heat input and high welding speeds. Laser welding minimizes metallurgical changes that could impair the corrosion resistance of the weld metal. Another advantage of using laser welding austenitic stainless steels is the small weld distortion produced by the low heat input and the laser weld shape.

### RECENT APPLICATIONS OF STAINLESS STEEL SANDWICH PANELS

Steel sandwich panels have been used for commercial applications during the last 15 years. Stairs and staircase landings, bulkheads and decks are the main application areas of metallic sandwich panels in cruise ships and in other marine applications.

In recent years a wide variety of applications of stainless steel sandwich panels are used in civil and mechanical engineering as well as in other industrial sectors. These include floors of buses, walls and floors of elevators, working platforms in industrial applications and balconies of shipyard (Kujala et al, 2003).



**Figure 6.** Stainless steel sandwich panels made of austenitic stainless steel grade 1.4301 (AISI 304) used in the wood drying tunnel. (Photo: Kennotech Oy)

### CONCLUSIONS

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. ◀

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#### About the author



#### Mr Jukka Säynäjäkangas

Mr Jukka Säynäjäkangas, M.Sc. (Eng.), is working as a Senior Research Engineer at Tornio Research Centre of Outokumpu Stainless Oy. His earlier professional experience consists of both industrial and educative duties over a 12 years period at Metso Paper Machinery Inc. Currently he works in the field of product development and he is responsible for the constructional applications made of stainless steels.



#### Mr Tero Taulavuori

Mr Tero Taulavuori, M.Sc. (Eng.), is the Research Manager of Tornio Research Centre in the field of product development. He is responsible for the development of new innovative products based on the new and existing production facilities in the field of stainless steel. His eight years experience at Outokumpu consists of both technical customer service and research duties.

#### Facts about the Finnish manufacturers of steel sandwich panels

*Currently there are two sandwich panel manufacturers in Finland.*

##### Kennotech Oy

(<http://www.kennotech.fi>)

The industrial production is based on the latest development of laser welding technology, strength calculation methods and new high strength steel materials.

The customer segments are

- Transportation
- Construction
- Shipbuilding
- Process industries

The company optimises structural configurations for different applications achieved by varying the thickness of cover plates and cores, material and the core shape.

##### Mizar Oy

(<http://www.mizar.fi>)

Mizar is specialized in laser welding of steel sandwich panels. The company has highly automated production equipment and the business idea is to produce laser welded sandwich panels and other sheet metal structures for construction industry, ship building industry and other industry.

Equipment consists from three pieces of gantry type laser welding stations:

- 1 station equipped with 5 kW laser for cutting and welding
- 2 stations equipped with 8 kW laser for welding

The maximum size of the sandwich panels produced is 17 m x 4 m x 0,5 m and sheet thickness range is between 0,7 - 6 mm. Utilization of bigger thickness is also possible.