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Hybrid laser + electric arc welding. Development and possibilities (Part I)

Abstract: The article briefly presents the history of hybrid laser welding (laser + arc), describes the advantages of the latest laser sources used in welding engineering, presents technological heads for hybrid laser arc welding (HLAW) and demonstrates the advantages of hybrid welding if compared with laser welding and arc welding used separately.

Keywords: hybrid laser arc welding, HLAW, laser welding, arc welding;

Introduction

Research centres and producers of various welding equipment and consumables continually work on improving metal joining technologies having in view increasing the efficiency and quality of welding processes. Presently according to DVS (Deutscher Verband für Schweissen) most research works are concerned with arc welding (Fig. 1), yet the fastest developing method is laser welding [1].

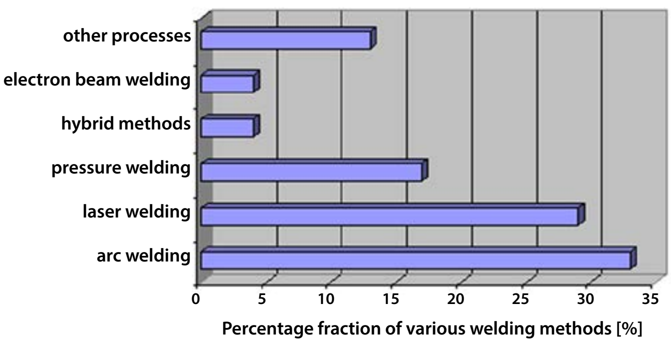

Fig. 1. Percentage fraction of research works concerning various welding technologies [1]

A concentrated laser radiation beam can be used in various welding methods. The commonly applied laser welding method is melting a non-bevelled interface of elements joined with one focalised laser radiation beam (classical method). Other popular and constantly improved laser welding variants include welding with a filler metal, welding with a scanning beam, or welding with two focuses.

One of the most promising methods used in laser welding is hybrid welding – laser + electric arc referred to as Hybrid Laser Arc Welding (HLAW). This article outlines the history and current development of hybrid welding equipment, technologies and areas of application.

Hybrid welding method

Hybrid welding consists in using two heat sources, i.e. laser welding and an electric or plasma arc in the same place and at the same time (Fig. 2a). This method, using a heat source

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combining laser radiation and an electric arc, is characterised by numerous advantages if compared with each of these processes viewed separately as their interaction is mutually advantageous. A laser beam stabilises an arc and causes it to more effectively affect a material being welded than arc welding alone.

The method of welding with a laser and an electric arc simultaneously, when both these heat sources do not work in one liquid metal pool (Fig. 2b) is not hybrid and according to ISO 15609-6 is referred to as a combined process [2].

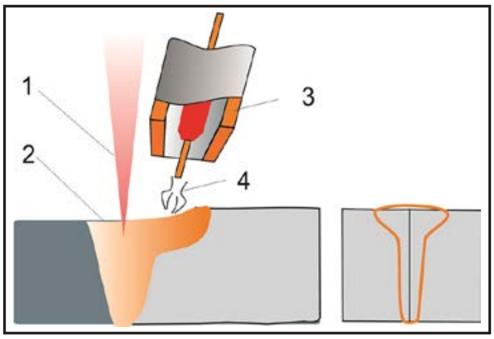

Fig. 2a. Hybrid welding process laser + electric arc
1) laser beam, 2) liquid metal pool common for both methods, 3) arc method welding torch 4) electric arc

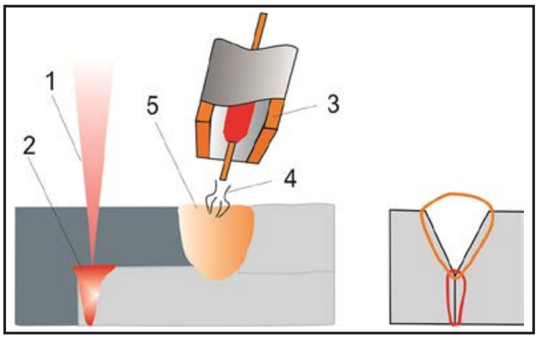

Fig. 2b. Combined process laser + electric arc
1) laser beam, 2) liquid metal pool formed by laser beam action, 3) arc method welding torch 4) electric arc, 5) liquid metal pool formed by arc action

Beginnings

Research on hybrid welding started almost at the same time as research on classical laser welding. The first mentions of the combination of two heat sources (a laser beam and an electric arc) were contained in a publication entitled *Laser will feed an arc in material processing in the magazine Journal of Applied Physics* in 1980 [3]. Initially most research works were conducted using low-power lasers and were focused on joining laser with the MIG/MAG method. Shortly afterwards researchers started to carry out tests dedicated to joining lasers with other arc sources, the TIG method (1984) and plasma arcs (1995) [3].

