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Laser welded sandwich panels for shipbuilding and structural steel engineering

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Abstract

New structural components, such as sandwich panels, can be efficiently manufactured by using the deep penetration effect typical to high power beam welding techniques. Sandwich structures offer high accuracy, higher structural performance, increased fire safety as well as benefits in assembly. For the first time those structures are now available on the market. Potential applications cover both shipbuilding and various areas of structural steel engineering such as bridges, railway vehicles and buildings. To provide a base for successfull application, a considerable amount of structural testing along with the development of efficient manufacturing and assembly methods and the approval of the structure by classification societies has been necessary. This paper briefly describes the manufacturing process and operational properties of sandwich panels.

1 Laser Welding in Shipbuilding - Brief historical Survey

Despite of numerous investigations into laser welding of comparatively thick ship structures starting as far back as the 1980's, the practical use of lasers in shipbuilding is presently limited to a few prototype applications. This is due to the fact, that problems of efficient manufacturing and assembly under industrial conditions are not sufficiently solved for many applications and that little experience exists on the structural behaviour of laser welded components under operational conditions. Practical shipyard applications are needed to obtain practical experience with the new technology.

Upcoming applications and concepts for laser welding in shipbuilding can be classified to three principal approaches[1]:

- The "traditional" approach, aiming to replace conventional welds, like butt and fillet welds, with laser welds. Benefits of this approach could be an increased welding speed and a reduction of distortions, however comparing the advantages and risks laser welding to the potentials of modern high performance arc welding techniques, applications for this approach will be limited by the authors opinion.
- The "new design" approach intends to create new design solutions, which can not easily be produced by conventional welding techniques. Stake welds in sandwich structures as shown in figure 1 are a good example. The approach combines the benefits of laser welding techniques with those of lightweight structures and was therefore chosen as the most promising by Meyer Werft when starting the development of laser welding in 1994.
- The "flexible tool" approach, intended to use the properties of the high power laser beam for multiple manufacturing processes, such as cutting, welding or cladding. This approach could help to better utilize the high investment cost of a laser installation in small companies, but is also used by Odense Steel Shipyard in Denmark for a prototype installation aimed to increase flexibility in production.

The risks and potential benefits of these principle approaches were more extensively discussed in 1996[1].

2 Lightweight Sandwich Structures

Various types of sandwich structures, such as bonded, tack welded and mechanically joined panels, are currently used in industrial applications.

However, beam welding offers a number of benefits as compared to alternative manufacturing methods. Laser welding with high power sources above 10kW allows for continous stake welds of large parts with a very high accuracy and eveness. Such laser welded sandwich structures offer high strength and stiffness at comparatively low weight. Weight savings up to 40% and more are possible in some cases. The manufacturing cost of the sandwich components compared to conventional design can be considerably cut by using an optimized semi-continous material handling in line with the high welding speed. Increased fire safety and heat insulation as well as easy assembly due to the absence of external stiffeners are additional advantages of sandwich structures.

Though several prototype panels have been manufactured in laboratories in the UK, Finland and the US for almost ten years and mostly used aboard of US Navy ships, Meyer Werft is now the first to offer laser welded sandwich components in a constant good quality at a competitive price for all types of ships and structural steelwork.

The sandwich panels produced at Meyer Werft consist of two covering sheet plates of 2.5 to 5 mm thickness which are connected by flat bars (see figures 1 and 2). The maximum size of the panels is currently 10m x 3m, an extension to 20m in length is being considered.

Before being able to offer the sandwich structures on the market, a manufacturing technology has been developed which guarantees a reliable and effective process under industrial conditions. More importantly, the operational behaviour of the laser welded steel components and their connections towards conventional plate-stiffener structures had to be qualified towards classification societies, customers and shipyard staff. This was particular challenging as a new manufacturing technique is combined with a completely new structural design. Other important issues of the work carried out by Meyer Werft was to develop effective solutions for the assembly of sandwich panels as well as for the integration of outfitting operations such as tube intersections or insulation and to design a modular system of sandwich panels, covering various applications in shipbuilding and structural steel.

