

LaserHybrid Welding and LaserBrazing: State of the Art in Technology and Practice by the Examples of the Audi A8 and VW-Phaeton

Staufer, H.; Rührnöbl, M.; Miessbacher, G.:

Fronius International GmbH, Wels - Austria

Abridged version:

In view of the demands made by the end users in the field of application of vehicle construction for an ever-higher product quality and improved performance, continuous innovations are considered to be absolutely decisive for being successful. This especially applies to the welding technology, and therefore the goal is to develop new, better and more powerful welding processes. In joining technology the high welding speed on the one and the good gap bridging ability on the other hand play a significant part. However, both features cannot be achieved by conventional laser welding processes. Therefore, a hybrid process is being applied, the LaserHybrid welding or also called LaserBrazing. It is no doubt that the laser beam welding and the MIG welding have been established in the welding technology for very long, and that both processes allow a wide field of application in the joining technology. New possibilities and synergetic effects, however, are based on the combination of both processes. The laser radiation causes a very narrow thermally affected zone with a high ratio between welding depth and seam width. In the case of the laser welding process the gap bridging ability is very low due to the small focus diameter, however very high welding speeds can be achieved. The MIG welding process features a significantly lower energy density has a larger focused spot on the material surface and is characterised by its good gap bridging ability.

The LaserBrazing including an automatised brazing-wire feed-system represents a new joining process with low heat input. Since manual brazing is quite expensive and brings about varying brazing qualities, the use of a process that can be automatised is of highest interest. The laser beam brazing with its easily controllable and accurate energy input has a very high potential in this regard. When welding galvanised steel plates, the coating in the area of the weld seams is damaged or destroyed, and thus the joining area is accordingly susceptible to corrosion, the brazing seam itself, however, does not corrode.

While the laser arc welding is applied to aluminium, unalloyed, alloyed and high-alloy steel, the LaserBrazing is especially used with galvanised steels.

1. Introduction:

The combination of laser light and arc in one welding process has been known since the seventies, however, has not been developed any further [1, 2]. This technology was taken up again recently. Now, the point is to combine the benefits of the arc with those of the laser in one hybrid welding process [3, 4]. At the beginning, the laser beam sources had to prove their suitability for industrial use, now they already form part of the conventional technology employed in the automotive industry.

The combination of the laser welding with any other welding process is called hybrid welding process. This means that both a laser beam and an arc simultaneously act on the welding zone and that they affect and support each other. Here, fantasy knows no bounds. As an example: recently process-technological examinations of the CO₂ laser beam welding with filler wire and in combination with the MSG welding process have been carried out [5].

2. Laser systems:

The LaserHybrid welding does not only require a high laser power but also a high beam quality in order to be able to achieve the so-called deep-weld effect.

Thanks to the good beam quality the CO₂ laser has conquered the area of cutting and will certainly remain there. It seems as if the slab laser and the diode-pumped laser were of special interest for the future, as it is perfectly suitable for cutting and welding of aluminium due to the good focusing ability, the high beam quality and the resultant high intensity that can be achieved. However, the use is limited due to the low jointing cross section - as a direct consequence of the high intensity - especially in the case of square butt welds on the lap joint. Due to the fact that Nd:YAG solid lasers with an ever-increasing power are being offered on the market, these are used for welding more frequently. As the solid laser is operated with flexible light pipes, they are considerably more advantageous compared to the rigid beam arms used for guiding the CO₂ laser light. A flexible beam manipulation allows welding jobs carried out inside passenger compartments, trunks, doors, opening hoods or body front ends [7]. The CO₂ laser, however, is still in demand when it comes to two-dimensional or to simple three-dimensional applications on the outside. The compact high-duty diode laser starts to establish a market. It is ready for being employed for LaserBrazing and will be able to carry out the first welding jobs for thin sheets before long. However, this makes further development necessary. Further development with regards to further increasing the power with an optimised focusing of the laser beam, in order to get from high conduction welding to deep penetration welding. Today, the diode laser costs as much (DM/kW) as other high-duty lasers, however, the price for this kind of laser will certainly be reduced with the decreasing costs of the diodes.

