Investigations

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Laser + MAG Hybrid Welding of Various Joints

Abstract: The article presents the possibilities of hybrid welding (laser + MAG arc), particularly as regards the welding of butt joints. The article discusses technological conditions and equipment configurations when welding sheets having the same and different thicknesses both in PA and PC positions. In addition, the article presents exemplary welding of multipart joints (nodes of three sheets) and angle joints using the hybrid method as well as the possibilities of combining the HLAW method with other methods.

Keywords: laser welding, laser + MAG, hybrid welding, butt joints, multipart joints

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Introduction

The HLAW (Hybrid Laser Arc Welding) method is currently becoming one of the most promising methods of welding various types of metallic materials, where laser and MAG method electric arc are used in one process. The HLAW technology was first used in high-volume industrial production in the late 1990s. Over the past 15 years, the HLAW method has become increasingly popular in industrial applications and found implementations in the shipbuilding industry, power engineering, automotive industry and in the production of large-sized load-bearing structures, e.g. elements of cranes, gantry cranes, bridges, vessels etc. [1, 2]. In 2013, the first European HLAW-related standards came into existence. The above-named standards enable assessing the quality of hybrid-welded joints [3] and make it possible to qualify the HLAW process [4, 5].

The development of the hybrid technology is based on the development of the design and the increasing availability of modern medium and high-power, initially CO_2 and next disc and fibre, lasers [6-8]. Research on the HLAW method has been intensively performed at various research institutions and at R&D centres of global companies manufacturing welding equipment and making welded structures [9–15].

Presently, the HLAW method is used in the joining of various steel grades, e.g. toughened ship steels having high yield points (S690QL, S960QL etc.), TMCP (thermo-mechanical control process) steels (S700MC etc.), power engineering steels, structural steels (e.g. S235 and S355) etc. The above-named hybrid method is used when welding joints having thicknesses restricted within the range of several to between ten and twenty millimetres, both in small and large-sized structures [16-24].

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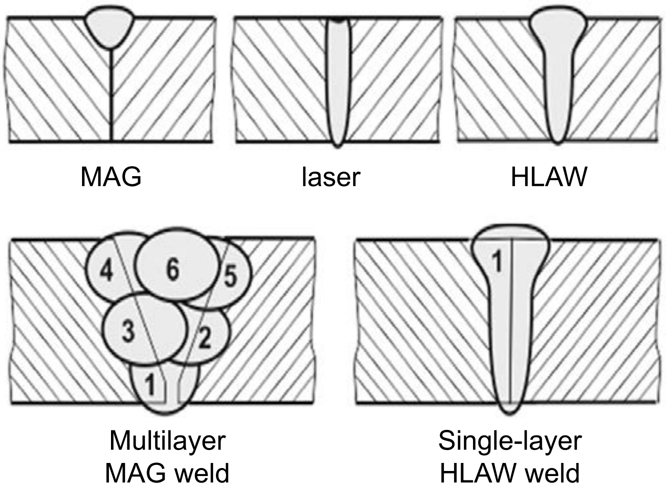

Fig. 1. Shape and geometry of welds obtained using MAG welding, laser welding and hybrid welding (HLAW)

In industrial applications, the HLAW method is usually used when welding butt joints in their simplest "classical" variant i.e. when welding involves the single-run melting of the unbevelled interface of sheets having the same thickness, where the laser beam and the MAG welding torch are in the same plane and the process of welding is performed in the flat position with the free formation of the weld root. In the above-named variant, in comparison with laser or MAG welding, the primary HLAW method advantages are easily demonstrated and include higher welding rates, the possibility of welding with a specific interface gap (not acceptable when welding is based on laser alone) as well as the possibility of replacing multi-run welds with an optimally-shaped single-run weld (Fig. 1).

In addition to the single-run melting of the interface, the HLAW method can also be used in the welding of other joints present in contemporary structures, e.g. T-joints, overlap joints or nodes of several sheets/plates. In each of the above-presented cases, in comparison with laser or MAG welding, the HLAW method provides additional possibilities of shaping weld geometry, optimising the structure and quality of a joint and increasing process efficiency.

Based on research performed at Instytut Spawalnictwa, this article presents the possibilities and exemplary applications of the HLAW method in the welding of various types of joints requiring various edge preparation and sheet matching manners.