The early research results implied that this method could have a great potential as regards its industrial applications. During hybrid welding tests, researchers encountered numerous problems. Initial difficulties were connected with the low power and lack of focusing precision of then-available lasers. One of the researcher carrying out tests stated "In my opinion our research was greatly inconvenienced by the fact that we had a big, "clumsy" and old laser unable to properly focus a laser radiation beam" [4]. At the time small-scale industrial application of hybrid welding was caused by the risk of low or non repeatability of desired results in industrial applications due to equipment imperfections and necessity of ensuring the stability of a vast number of process variable parameters.

Initially the main interest in hybrid welding was dictated by the pursuit of increasing efficiency in military production, e.g. in welding HY-80 steel used in the production of submarines and for welding long-range steel pipelines.

In 1990, a German shipyard Meyer Werft in collaboration with the RWTH Institute from Aachen, Germany started works on using the hybrid method in shipbuilding. The result of this cooperation was starting up a new technological line in the shipyard in 1999 [5]. The line was used for joining ship board panels and bulkhead stiffeners by means of hybrid welding utilising a CO_2 laser. It was a significant step forward in the development of the hybrid method. Accepting the industrial hybrid welding technology made related classification bodies develop and adopt new standards and acceptance conditions for this method in relation to the shipbuilding industry.

Research on the hybrid technology and its implementation in shipbuilding was also carried out in the United States of America and Canada. The company of Applied Thermal

Sciences (ATS) collaborated with the US Navy in this area. The first application of the research was the use of hybrid welding for joining HSLA steel ship structural elements and for welding lightweight LASCOR stainless steel sandwich panels applied in building DDG-1000 new generation prototype submarines in the Bath Iron Works shipyard [4].

Further development and improvement of HLAW

After 2000 it was possible to observe considerable technological progress in laser design and building, which significantly contributed to the development of hybrid welding. Previous welding applications based on CO_2 lasers, Nd:YAG lamp lasers and diode lasers were extended by disc lasers and fibre lasers.

Disc lasers

Disc lasers and fibre lasers are the latest generation of solid-state lasers. They emit a radiation beam with an approximately 10 times shorter wavelength than CO_2 molecular lasers used at the initial stages of the development of the method. The disc laser radiation wavelength is 1.06 µm, and that of fibre lasers amounts to 1.07 µm. Both laser types are excited optically by means of laser diode packages. The lasers are schematically presented in Figures 3 and 4.

The active element of a disc laser is a 150÷300 µm thick disc-shaped YAG crystal with a diameter of up to approximately 12 mm. The crystal is usually ytterbium doped (Yb:YAG). A laser disc is mounted on a copper radiator taking off heat caused by the generation of a laser beam. The flow of heat generated in the crystal, due to its geometry, is unidirectional – along the optical axis of a resonator [6]. Such a solution allows much more significant loading of the laser active element (in comparison with classical Nd:YAG lasers) without risking its damage and maintaining the high quality of the generated laser beam.

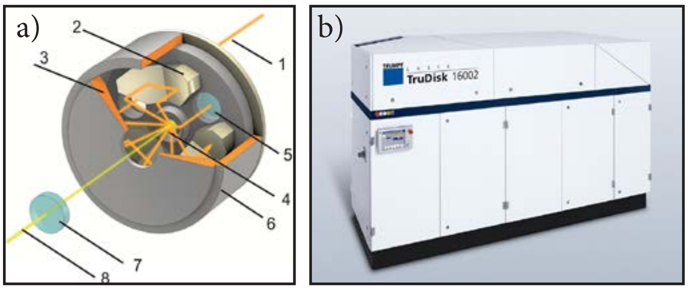

Fig. 3a. Scheme of a Yb:YAG laser with a disc-shaped active element. 1 – excitation radiation, 2 – refracting mirror, 3 – spherical mirrors,
4 – disc (Yb:YAG crystal), 5 – reflecting mirror, 6 – housing, 7 – output mirror, 8 – laser beam [6]
Fig. 3b. Trumpf-manufactured TruDisk disc laser with a power of 16 kW [6]