3 Manufacturing of Laser Welded Sandwich Panels

Though high power laser sources ranging up to 45 KW power output are available on the market, laser welding under shipyard conditions is still facing several problems which lead to a high technical and economic risk. Some of these problems are briefly described below:

- High laser powers needed to obtain satisfactory welding speed (up to 7 m/min at 5mm penetration in the Meyer Werft application) combined with extremely long passes may cause thermal distortions of the optical components in the beam pass. Standard systems available on the market often proved to be not sufficient, making modifications and optimization work necessary.

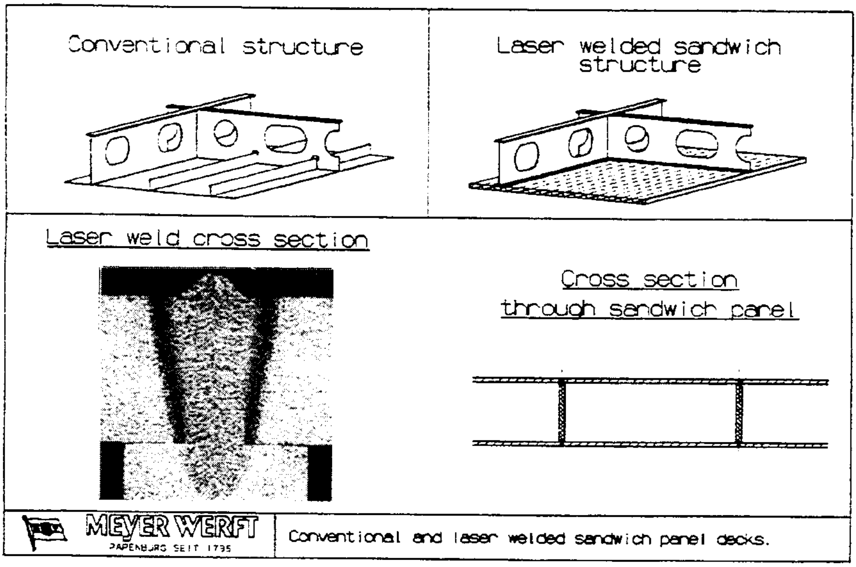

Figure 1: Steel structures using conventional and laser welded sandwich panels

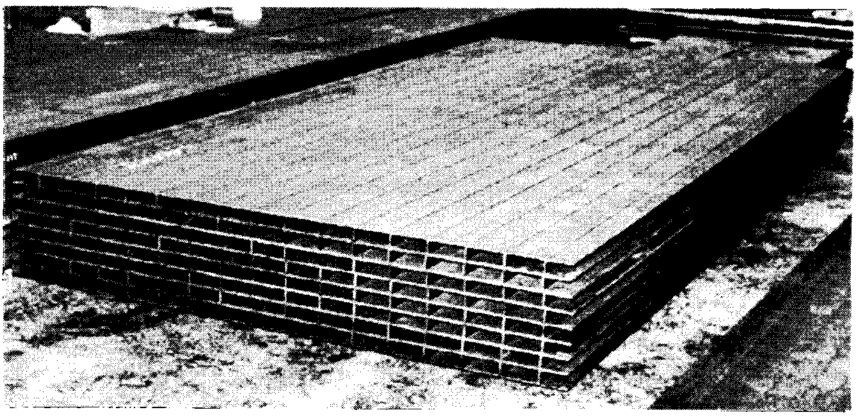

Figure 2: Laser welded sandwich panels. No visible distortions after laser welding

- Environmental conditions in a shipyard are extremely harsh for laser applications as compared, for instance with the automotive industry.
- Process monitoring and measuring devices for the high power beam were not available on the market or did not work properly under industrial conditions. New developments were necessary which now allow for an 100% online monitoring of the laser weld quality. Weld defects are directly marked on top of the panel or in a welding protocol. All process parameters as well as the signal obtained from the plasma monitoring systems are stored in a data base along with macro-sections of the weld and results gained from destructive testing. This is to prove the constant good quality of the laser welds and to optimize the process by means of multi-dimensional statistical methods.
- Though the heat input into the workpiece is considerably lower for beam welding compared to arc welding techniques, particular attention has to be paid on fixturing and clamping devices. This is especially true for the large components manufactured at Meyer Werft, where the internal stiffeners have to be exactly followed by the welding head in order to obtain high quality welds.