Butt Joints Made Using the HLAW Method in Various Types of Structures

Because of the ease of preparation and hybrid method-based welding, butt joints with square preparation made of sheets having the same thickness are both the simplest and the optimum type of joints. Today, they are usually used in structures welded using the HLAW method. Exemplary structures containing the above-named joints are presented in Figures 2-5.

Fig. 2. HLA-welded segments of crane telescope pipe extension arm [25]

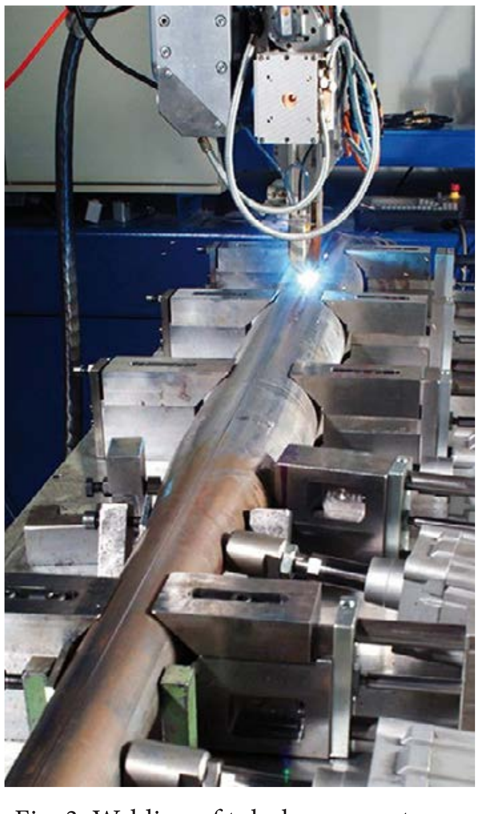

Fig. 3. Welding of tubular support performed using the HLAW method [26]

Fig. 4. Hybrid welding of ship plating panels, butt joints and the welding of stiffening elements. Laser CO_2 12 kW. Meyer Werf Shipyard, Germany [22]

Fig. 5. Hybrid welding of carriage elements; high strength steel; CO_2 laser having a power of 20 kW [19]

Butt Welding Technological Conditions

From the technological point of view, in comparison with MAG or single-spot laser beam welding, the HLAW method is more complicated as it entails the necessity of selecting and correlating many process parameters (Fig. 6), each of which significantly affects the quality, shape and operating properties of joints.

During the welding of the butt joints made of sheets having the same thickness, the proper formation of a joint can be obtained by the positioning of the laser beam and the MAG welding torch in one plane (Fig. 7a, b), i.e. using hybrid heads of the simplest design. Depending on the thickness of a joint, an acceptable gap in the interface and the type of materials being welded, the obtainment of proper joints requires the selection and precise adjustment of, among other things, a proper optical fibre diameter, laser focus diameter and position (Fig. 7c), welding rate, arc power, laser beam power and the type of shielding gas.

The macrostructures of exemplary butt joints with square preparation made using the HLAW method are presented in Figure 8.

When making large-sized structures, the appropriate square preparation of the interface of sheets with the perpendicular surfaces of sheet edges is not always possible or requires the use of precise press brakes having high