Fibre lasers

The designs of fibre lasers include special three-layer flexible optical fibres (Fig. 4a). Laser radiation is generated in the area of a very thin optically active core closed on one end with a reflecting mirror, and on the other with a partially-transmitting resonator output mirror. The core fibre in high-power lasers is usually doped with ytterbium (Yb) ions. The optical pumping with the light of laser diodes causes the active fibre located in the axis of a transmitting optical fibre to emit laser radiation with a wavelength of 1.07÷1.08 µm. In welding equipment

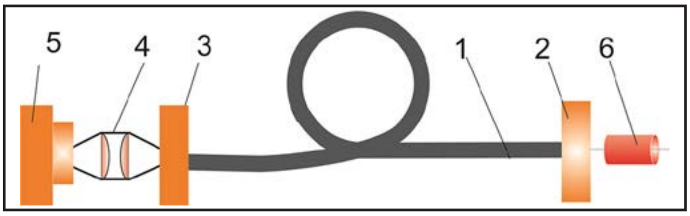

Fig. 4a. Schematic design and the principle of operation of a fibre optic laser. 1 – three-layer optical fibre, 2 – output mirror, 3 – reflecting mirror, 4 – optical system putting pumping radiation in the outer layer of a core, 5 – source of pumping light- diode laser, 6 – laser beam

Fig. 4b. IPG-manufactured YLS-10000-SM fibre optic laser with a power of 10 kW [7]

radiation is usually put in classical transmission optical fibres having a length of up to approximately 150 m and transmitted to the welding area. The power of fibre lasers depends primarily on the length of the core and the power of pumping radiation. In general, fibre lasers are made of the thinnest possible fibres but of a significant length.

The most important advantage of both these laser types over previously dominant CO_2 lasers was the possibility of the fibre optic transmission of generated laser radiation to a working head and an area being processed, a compact design and high efficiency exceeding 25% [6,8]. Using the advantages of these lasers made it possible to simplify the designs of hybrid welding stations and increase the process efficiency. It also enables the use of robotised stations for welding with the HLAW method.

Laser types and arc methods currently used in HLAW are presented in Table 1. Lasers used in the HLAW method differ mainly in the type of a resonator active element and, consequently, the wavelength of an emitted laser beam and the interaction with the material being processed. Likewise, arc methods significantly differ in arc and process parameters. Each of the combinations of both heat sources is specific and requires the precise selection of parameters and welding technological conditions.

Hybrid welding stations

A hybrid welding station can be built with standard modules used in laser welding machines such as semiautomatic MIG/MAG welding machines or standard TIG welding machines. However, it is necessary to construct an additional module enabling the precise spatial positioning of the welding torch and the laser beam. It may become necessary to modify the shielding gas jets or the "cross-jet" system of standard laser welding heads. For such a station it is also necessary to develop and adjust a control system for activating and controlling parameters of both heat sources as well as for controlling a shifting system.

Examples of laboratory stations created at Instytut Spawalnictwa and based on standard laser systems and arc method current sources are presented in Figures 5, 6 and 7.

In industrial conditions, systems for hybrid welding are designed depending on the type dimensions of the elements to be joined, joint structural solutions, weld types and production character. An example of a specialised station for welding large-size structures in the shipbuilding industry are presented in Figure 8.

Table 1. Types of lasers and arc welding methods used in hybrid welding [8]

Laser types	– molecular gas lasers (CO_2) – disc lasers (Yb:YAG) – fibre lasers (Yb:Glass) – neodymium lasers (Nd:YAG - lamp and diode) – high power diode lasers (HPDL)
Arc welding methods	– MIG/MAG method – TIG method – plasma (PTA) – submerged are (SAW)

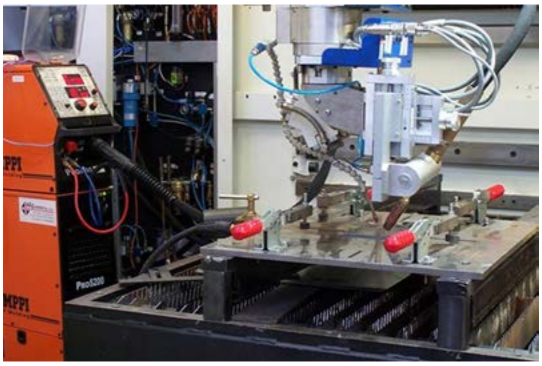

Fig. 5. Laboratory station for testing hybrid welding: Trumpf TLC 1005 CO_2 laser (3.8 kW); Kemppi Pro Evolution semiautomatic welding machine