3. Laser welding process:

Up to a power density of 10^6W/cm^2 we speak of high conduction welding. If the intensity is increased, the welding depth increases erratically. If the intensity is further increased, the welding depth also increases significantly. A cavity forms in the workpiece due to the high power densities, which remains open due to the vapour pressure of the evaporating material. The laser beam profoundly penetrates the workpiece through this cavity, the condensing vapour flows around the cavity, solidifies and forms a slim weld seam [8]. This is exactly the advantage compared to most of the conventional welding processes where the seam depth is a function of the heat conduction, so that a relatively wide seam with a low welding depth is formed [9].

4. LaserHybrid process:

For the welding of metal workpieces the Nd:YAG laser beam is focused on intensities above 10^6W/cm^2 . As soon as the laser beam impinges on the material surface, the surface is heated on this spot to evaporating temperature and due to the flowing metal vapour a cavity forms in the weld metal. The weld seam features a high ratio between depth and width. The energy flow density of the free arc is slightly above 10^4W/cm^2 . Figure 1 shows the principle of LaserHybrid welding. The shown laser beam puts in additional heat to the weld metal in the upper weld region in addition to the arc. In contrast to a series-connected arrangement the hybrid welding is the combination of both welding processes in one process zone. The resultant mutual influence of the processes can have different intensity and characteristics depending on the arc and laser process used and on the process parameters applied.

Compared to the individual processes the welding depth and the welding speed are increased together with the realisation of the laser process and the arc heat. The metal vapour evaporating from the cavity reacts on the arc plasma. The absorption of the Nd:YAG laser radiation in the working plasma remains negligibly low. Depending on the selected ratio of the powers either the laser or the arc character prevail.