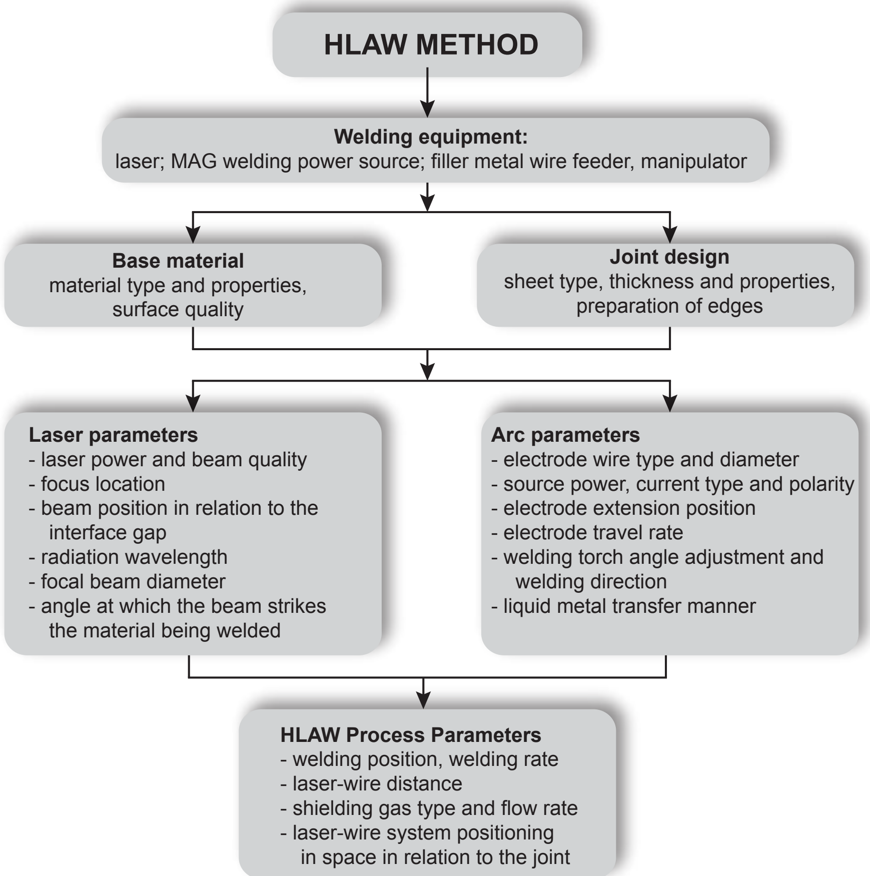

Fig. 6. Adjustment of hybrid welding technological conditions

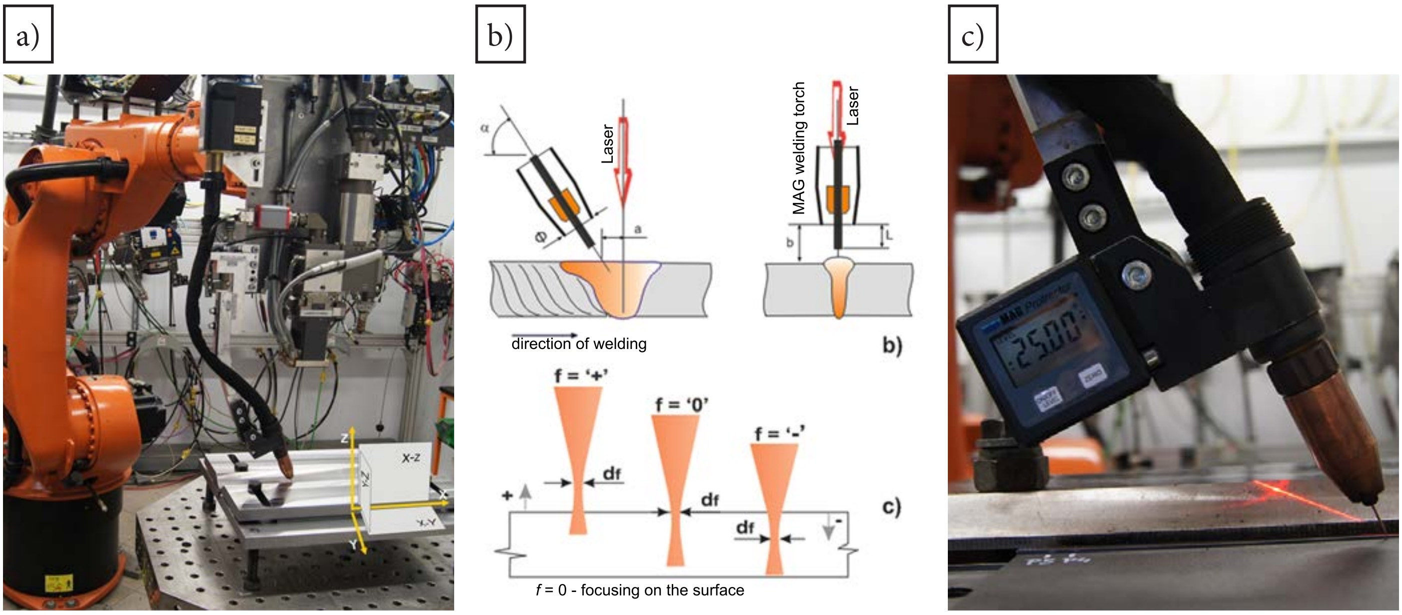

Fig. 7. Primary technological conditions in hybrid welding: a, b) positioning of the hybrid head in the space, the laser beam perpendicular to the material, the MAG welding torch and the beam in one plane (X-Z); c) possible variants of a laser beam focus position in relation to the sheet surface; d) MAG welding torch inclination angle; (a- distance electrode terminal end – laser beam, Φ – nozzle diameter; Lw- electrode extension, b – distance between the nozzle and the sheet surface, df- beam diameter in the focus, α- MAG welding torch inclination angle)

