Laser welded joints in shipbuilding

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Abstract

The development of high power laser technology has enabled the production of modern structures, capable of providing adequate strength for ship construction. In the paper conditions for laser welding implementation are specified, several joints applied in construction of ship hulls are presented and problems of new technologies application are discussed.

1 Engineering and technologic innovative potential in ship building

Requirement imposed by economy, namely short ship building cycles and high rate of production demand highly efficient organization of labour and new ship building technologies.

Shipyards of Central Europe are still in the period of transition from production plants to assembly shops. In such shipyards the jobs cover production of most hull sections and their assembly on prefabrication, building slip or in the dock.

Productivity in section prefabrication, joints, planes and spatial sections depends on jobs requiring high temperature (cutting, welding) which cause significant distortions. To reduce the distortions oxy-acetylene cutting is replaced, to a large extend, by highly efficient underwater plasma cutting which decreases the amount of heat supplied to the welded material.

Regaining appropriate geometric form and dimensional accuracy of distorted welded structures is time consuming, it amounts approximately to 20-25 % of total hull labour consumption. Implementation of building methods in limited tolerances can improve the accuracy of construction, but does not prevent welding distortions.

Welding jobs amount to 30 % of total hull labour consumption. Significant increase of welding jobs efficiency by improving known and widely applied methods seems to be impossible. Higher welding efficiency can be achieved by laser welding which is based on different physical phenomena. This welding method can result in great improvement in the accuracy of welded structures and also to significant decrease of labour consumption.

2 Laser welding mechanism

In industry lasers using carbon dioxide are widely applied, they operate within the range of infrared radiation at wave length of 10.6 μm. They produce sufficient power for cutting, welding and heat treatment of metal elements.

To enable laser welding, the beam of infrared radiation is focused just below the element surface on centerline of the joint. Shielding gas (helium) is supplied coaxially around vertical laser beam, and plasma control gas (also helium) is in introduced at the angle of 45^0 to the laser beam, directed towards the beam-workpiece interaction point. When the process starts most of the radiation energy is reflected. The reflection decreases slowly with the growth of metal surface temperature until it reaches vaporization point. Rapid removal of metal due to its vaporization forms small crater supported by vapour pressure. If the radiation beam is moved along the joint, hot crater melts the material in front of it and thus elements are joined as the material solidifies. As a result during a single pass a joint of appropriate height is formed, fig. 1, [5].

Properly prepared joints do not require additional filling. But in shipbuilding in some joints occur gaps caused by inaccuracy in treatment and assembly therefore laser welding with filling is applied where filler wire is cut by the laser beam, fig. 2, [2].

Laser welding is a modern technique of joining metals which is characterized by short heating time and small amount of heat supplied to the joint at high power density (10^6 W/cm^2) and narrow fusion zone. It enables welding butts of relatively thick elements during a single pass and leaves narrow heat affected zone and also results in insignificant shrinkage and low distortion. This welding methods is much faster than the traditional electric welding but its efficiency depends, to a large extent, on thickness of joined elements.

However narrow heat affected zone decreasing welding distortion has disadvantageous effects on the structure of material. Fast metal cooling after welding causes material hardening and the increased amount of martensite in the zone. Experiments proved that macrohardness in the heat affected zone in high tensile steel can be as high as 420-450 HV10. Narrow heat affected zone together with high gradient of material change results in susceptibility to brittle cracking.

Typical weld shape of butt joint is shown in fig. 3, [8].

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3 Conditions for laser welding implementation

Investigations on materials allowed to obtain first practical results regarding brittle cracking prevention. The threat of brittle cracking can be reduced by application of steel with proper chemical composition, useful for laser welding.

For a long time the limited power of laser beam has been another obstacle preventing the use of laser welding. Now, the advanced gas lasers based on carbon dioxide can produce beams power exceeding 100 kW which is sufficient for welding hull sheets and welding machines appeared on the marked. Their mechanism is illustrated in fig. 4, [6].

The rate of welding and laser beam power determine the penetration of welding thus thickness of welded material, fig. 5, [1].