Figure 3 gives a general view of Meyer Werft's laser installation. The workpiece is moved on a table while the welding head is fixed on a gantry during the actual welding process. The welding head which is connected to pressuring rollers in order to minimize the gap between the covering sheet and stiffeners is shown in figure 4. Welding installation and manufacturing process were described in a previous paper[2] in more detail.

4 Operational Behaviour of Laser Welded Sandwich Panels

4.1 Structural Testing

As the scientific knowledge and experience about the behaviour of laser welded structures under operational conditions in ships are limited, Meyer Werft has decided to carry out a wide range of static and dynamic structural strength tests. Existing rules on laser welding[3] and on the qualification of new welding procedures do not cover the laser stake weld and thus were not sufficient for qualification.

Static tests comprised bending under various loads, shear parallel and perpendicular to the stiffeners, compression stability etc.. In all tests the specimen failed by global and/or local buckling. Laser welds were only affected in close vincinity of the buckles, and only when those became extremely high. A zipper effect was never observed. Bending tests with a comparable conventional panel (sheet plate with bulb profiles) showed, that sandwich panels can bear approximately three times the load of conventional panels (see figure 5).

Fatigue tests have been made for the laser weld itself (figure 6) and at sandwich panels sized up to 2.7m x 4m. Tests simulated an operational load of 500 kg/m^2 as well as local load caused by equipment placed on top of the panels and fixturing of tubes etc. on the lower side of the panels. The impact of weld defects of a varying length has also been tested. All fatigue tests at sandwich components have shown, that they can easily withstand the ship design load for public areas.

Further tests to investigate the blast and shock behaviour of laser welded sandwich panels are being prepared.

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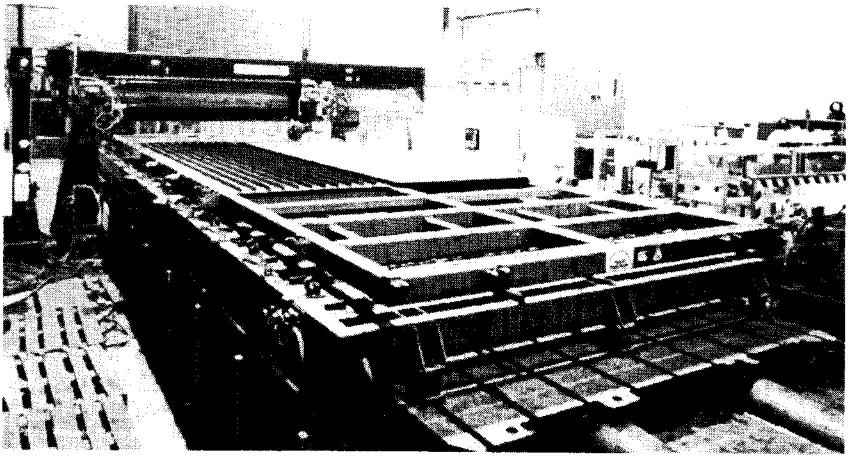
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Figure 3: General view of the Meyer Werft laser welding installation