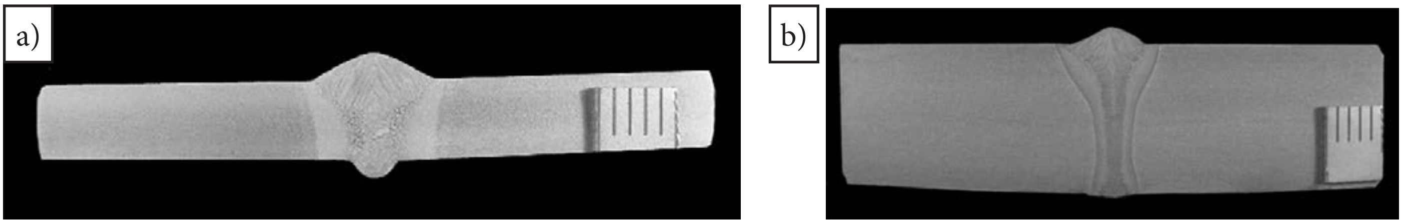

Fig. 8. Macrostructures of HLAW butt joints: a) material – steel S960QL, joint thickness - 5 mm, b) material – steel S960QL, joint thickness - 12 mm,

pressure force or the additional machine cutting-based preparation of edges. The interface of sheet edges may contain a gap having diverse geometry, e.g. similar to a v-bevelled weld groove (Fig. 9a, b). In such cases, the use of welding based on laser alone becomes impossible, whereas the use of the hybrid method enables the obtainment of proper joints (Fig. 9c). When welding the interface prepared in the above-named manner, the laser and the beam can be positioned in one plane, yet it is necessary to more precisely adjust process parameters (e.g. laser focus position, welding rate, filler and metal feeding rate) than when welding a typical butt joint with square preparation and without a gap.

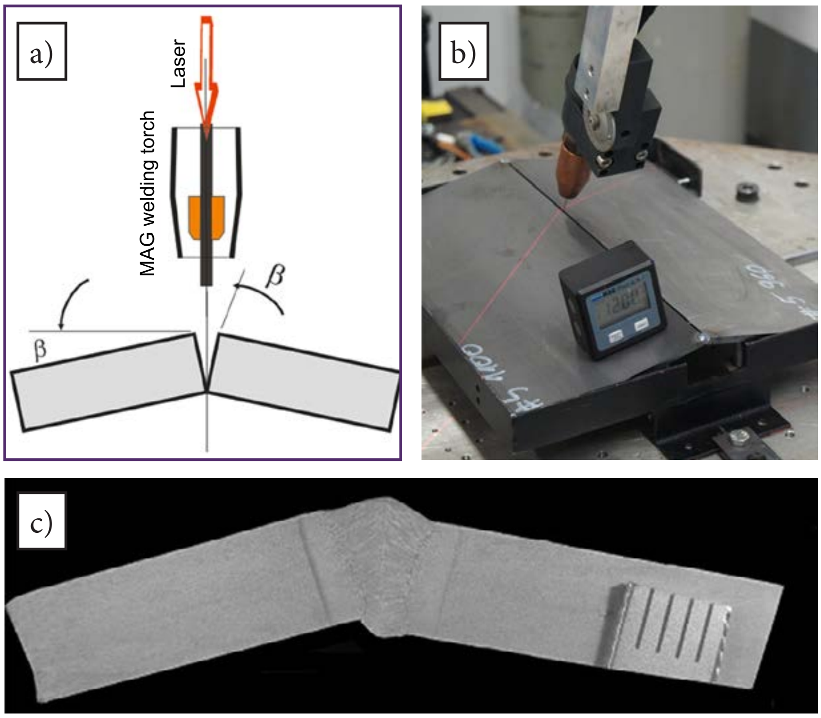

Fig. 9. Hybrid welding of joints having a thickness of 5+5 mm at the angle of sheet inclination β=12o: a) mutual positioning of the laser beam and of the torch, b) sheets fixed in the equipment, c) joint macrostructure