Present ship constructions are not adjusted to meet the demands of laser welding. There are three methods enabling the use of laser in production:

- **conventional method based on adjusting laser technique to existing structures** - thickness of construction elements remains unchanged, cross joints are welded at an angle, low efficient welding of significantly thick elements butts. Laser welding of fillet joint is shown in fig. 6, [2]. In spite of sufficient laser power its implementation causes come reservations concerning economic efficiency.

  Mahlke & Kothe [3] present an attempt to calculate economic effects of laser welding in comparizon with traditional welding methods (flux welding and welding in gas shield). The results are shown in fig. 7, 8 and 9, [3]. High cost of laser and peripheral equipment increasing with higher welding rate, fig. 8, does not a priori means that this method is less efficient. High welding rate decreases unit cost per running metre which is nearly double in case of welding in gas shield, fig. 9.
- **developing new structure appropriate for laser welding** - thin-walled structures, panels, highly efficient single butt welding, different forms of T-shaped joints, according to examples, fig 10 & 11, [2,4,7].

  The second solution is more likely to be applied.

Survey of existing solutions in light weight structures shows possibility of applying a corrugated-core sandwich panel - CCSP, fig. 10, [2,4] and fig.11, [2]. Research carried out at the Department of Marine Technology at University of Newcastle upon Tyne proved that upper plate of a ship tank (18 mm thick, bulb stiffeners 300 mm x 11 mm) can be replaced by CCSP (core 100 mm high and 13 mm thick, covering plates 8 mm thick). Other research carried out by U.S. Navy show mass saving for CCSP in comparison with traditional panel with stiffeners of the same strength at 40 %, [2].

4 Problems to be solved before industrial applying of CCSP

To use CCSP in ship constructions some problems need to be solved. They concern:

- **the possibility of joining CCSP to traditional structure** - CCSP can not be applied everywhere, e.g. in places exposed to mechanic point action (e.g. inner bottom which is struck by cargo handling devices);
- **static strength** - typical core failure is shown in fig. 12, [9];
- **counteracting brittle cracking** - due to high temperature gradient at welding the joint gets hardened;
- **notch forming and susceptibility to fatigue** - narrow weld resulting from welding acts as a notch;
- **anticorrosion protection of structure** - difficult in case of traditional method due to small parts (e.g. the height of corrugated core is 100 mm) inaccessible to cleaning and spraying devices;
- **inspection of sealed parts** - according to IMO regulations all construction elements should be accessible to classification society inspectors, which in case of CCSP is impossible.

At present there are no regulations allowing to evaluate in an explicit way the behaviour of laser welded constructions under exploitation. Also there are no principles allowing to choose the best structure. This situation can be changed as a result of research work which should be sponsored by governmental institutions (Research Committee) and ship building industry.

5 Prospects for new technologies in ship building

Fig. 13 illustrates the degree of applying lasers in Germany sold by German manufacturers in 1990. Lasers used for welding amount 10 % of the total production, [11]. As application of the laser technics in metal industry increases in non-linear way, up till now the situation has changed dramatically.

Laser technology can also be widely applied in ship building. New laser welded panel structures can be used as walls and decks of superstructures, inner walls and tank bulkheads, helicopter landing ground as well as parts of hull as shown in fig. 14 which illustrates module of high strength warship (a ship-weapon module), [10].

6 Conclusions

Highly efficient laser welding enables wide application of sandwich panel constructions. Several problems require computer and laboratory investigations to confirm strength and exploitation properties of new structures.

Application of the presented solutions can enable automation of ship building processes which until now have required a great number of simple job performed manually.

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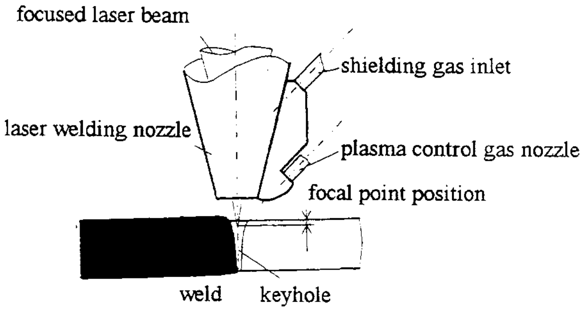

Figure 1. The laser welding of a butt joint, [5].