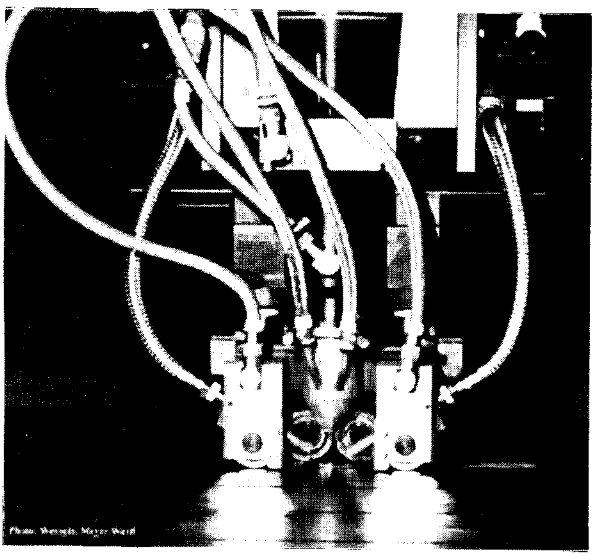
Figure 4: Laser welding head

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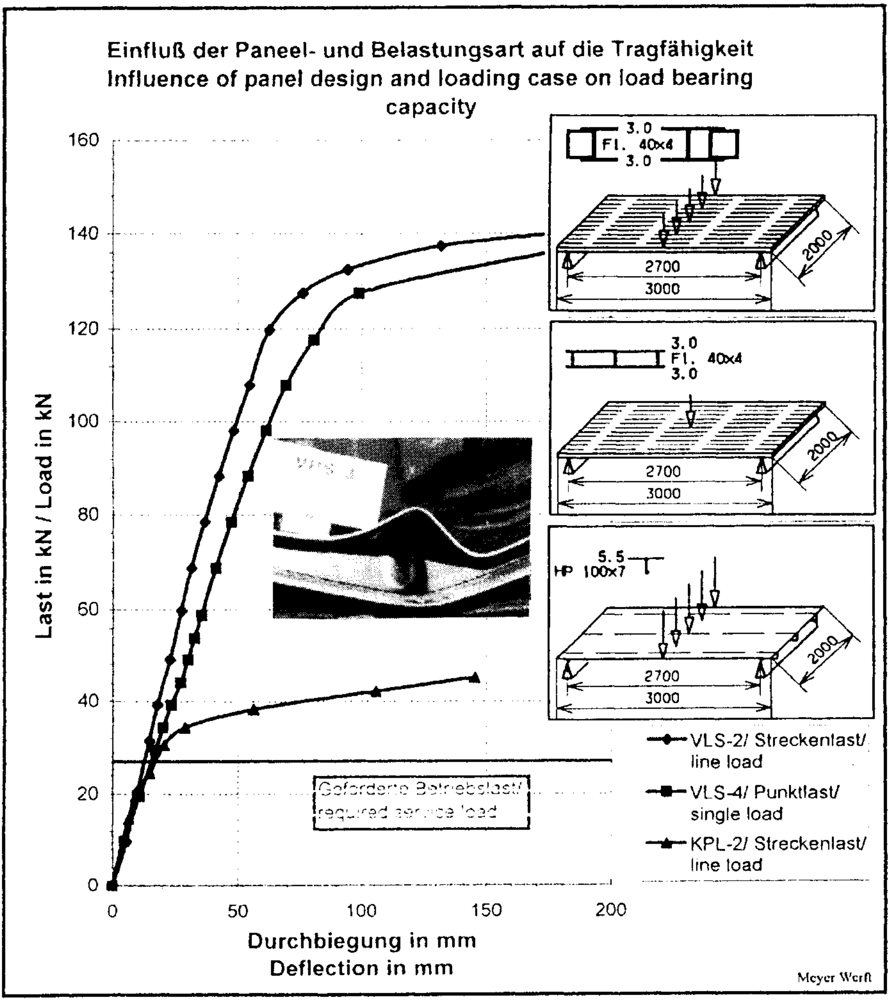

Figure 5: Static strength of laser welded panel compared to conventional panel of equal weight