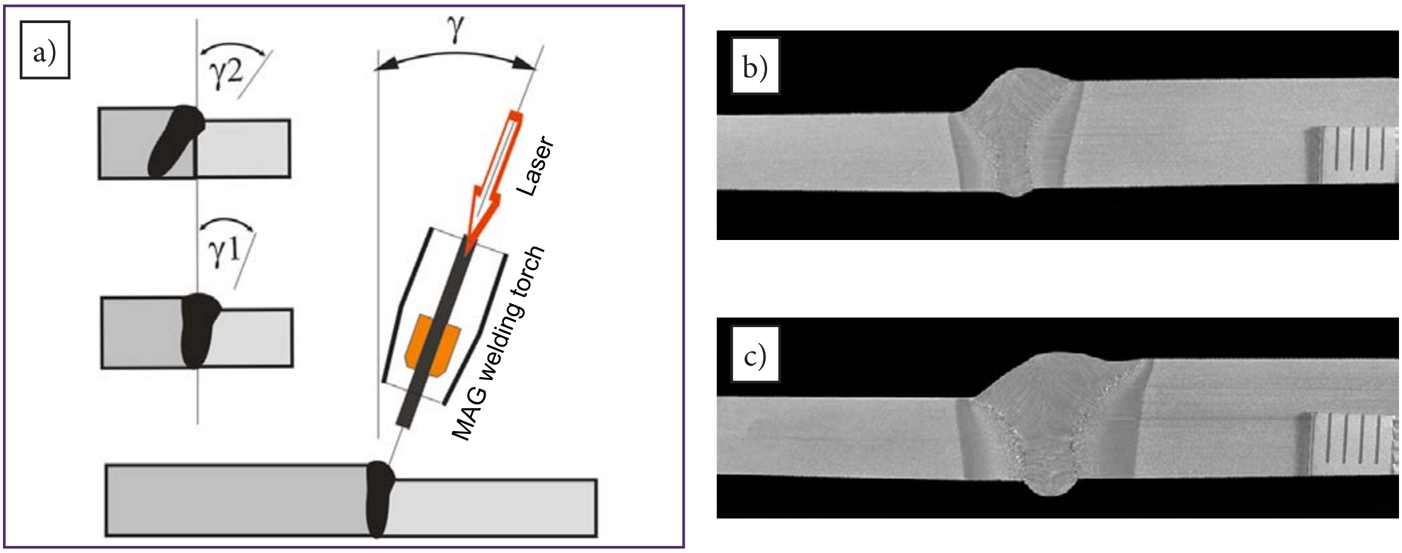

Fig. 10. HLA welding of butt joints of sheets having various thicknesses: a) adjustment of various laser beam inclination angles γ and of the MAG welding torch in relation to the joint as well as the effect of the head inclination angle on the shape of the butt weld in the joint, b) macrostructure of the joint welded in the flat position – steel S960QL, joint thickness – 5 +7 mm; c) macrostructure of the joint welded in the horizontal position – steel S960QL, joint thickness – 5 +7 mm

Welding of Butt Joints Made of Sheets Having Various Thicknesses

In many types of structures, because of the reduction of weight, the necessity of ensuring required strength as well as due to the optimisation of the distribution of stresses and strains, it is necessary to join sheets/plates having various thicknesses. The hybrid method allows making such joints. The appropriate adjustment of process parameters, the mutual positioning of the laser and the electrode wire as well as the appropriate positioning of these heat sources in relation to the interface plane enables the obtainment of proper quality joints. The positioning of the laser beam and that of the welding torch as well as exemplary joints are presented in Figure 10. In addition to technological parameters, it is necessary to adjust (depending on sheet thicknesses) laser beam inclination angle γ in relation to the plane of the sheet interface (Fig. 10a). Sheets having the same or various thicknesses can be welded both in the flat and horizontal position (Fig. 11). Welding performed in the horizontal position requires the correlation of welding parameters and the arrangement (in the space) of both welding power sources in relation to the sheet interface plane. The adjustment of the above-named parameters should take into consideration the position of the thicker sheet in relation to the thinner one (above or below).