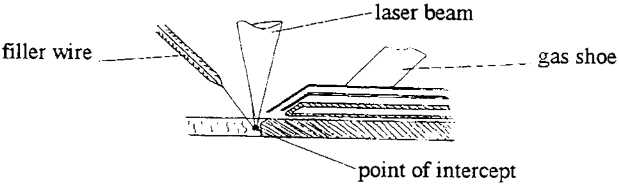

Figure 2. The intercept laser welding method, [2].

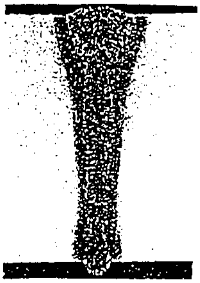

Figure 3. Typical weld shape of a butt joint, [8].

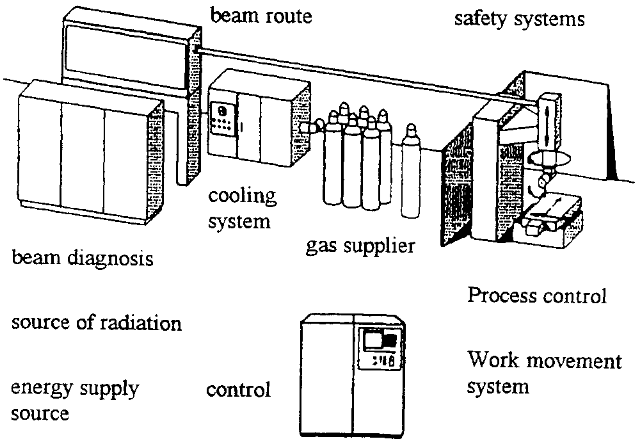

Figure 4. Outline of the laser treatment stand, [6].

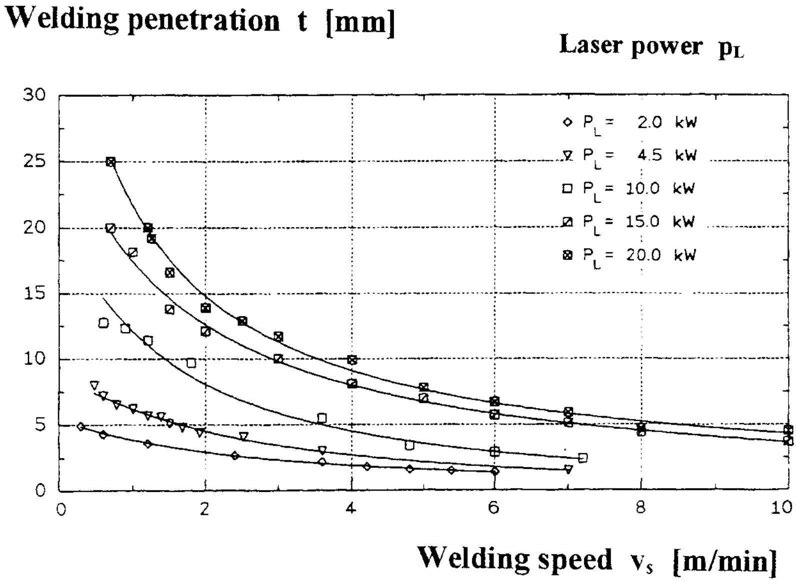

Figure 5. Welding speed versus plate thickness, normal tensile steel, [1].

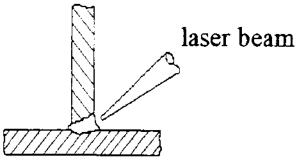

Figure 6. Laser-welding of fillet joint, [2].

