Fatigue tests of steel sandwich panel

J. Kozak
Faculty of Ocean Engineering and Ship Technology,
Technical University of Gdansk, Poland.

Abstract

Laser welding techniques start to find their position among different methods of joining which allow changes in configuration of typical ship structure: instead of shell plating supported by perpendicular system of heavy stiffeners one can use the SANDWICH panel: two shell plating of thickness in the range 3-4 mm with height about 40 mm, supported internally by uni-directional system of stiffeners - all components connected by laser welding. Paper presents idea of the SANDWICH panels as well as the preliminary laboratory fatigue tests results of such panels tested in natural scale.

Introduction

Accelerated development of new technologies which is observed during last several years have made impact on shipbuilding structures too. The new materials and new manufacturing techniques have been developed. Among other new ideas, the laser welding techniques start to find their position among different methods of joining components of ship structure. The use of such technique offers new, attractive possibilities because it enables implementation of the welding processes to the places not accessible for welder so far. Such capabilities create new opportunities of changing of configuration of typical ship structure: instead of “classical” design consisted of shell plating supported by perpendicular system of heavy stiffeners one can imagine design already applied in glass reinforced plastic structures – two shells connected by internal system of
thin stiffeners. This is an idea of SANDWICH structure – steel or aluminium panels manufactured from two shell plating of thickness in the range 3-4 mm with height about 40 mm, supported internally by one directional system of stiffeners - all components connected by laser welding. The application of such new structure requires to find out its characteristics taking into account strength, corrosion, vibrations, fire protection and fatigue, to prove to classification societies that its properties are not worse in comparison to the classical structure. Majority of such parameters are obtained by wide series of the laboratory tests carried out on models of structure in scale ranging from small to the natural one.

**General idea of the sandwich structure**

The idea to replace the classical construction of the ship hull by two-shells, thin structure supported by stiffeners located inside between shell platings was manifested at the beginning of 50-ties last century as the result of the studies carried out by NASA. As the effect of such works, some theoretical deliberations on the methodology for estimation of stiffness indicators of such structure have been published [1],[2],[3], but serious interest in such ideas was shown by US Navy at the end of 80-ties. It was then US Navy developed LASCOR panel type and applied it – among others - to the wall structures and to high located antenna decks. Most spectacular example of such design was application of it for antenna platform on USS "Mt. Whitney", which allowed reduction of weight up to 9 tons of highly located structure. Another example of the laser welded panels are structures manufactured by Meyer Werft in Pappenburg. Those structures are fabricated in large amount – actually series of the big river ships with deck structures completely fabricated as sandwich panels, is build in one of the German shipyards.

Both mentioned types of sandwich structures show the similar idea of the design. It consists of the steel or aluminium panels fabricated as two shell plating of thickness of 1 to 6 mm each, with distance between them of 40 to 120 mm, connected and stiffened by system of uni-directional stiffeners with 40-120 mm span using the laser welding technique – Fig.1.

![Fig. 1. Deck structure of Ro-Ro ship.](image_url)

a) Deck structure of Ro-Ro ship. Meyer sandwich type structure - (a), conventional - (b).

Application of the structure like in Fig.1a) instead of conventional one, will give about 34% weight reduction and about 50% reduction of the manufacturing costs, [5].

Another approach to the sandwich structure presents SPS system (Sandwich Plate System) introduced by prof. S.Kennedy, Ontario University, USA. This
idea consists of two steel shell plating connected by elastomer filling material (BASF Inoac) – Fig. 2, [6],[7].

 Such panels have been applied among others as parts of the structure of the deck on modernised ferry „Pride of Cherbourg”. In both cases the basic grillage structure of ship stiffeners system have to remain the same to guarantee proper global strength characteristics. Independent on idea or manufacturing method, panels can be used as basic structural elements of bulkheads, decks or walls. It is expected that in each case application of such structure will have advantages like weight or labour reduction or increase of internal volume which in each case will bring economic effects. Fig 3 [7] presents studies on way of simplification of the structure of oil tanker by application of the SPS structure. It is expected that such simplification will reduce about 40% of welds in analysed area [7,8].

Fig. 3. Simplification of the tanker structure by application of SPS concept [7]
Characteristics of sandwich panel

Implementation of the new concept in the structural design – especially for ship structure which is strictly ruled by regulations of Classification Societies - requires full knowledge on its behaviour: static and fatigue load characteristics, information on fire resistance, corrosion process, etc. Due to the fact that steel sandwich structure is a relatively new idea, there is only limited amount of data on strength properties available, and only single data are published.

Fig. 4 [5] shows results of the static bending test of Meyer panels, which are compared with those for conventional structure, whereas Fig. 5 presents comparison between two characteristic of the in-plane axial loaded stiffened panel with different cross section geometrical parameters [4].