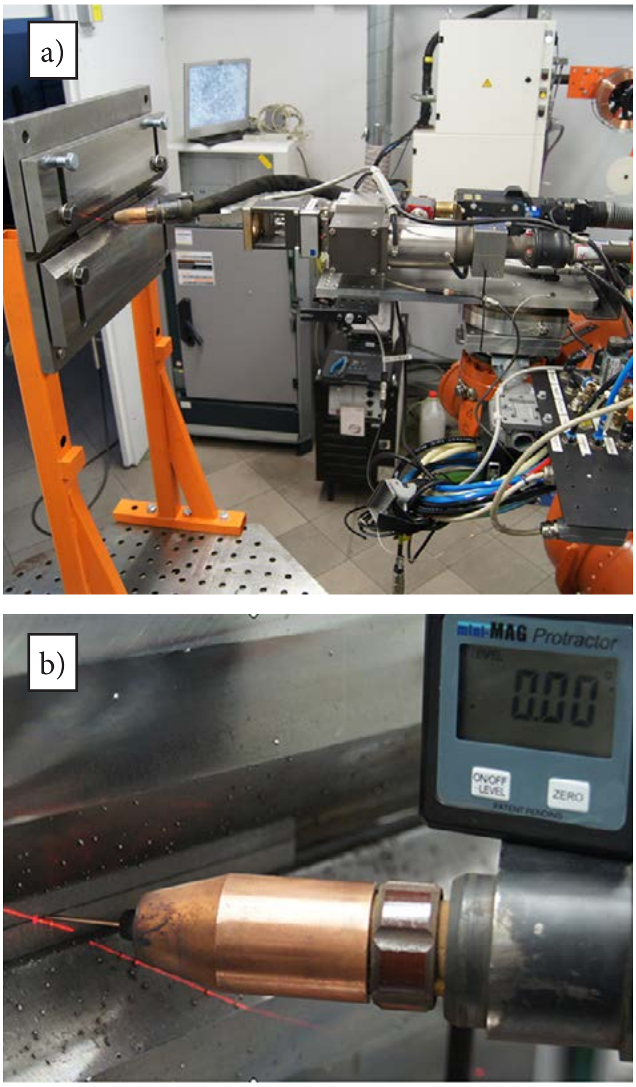

Fig. 11. Welding of butt joints in the horizontal position: a) HLAW station at Instytut Spawalnictwa, specimens in the horizontal position; b) positioning of the beam and MAG welding torch in relation to the interface of the sheets being welded

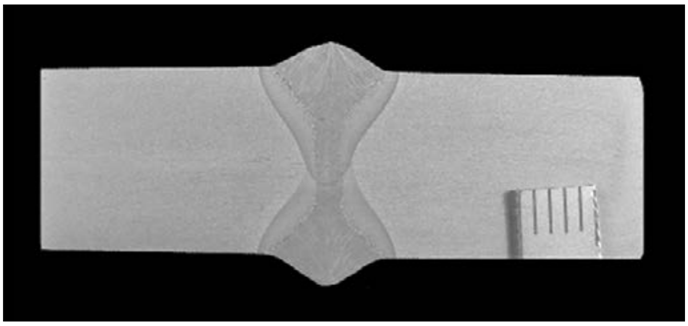

Fig. 12 Macrostructure of the HLAW two-side welded joint; base material: steel S960QL, joint thickness: 12 mm

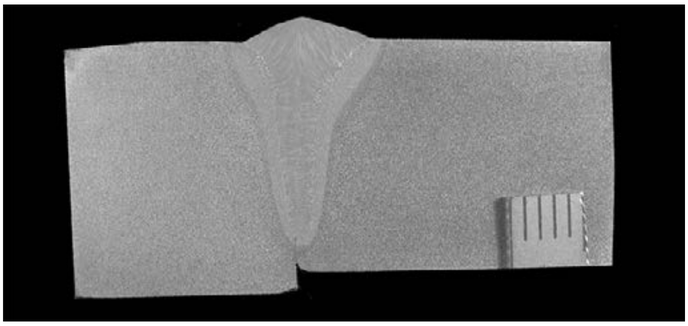

Fig. 14 Macrostructure of the hybrid-welded joint; base material: steel Hartplast, joint thickness: 18 mm