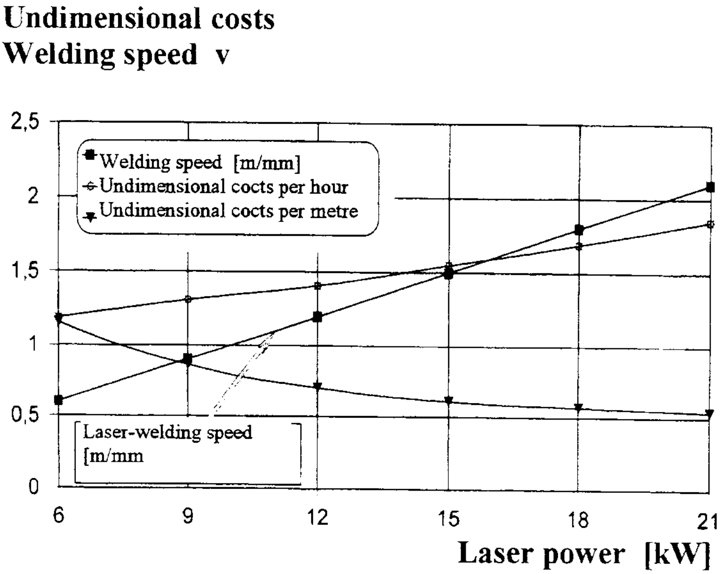

Figure 7. Comparizon of the laser welding and flux welding; butt welding, plate thickness of 12 mm, normal tensile steel, comparizon base: the cost of flux welding at v=0.6 m/min (for one work hour and one running metre), [3].

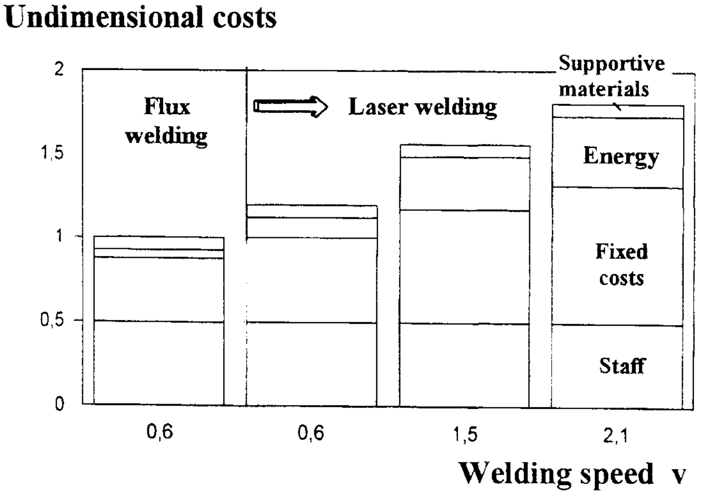

Figure 8. Cost comparizon of various welding methods; butt welding, plate thickness of 12 mm, normal tensile steel, comparizon base: the cost of flux welding at v=0.6 m/min, [3].

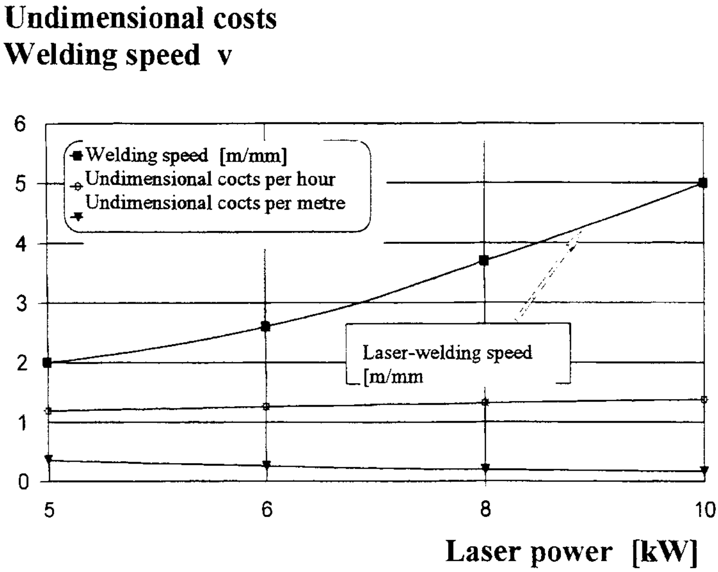

Figure 9. Comparizon of the laser welding and MAG welding; fillet welding, thickness of the welded element of 8 mm on the plate of 12 mm thick, normal tensile steel, comparizon base: the cost of MAG welding at v=0.6 m/min (for one work hour and one running metre), [3].