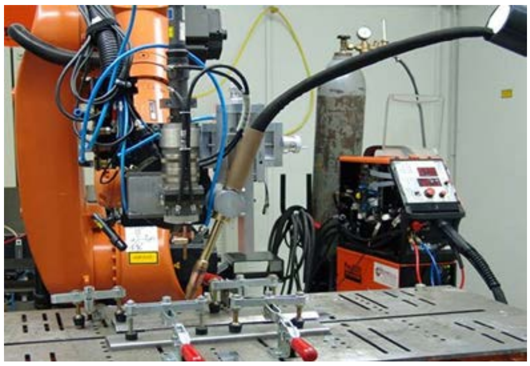

Fig. 6. Laboratory station for testing hybrid welding: Trumpf HL 2006D/LCU Nd:YAG laser (2 kW); Kemppi Pro Evolution semiautomatic welding machine

Fig. 7. Laboratory station for testing hybrid welding: Trumpf TLC 1005 CO_2 laser (3.8 kW); Esab-manufactured Aristotig 200 welding machine

Hybrid welding heads

As disc lasers and fibre lasers with the fibre optic transmission of laser radiation appeared, a number of companies developed specialist universal heads for hybrid welding. At present producers usually offer welding heads for hybrid welding laser + MIG/MAG with laser optics, an arc method welding torch (Fig. 9) and an appropriate power source already integrated. Such solutions are comfortable as, on the basis of experiments and companies' own research, they have a preconfigured setting of the welding torch and laser optics, which simplifies (but also restricts) the adjustment of laser-arc spatial configuration parameters necessary for the proper course of the process. These heads can be equipped with almost any type of optical fibre connection terminal depending on the laser and optical fibre used as well as with special clamps for fixing heads on manipulators, e.g. on a robot wrist.

Fig. 8. Hybrid welding of ship deck plating panels, butt joints of plates and welding stiffening elements. Laser CO_2, 12 kW. Shipyard Meyer, Germany [5]

The use of disc and fibre lasers as well as robots and specialist heads enabled and simplified the design of both specialist and very universal robotic stations for hybrid welding. The latest systems offer the possibility of controlling the whole station by means of a manipulator controller from one control panel.

Technological advantages of the HLAW method

In addition to numerous advantages, laser welding with a single beam (a classical method) is also characterised by some significant

a) b) c) d) e)

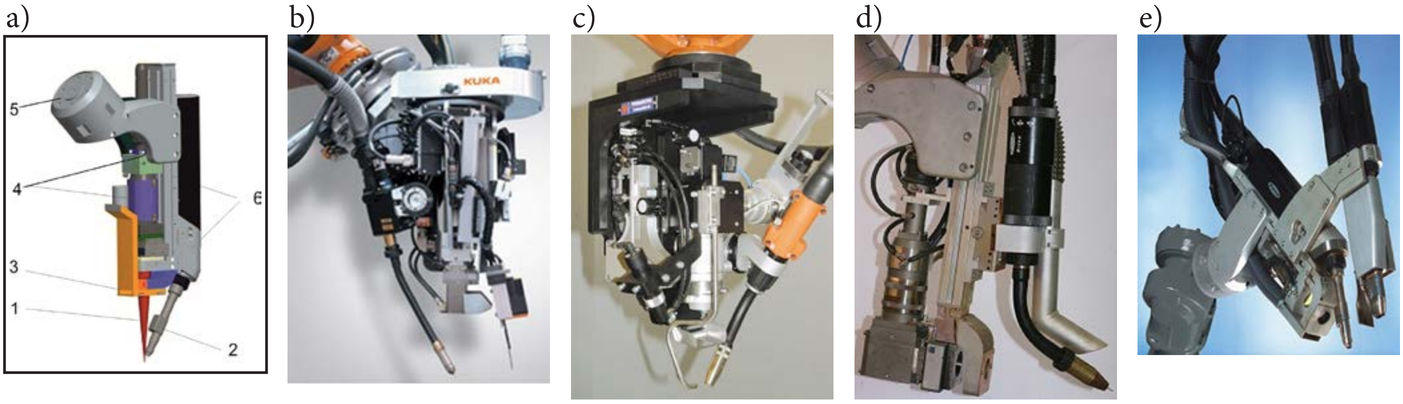

Fig. 9. Specialist HLAW heads: a – basic modules of a hybrid welding head [10]: 1 – laser beam, 2 – arc method welding torch, 3 - cross-jet, 4 – optical system and a fibre optic coupling, 5 – fixing clamp, 6 – base plate, b – KUKA-manufactured KS HybridTec head [11], c – Permanova-manufactured WT03 head [12], d – Fronius- manufactured head for welding fillet welds [10], e – Fronius- manufactured "tandem" type head [10]