Fig. 4. Transverse load bending test result - comparison between Meyer panel and conventional structure [5].
Fig. 5. Characteristics of axial loaded stiffened panel [4].

Fig. 6 presents results of the mechanical shock tests, whereas Fig. 7 shows comparison of vibration damping for sandwich structure [7,8].

Fig. 6. Transverse shock test results [7,8].
Fig. 7. Level of vibration decay for SPS panel and conventional structure [4,8].

**Laboratory tests of sandwich panels**

In the process of implementation of the new structural design it is necessary to have the reliable design tools – on one hand with sufficient accuracy, and on the other – as simple as possible to be applicable in average design office. Finite Element Methods (FEM) is doubtless one of them, but it is expected that for sandwich structure such method requires some modification in standard elements libraries due to expected contact processes in place of connection of the shell plating and internal stiffener. The other possibility is application of semi-empirical formulae but creation and verification process of their development requires large amount of data related to structure behaviour. It was the baseline for idea of the research programme which aim was to find out answer to some – often cross linked – questions related to strength behaviour of the sandwich structure. First of all, the optimisation process of the cross section of the sandwich panel geometry had to be carried out as well as pre-selection of the filling materials, taking into account strength, corrosion, fire and economic properties. For such preliminary limited geometry the verification process of basic strength characteristics had to be done. Parallel studies on problems of the connections between sandwich panels as well as between sandwich panel and conventional structure were done. Finally the full spectrum of the strength properties obtained from laboratory tests of sandwich panels in natural scale had to be done. Necessity of verification of analytical formulae requires having wide spectrum of data – for all reasonably possible boundary conditions as well as load applications. Because of inter-combination of different types of failure: local buckling, global buckling and global bending the way of destruction of
large structure is rarely simple. Moreover influence of the less deformed part of structure on more affected region causes that model of loading of such region varies between load and displacement limitations. The purpose of the tests of the lateral bending of the large scale sandwich panels is to find out the qualitative relationship between geometry and filling material parameters of the model and static or fatigue behaviour and mechanism of destruction and further - quantitative parameters related to ultimate strength of the tested structure: load-deformation characteristic as well as S-N curve. To obtain wide variety of data for determination and verification of analytical formulae, relatively wide set of load and boundary conditions have been assumed. Such formulated programme was baseline for SANDWICH research program supported by V-th Framework Programme of European Community. Faculty of Ocean Engineering and Ship Technology, Technical University of Gdansk, Poland which is one of the programme partners, focused its activity on carrying out of the laboratory tests of SANDWICH structure in natural scale. Taking into account geometry of the stiffener system for typical ship hull structure as well as laser welding stand capabilities, finally adopted tested model has dimensions 3000x1500 mm with two variants of core stiffener system: perpendicular to the shell plating (I-core) and corrugated (V-core). Basic geometrical data of the tested model are presented in Fig. 8.

Fig. 8. Geometry of the tested model
For such geometry three parameters have been assumed as independent: height, thickness and distance of the stiffeners. Finally 17 combinations of boundary - load conditions have been selected for static testing. Each model should pass static load tests through all combinations of load-support conditions.

Fatigue tests results

Fatigue tests were carried out for all model’s edges clamped and pulsating point load applied in centre of model. Fig. 9 presents model during fatigue test.

In calibration process prior to fatigue tests, series of static load cycles have been applied and registration of strain and displacement in selected points of structure was conducted. Fig.10 shows fatigue test results with P-N curve plotted with RMS method. (P means load, N - represents number of load cycles for crack propagation length = 5 cm). Inclination coefficient of the curve amount of approximately 4. Comparing this value with fatigue S-N curves suggested by classification society [9] one can find out that such value is placed between inclination coefficient m=3 for welded joints and m=5 for notches at free plate edges. Fatigue cracks – generally – occurred in area close to weld toe and
develop down to laser weld. Fig 11 presents general crack location with detail of section of destructed model.

Fig. 10. Fatigue test results

Fig. 11. Model after destruction
Conclusions

A review of state of development of steel sandwich structures has been presented. Such structure offers high potential both from the design, manufacturing and ship production point of view. Selected characteristics of sandwich structure have been shown and laboratory, natural scale strength test program and results are described. The results indicate that except maximum allowable strength criterion which is sufficient for typical steel stiffened panels, maximum acceptable deflection criterion for sandwich panels have also to be introduced, to take into account its higher flexibility as compared with "classical" structure.

The SANDWICH project will contribute significantly to the increase of knowledge about those new structures.

Acknowledgements

This paper is based upon results of the works carried out in frames of European Union supported GROWTH research project “Advanced Composite Steel Sandwich Structures” – acronym SANDWICH.

References