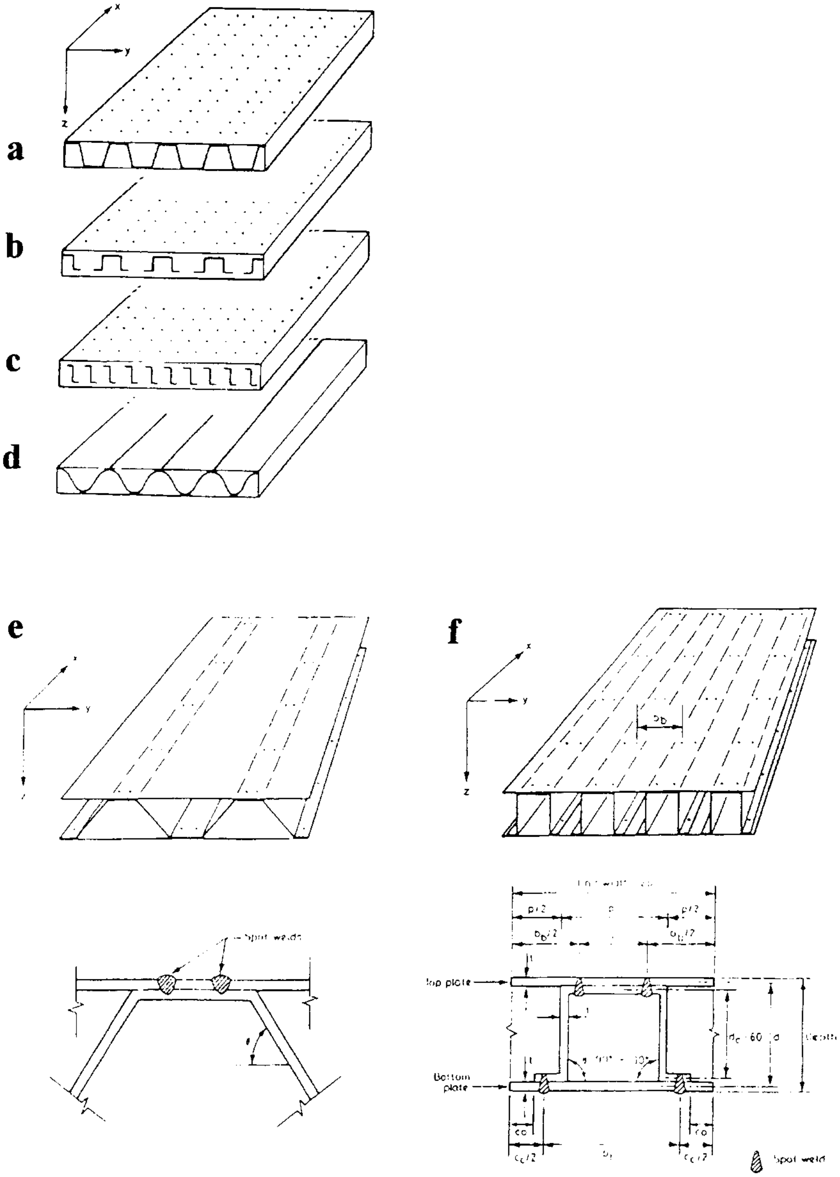

Figure 10. Examples of corrugated-core steel sandwich panels - a, b, c, d and details of welding - e, f, [4,7].

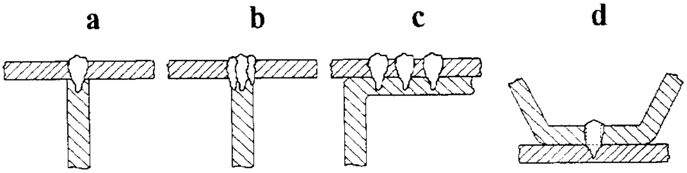

Figure 11. Details of laser-welded joints, [2].