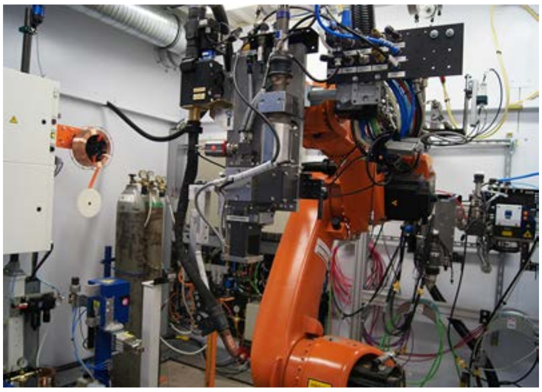

Fig. 10. Robotic station with a specialist hybrid welding head at Instytut Spawalnictwa: Yb:YAG Trumpf TruDisk 12002 laser (12 kW); KUKA-manufactured KS HybridTec head; EWM-manufactured Tetrix T270 power source

technological disadvantages. Elements welded with this method should be matched with each other practically without a gap, which in the case of industrially popular guillotine cutting methods and classical thermal cutting methods (plasma cutting and oxygen cutting) is difficult to achieve. The lack of strict edge preparation tolerances is responsible for the appearance of welding imperfections such as weld face reductions or undercuts and, in extreme cases, the lack of a joint. Large-size structures cause additional problems connected with establishing and precise positioning of elements in order to ensure the required preparation of a joint for a single laser beam welding. Moreover, the process does not provide the possibility of modifying the chemical composition of a weld, which is often required while welding many different material grades. In addition, in many cases single beam laser welding causes the excessive hardening of a joint area due to a dynamic thermal cycle.

In turn, although continually improved, arc welding methods are incapable of ensuring such a penetration depth and process efficiency as can be achieved by means of high power laser welding (Fig. 11). The power density of a gas-shielded electric arc is significantly lower if compared with laser beam radiation. Hence, the welding rate is lower. Due to a wider arc effect area welds are characterised by a high weld shape coefficient value (a weld width-penetration depth ratio). Welds are usually multilayer. The heat effect of an arc on a material is significantly stronger, which at low rates often leads to the deformations of elements being welded and requires additional straightening. The edges of thicker elements require bevelling and therefore require an additional amount of work connected with initial mechanical processing. An advantage of arc-based technologies is the low cost of equipment and the possibility of welding with filler metals (particularly MIG/MAG methods), which translates to the possibility of filling a weld groove and modifying the chemical composition of a weld.

Using simultaneously a laser and arc methods in hybrid welding combines the possibility of obtaining a great penetration depth at low linear energy (characteristic of laser welding) with good joint properties and greater tolerance of pre-welding element preparation (characteristic of arc methods). The interaction of these two heat sources and the dominant effect of either is the function of power of each of them.

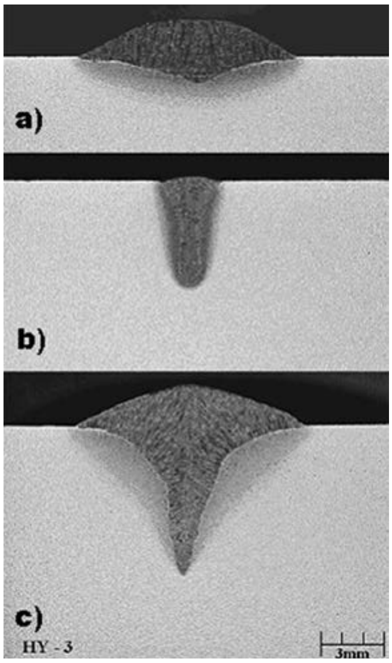

Fig. 11. Comparison of weld shapes obtained with arc, laser and hybrid methods [13].
a) MAG method: vs -1 m/min, E – 8.3 J/m, vd – 16.2 m/min, filler wire consumption – 5.7 kg/h;
b) Nd:YAG laser (4 kW): vs - 1 m/min, E – 2.4 J/m;
c) hybrid method: Plaser - 4 kW, vs -1 m/min, E – 10.6 J/m, filler wire consumption – 5.7 kg/h

Single-run hybrid welding makes it possible to achieve a result which would normally require the use of multilayer welding with arc methods (Fig. 12) [10].