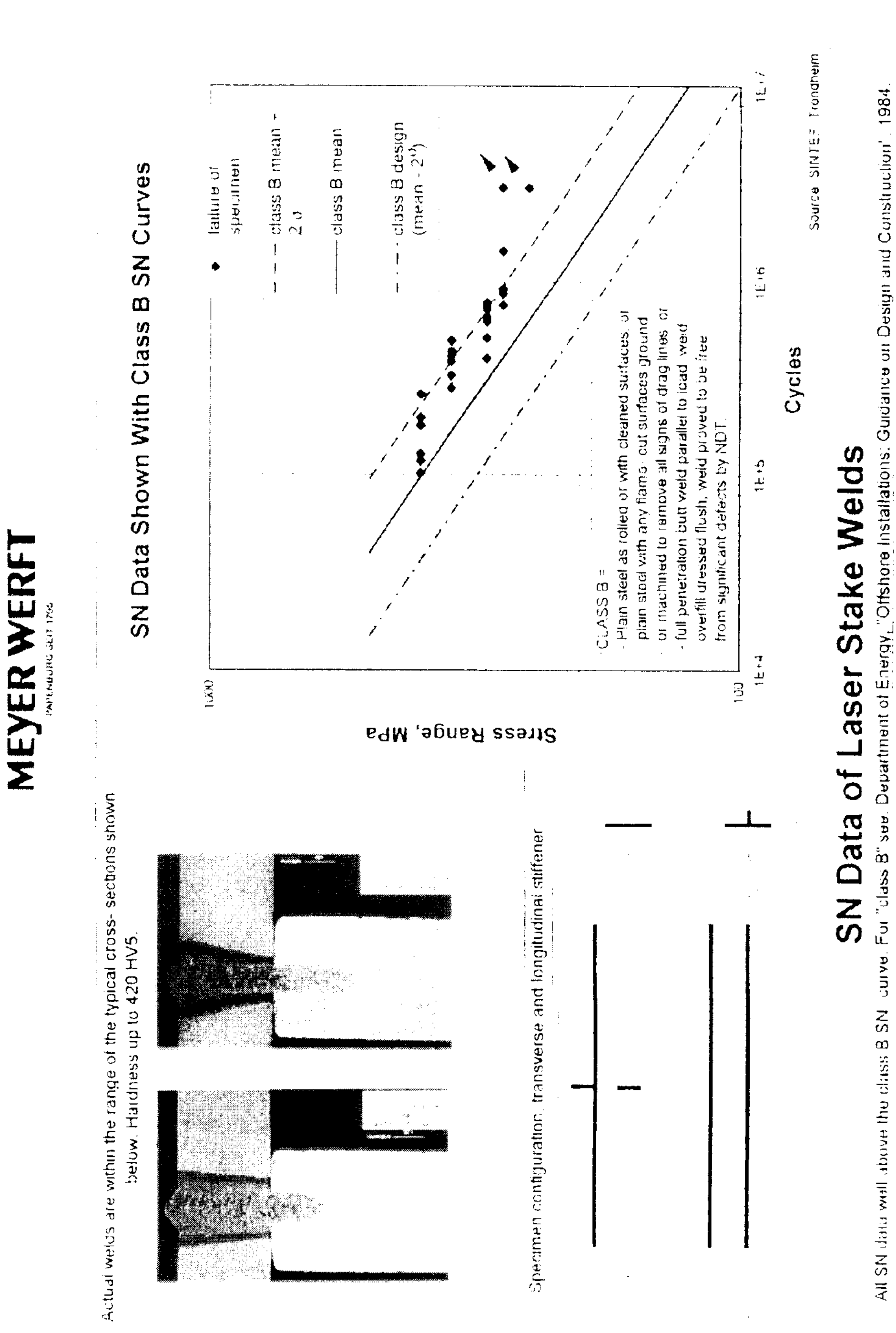

Figure 6: SN Data of laser stake welds

Intersections between laser welded sandwich panels and conventional ship structures are a critical issue especially in the upper decks of passenger ships, where longitudinal stress levels can easily reach 120 MPa and more. Consequently, the fatigue strength of these intersections are also investigated. Although the tests are not yet completed, preliminary results show, that the conventional welds used so far on the sandwich panels for connecting them with other panels or with conventional structures behave well within the known limits[4,5] of conventional welds.

Preliminary vibration tests have underscored results from fatigue tests. It has been shown that the general failure mechanisms are not due to the geometry of the laser weld or to the sandwich design but rather to high inconsistencies in stiffness. For the design of an actual component made from laser welded sandwich panels a combination of high stiffness inconsistencies and high loads will have to be avoided. Again, this does not represent any deviation of common design practice.