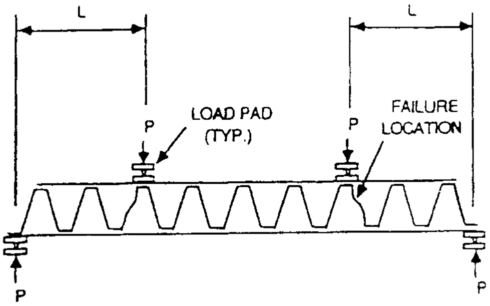

Figure 12. Typical core failure on four point bending tests, [9].

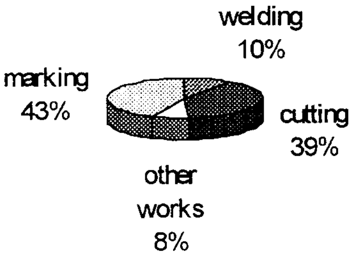

Figure 13. CO_2 and YAG laser systems for treatment of metals, [11].

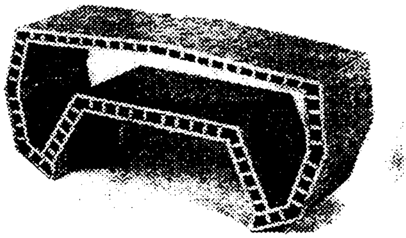

Figure 14. Laser-welded integral ship-weapon module, [10].

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References

1. Hendricks, M. Qualitätsuntersuchungen an Laserstrahlschweißverbindung un-, niedrig-, und hochlegierter Stähle, *Diss. RWTH*, Aachen, 1991.

2. Kattan, M.R. Steel sandwich construction for ships - a reality ?, *Proceedings of the 3rd International Sandwich Conference*, Southampton, 1995.

3. Mahlke, B. & Kothe, K. Perspektiven in der Umsetzung des Laserstrahlschweißens in der Schiffbaulichen Fertigung, *Vortrag am 15.11.1995 in Laserzentrum*, Düsseldorf, 1995.

4. Norris, C., Montaque, P. & Tan, K.H. All-steel structural panels to carry lateral load: experimental and theoretical behaviour, *The Structural Engineer*, Vol. 67, No 9/2, May 1989, pp. 167-176.

5. Partanen, T., Salminen, A., Lihavainen, V.M & Niemi, E. Experimental and Theoretical Studies on Fatigue Strength of Laser-welded Butt Joints, *IIW Doc. XIII-1534-94/XV-861-94.*

6. Seyffarth, P. & Hoffmann, J. Wirtschaftlichkeitsaspekte zum Hochleistungslasereinsatz, *Vortrag auf der Internationalen Tagung des DVS-Landesverbandes Mecklenburg-Vorpommern*, Rostock, Juni 1995, unveröffentlicht.

7. Tan, K.H., Montaque, P. & Norris C. Steel sandwich panels: finite element, closed solution, and experimental comparisons, on a 6m x 2.1m panel, *The Structural Engineer*, Vol. 67, No 9/2, May 1989, pp. 159-166.

8. Weichel, F. & Petershagen, H. Fatigue strength of laserwelded structural steels with thicknesses between 8 and 20 mm, *IIW-Doc. XIII-1590-95.*

9. Wiernicki, C.J., Liem, F., Woods, G.D. & Furio, A.J. Structural Analysis Methods for Lightweight Metallic Corrugated-core Sandwich Panels Subjected to Blast Loads, *Naval Engineers Journal*, May 1991, pp. 192-203.

10. Yagla, J.J., Haag, R.S., & Scott, M.E. Laser Welding Analysis and Experiments, *Journal of Ship Production*, Vol. 11, No 2, May 1995, pp 102-110.

11. NN: Gegenwind Laser, *Europäischer Lasermarkt*, Jan 1992, s.14 - 15.