Arc energy provides heat and melts the metal in the upper part of a joint being formed, the effect of the beam allows significantly deeper melting of materials, which is responsible for changing a weld shape typical of laser welding. The cross-section of welds made using the hybrid method has usually a glass-like or, more characteristic, mushroom-like shape (see Fig. 13) (Fig. 14). The face width is greater than in a typical laser weld, but the lower part of the weld and the root take the shape similar to a weld made exclusively with a laser beam.

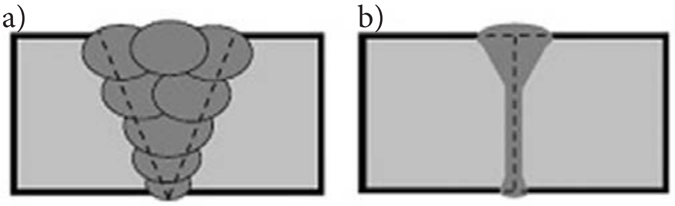

Fig. 12. Comparison of a joint obtained using multilayer arc welding (a) and a single-run joint made with the hybrid method (b)

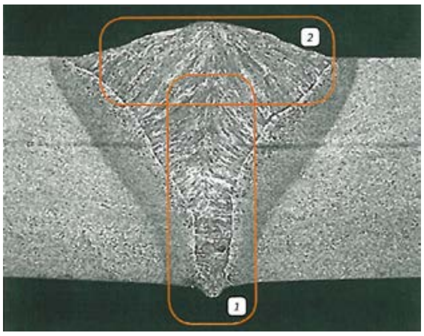

Fig. 13. Weld shape obtained in hybrid welding, 1 – effect of deep penetration obtained by means of a laser, 2 – the upper area of a weld and a weld face formed by an electric arc with a filler metal addition [13]

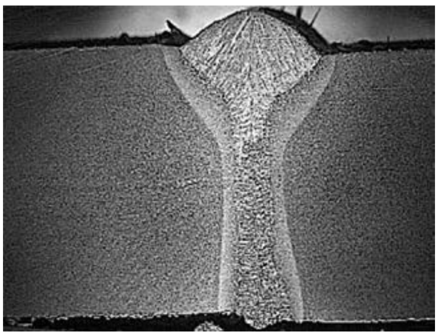

Fig. 14. Shape of a weld obtained during hybrid welding [14]

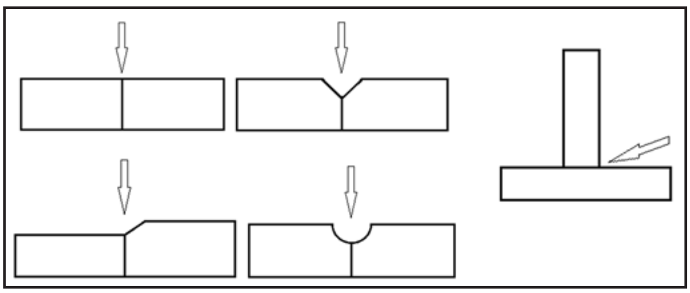

Fig. 15. Examples of joints used in hybrid laser welding [9]

If compared with arc methods, hybrid laser welding is a process usually causing smaller structural deformations due to a significantly better weld shape than that obtained by means of arc methods. In the hybrid method heat input is greater than during laser welding and the thermal cycle is less sharp, which reduces the risk of hardening structure generation in joints. Table 2 presents the synthetic comparison of the advantages of arc, laser and hybrid welding processes.

By properly adjusting hybrid welding parameters it is possible to make both linear and girth welds (orbital welding of pipes). The most popular types of joints and methods of preparing plates for hybrid welding are presented in Figure 15.

Table 2. Comparison of advantages of arc, laser and hybrid welding processes

Laser	Electric arc
• high welding rate • high penetration depth • low linear energy • min. deformations • narrow HAZ	• inexpensive traditional power source • high joint preparation tolerance • possibility of adjusting weld chemical composition (MIG/MAG method)
Hybrid Laser Arc Welding (laser + electric arc)	
☑ process stability due to the interaction of both processes ☑ increased joint preparation tolerance in comparison with laser welding – possibility of welding materials matched with a gap ☑ low welding linear energy ☑ possibility of increased welding efficiency by increasing a welding rate or the thickness of elements being welded ☑ usual lack of necessity of bevelling plates before welding	

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