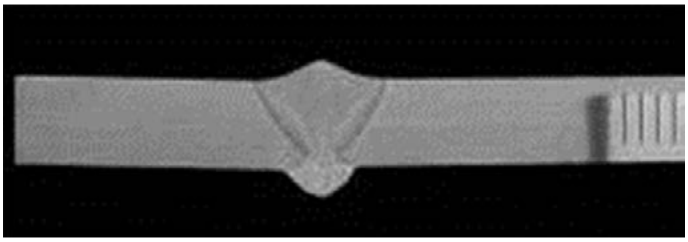

Fig. 13 Macrostructure of the hybrid-welded joint with the MAG pre-welding of the weld root; base material: steel S960QL, joint thickness: 5 mm

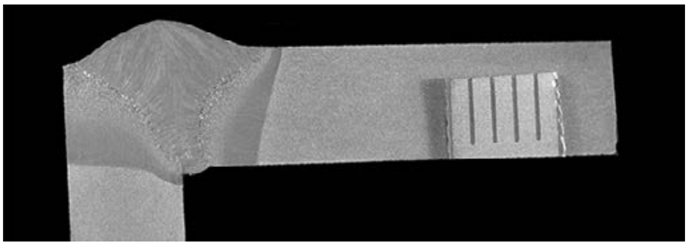

Fig. 15 Macrostructure of the hybrid-welded joint; base material: steel S960QL, joint thickness: 5 mm

Two-Sided Welding and Combination of Two Welding Methods

The thickness of elements to be joined using a single-run weld depends primarily on the power of a laser used in the HLAW process. The power of disc and fibre lasers, most commonly used in the hybrid method today, is restricted within the range of 4 to 12 kW. The prices of these lasers increase in proportion to the power of emitted beams. At the same time, the market offer includes relatively cheap low-power lasers of older generations (lamp and diode, YAG or CO_2 lasers). The above-named devices can be used successfully in the single-run HLA welding of thin sheets or when making two-sided welds (Fig. 12). Due to longer process times, such a welding manner is not equally efficient as single-run welding with the partial penetration of the interface. One of the advantages of the HLAW method used in the above-presented manner is the greater control both of welding stresses and strains as well as of the thermal process cycle (lower overheating of structure materials). For this reason, two-sided welding can be used in cases requiring the precise control of welding thermal cycles.

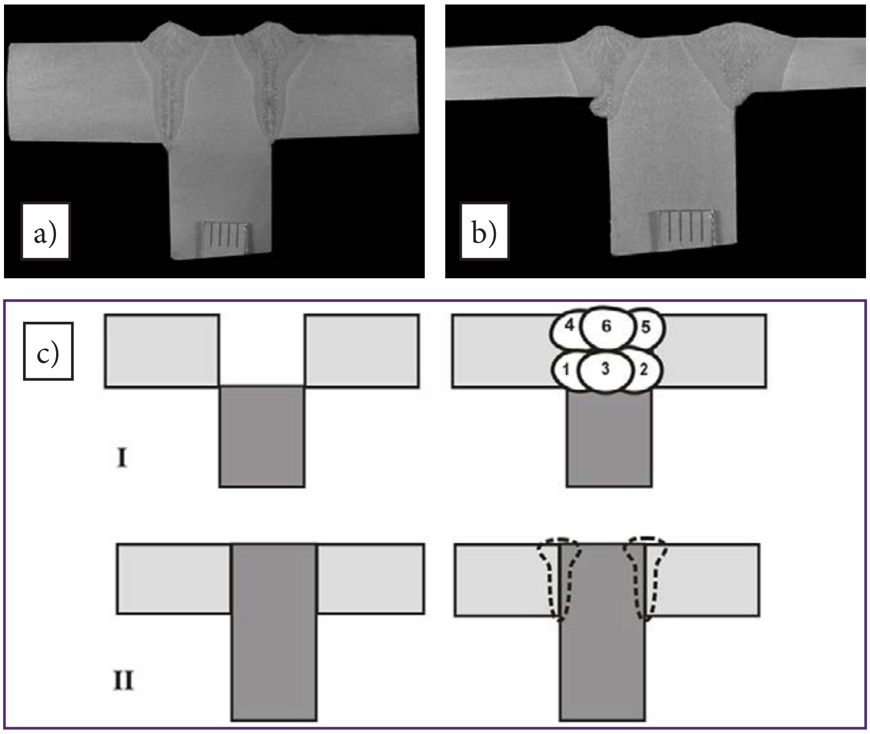

Fig. 16. HLAW used when making a node of three sheets:
a) joint macrostructure; material: steel S960QL, joint thickness: 12+12 mm,
b) joint macrostructure; material: steel S960QL, joint thickness: 5+12 mm,
c) difference between MAG arc welding (I) and the hybrid welding of a node of three sheets (II)