The strength tests are accompanied by finite element calculations in order to create a base from which other design solutions and load cases can be judged without the need of further testing.

4.2 Fire Testing

For the application of sandwich elements as fire divisions (e.g. decks, bulkheads) a number of fire tests have been executed according to IMO resolution 754(18). The insulation for the various fire classes was chosen according to the needs of conventional structures. As it turned out, in many cases this insulation is overdimensioned.

Heat transfer FEM calculations done by fire protection experts on behalf of Meyer Werft have shown that insulation thickness might be reduced while still meeting the necessary requirements. Accordingly, the heat transfer properties of laser welded sandwich panels tend to be better than those of similare conventional panels.

Finite element calculations also indicated, that the load bearing performance of the sandwich panels under fire conditions remains much higher than that of conventional structures and that no sudden collapse occures under reasonable loads.

4.3 Corrosion Testing

Since the outside of the sandwich panels can be considered not to be different from conventional steel, the emphasis of corrosion tests was on the interior of the panels.

The tests included 1,000h salt spray tests, 1.000h cyclic condensation tests and 1.000h at a relative humidity of 90% at 23°C. The specimen were prepared to represent different assembly conditions (i.e. with the interior welded close, welded close with drain holes, open) and various methods of internal corrosion protection (i.e. none, wax, primer, foam etc.).

The results showed, that the "welding close" of the internal voids will give sufficient corrosion protection even under rather harsh environmental conditions. For comparison with current practice it should be noted that hollow components in passenger ships, like pillars as well as in structural steel engineering are normally not internally coated with corrosion protection, but merely welded close as well. For extremely harsh environments the proper internal application especially of foam should do away with corrosion problems for a long time. Foam might also be used to increase local stiffness where very thin covering sheets are used and to improve heat insulation properties.

5 Steel Assembly and Outfitting

Along with improved operational behaviour sandwich panels also offer a number of advantages in subsequent assembly and outfitting, which again allows the shipyard to reduce manufacturing cost.

The eveness and accuracy of laser welded sandwich panels reduces the necessity of straightening and adjustment operations, which can easily reach an amount of up to 30% of total manhour in the steel shop when thin material is arc welded. The application of plaster which is used to eliminate buckles in conventional steel decks of passenger ships can also be reduced or even eliminated.

The absence of external stiffeners makes automation of subsequent welding operations (welding of girders to deck plating), as well as insulation work and the installation of tubes and cables considerably easier. Besides, transverse girders in the ship have a less complicated shape due to the lack of bulb profile intersections.

In most cases, the covering sheets of sandwich panels will be much thinner than the material ordinarily used for conventional design. This could lead to problems in subsequent welding as well as to local failure of the sandwich structure. Therefore, a number of solutions have been developed to join sandwich panels to each other and to conventional structures (see e.g. figure 7). Some of the intersections consist of special connection profiles which form a tongue-and-groove-type joint that can also adjust for tolerances.

Since flame cutting of sandwich elements is difficult, new tools for making post-assembly shipside alternations have been found. A modular design of pipe and cable intersections makes prefabrication under workshop conditions possible, thus reducing the amount of shipside assembly work.

The reduced weight along with the smaller thickness of sandwich structures as compared to conventional design with bulb profiles are significant advantages both for the shipyard and customers.

Different requirements towards assembly made it necessary to find special assembly techniques for structural steel engineering. Those techniques replace welding as a joining technique by mechanical joining, thus making an extremely quick and easy assembly possible. A modular system of design solutions for structural steel is being developed.

6. Conclusion and Prospects

Approximately 3.000 m^2 of laser welded sandwich panels are used as minor components, such as staircase landings, wing bulkheads and non-structural walls in passenger ships (figure 8). Some 4.000 m^2 were used for testing and prototype applications outside the shipbuilding industry.

Meyer Werft has now the approval by classification societies and customers to use a considerable amount of the panels as passenger decks in one of the next ships. Step by step the use of laser welded components will be increased. Applications outside Meyer Werft, such as deck houses, ro-ro decks, as well as bridges and any kind of buildings are currently being discussed.