In many cases, it is not only possible but also easier and cheaper to obtain welded joints by using two various welding methods, for instance, the making of a root run in a not easily accessible place (Fig. 13) or a making a weld composed of two runs made using the MAG method and the third run with deep penetration made using the HLAW method.

In many cases it is sufficient to use the HLAW method and make butt welds with incomplete penetration, yet with appropriately large (and guaranteed) excess weld metal. In such cases, large excess weld metal enables the processing (on the weld face side) (mechanical treatment, e.g. grinding) of large planes of sheets/plates joined in the above-named manner in order to ensure the appropriate tolerance of the flatness or the alignment of the entire structure. Exemplary welds are presented in Figures 14 and 15. In addition, the HLAW method can also be used when making but welds in angle or multiple joints (nodes of three sheets/plates) (Fig. 16).

When welding structures composed of thin workable sheets, it is possible to use the HLAW method for making frequently used joints of sheets with deflected edges (Fig. 17), e.g. joints on deflected strips.

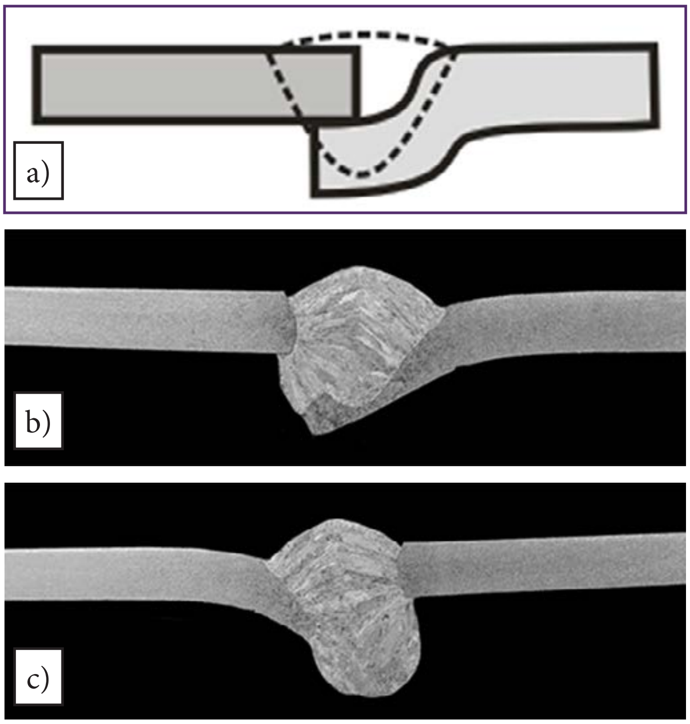

Fig. 17. Examples of HLAW joints on a deflected strip: a) preparation and setting up of sheets to be welded b), c) macrostructures of the joints: material – steel P235GH, sheet thickness - 4 mm

Summary and Concluding Remarks

1. Over the past 15 years, as a result of the development and availability of modern lasers and because of research concerning the fundamentals of the process and technology, the HLAW method has become increasingly popular in industrial applications and found implementations in the shipbuilding industry, power engineering and in the production of large-sized load-bearing structures, e.g. elements of cranes, gantry cranes, bridges, vessels etc.

2. The industrial acceptance of the above-named method results from the fact that, in comparison with MAG or single-spot laser welding, the HLAW method provided significantly more extensive possibilities as regards the control of welding thermal cycles, the shaping of weld geometry and the formation of a weld shape as well as the simplification and the reduction of interface preparation tolerance.

3. The HLAW method can be used when welding various types of butt welds in various configurations of sheet edge contact preparation both in the flat and horizontal position and can be combined with other welding methods. In each of the above-named cases, HLAW provides additional process efficiency and reduces the consumption of filler metals.

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