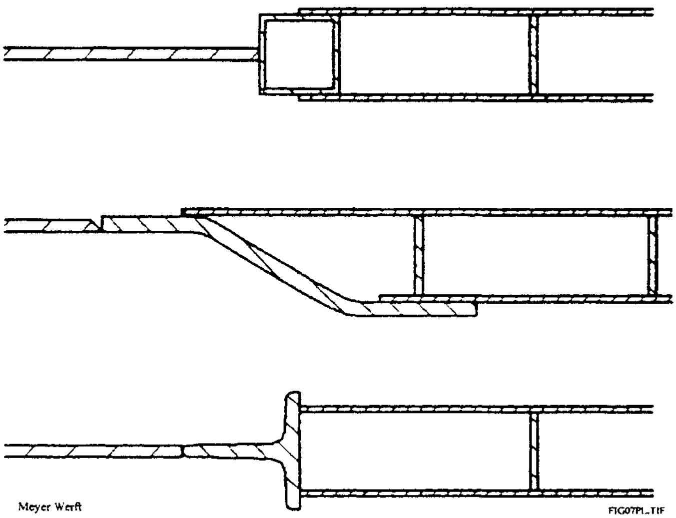

Figure 7: Some possible intersections of sandwich panels with conventional structure

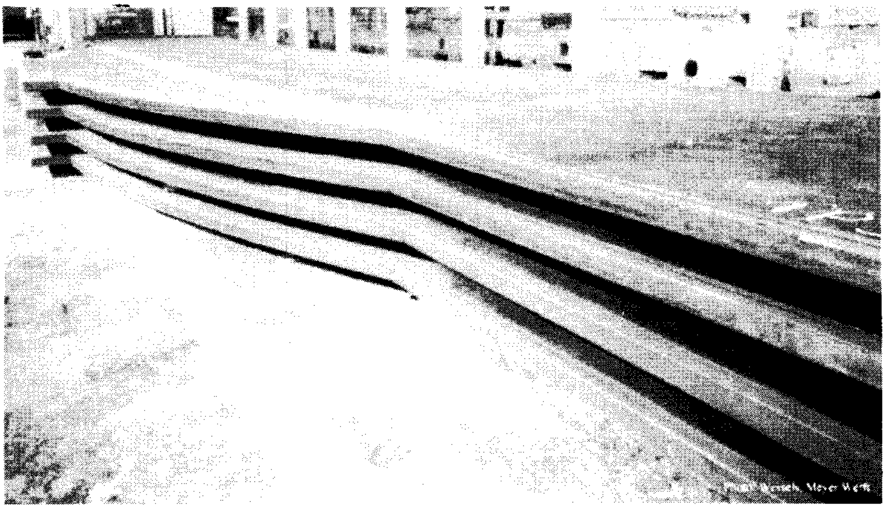

Figure 8a: Actual applications of laser welded sandwich panels as staircase landings

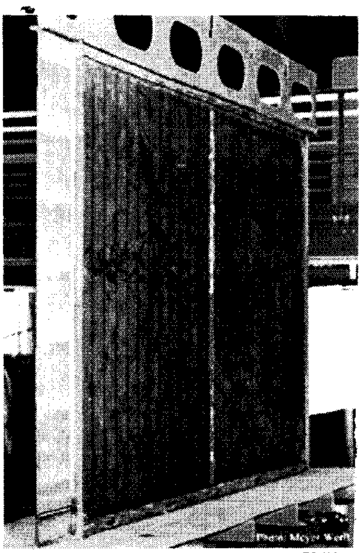

Figure 8b: Actual applications of laser welded sandwich pan 'ls as wing bulkheads

In long term, the high investment cost of a laser installation in line with a sufficient material handling system can not be justified, if the application of sandwich panels is limited to only one shipyard, even if the demand for a big passenger ship is estimated to reach up to 40.000 m^2 in the future. Meyer Werft is therefore trying to increasingly coo-perate with external partners in manufacturing, application and marketing of laser welded sandwich panels.

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