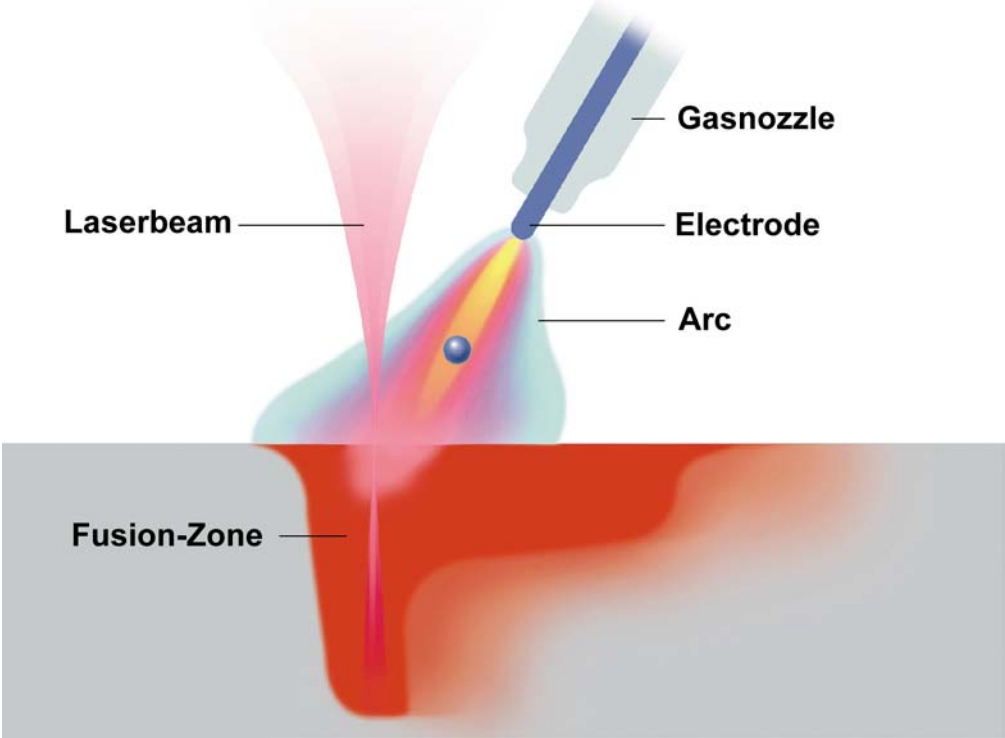


Fig 1: Schematic representation: LaserHybrid welding

The temperature of the workpiece is a decisive factor for the absorption of the laser radiation. To start the laser welding process, it is necessary to overcome the starting reflection – especially in the case of aluminium surfaces. After the evaporating temperature has been reached, the cavity forms so that almost the whole radiation energy can be input into the workpiece. The energy required for this is also determined by the temperature-specific absorption and the energy output due to the heat conduction in the workpiece. With the LaserHybrid welding not only the workpiece surface evaporates but also the filler wire so that there is more metal vapour available and the input of the laser radiation is facilitated. This also prevents process interruptions. Figure 2 shows the metal transfer in the case of the LaserHybrid process.

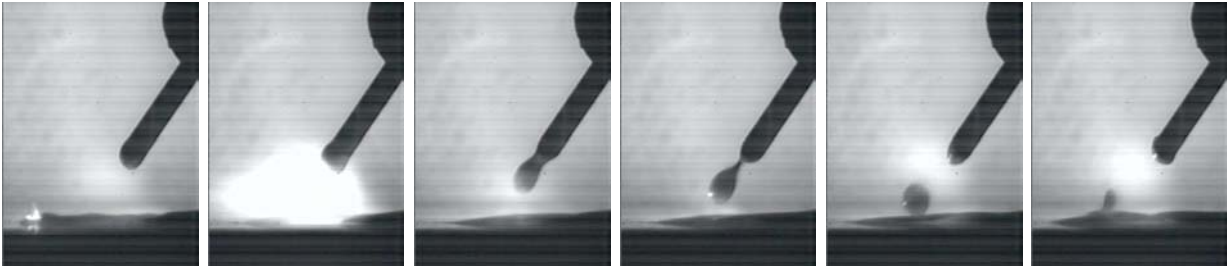


Fig. 2: metal transfer (background current phase, current rise phase, high current phase, necking, droplet detachment, dipping in molten pool)

Weld seam geometry:

If you compare the penetration characteristic of laser, MIG and LaserHybrid, it shows that the laser weld seam has weld concavity, while the MIG weld seam has an extreme weld reinforcement and a high weld seam width with the same penetration depth and the same welding speed. In order to be able to achieve the same penetration with the LaserHybrid process, you only need half the wire feed speed, thus 5.5m/min instead of the 11m/min that would be required for the MIG process. If you once again look at the LaserHybrid weld seam, you will notice that a slight weld reinforcement is reached with the same penetration depth.

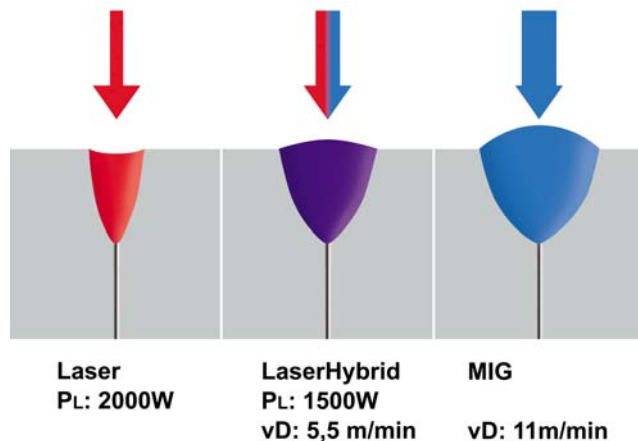


Fig. 3: Comparison between the seam geometry of laser, MIG and LaserHybrid weld seams with the same penetration depth and the same welding speed.

An integrated collision protection ensures that the robot switches off immediately in the event of a crash. The torch moves of course back into starting position so that the jointing process can be continued.

5. Applications in the automotive industry:

The MIG welding process convinces by its high gap bridging ability and the minimum groove preparation required. The benefits of the laser welding can be found in the concentrated heat input, the high welding depths and the high speed.

For welding the doors of the VW Phaeton the LaserHybrid process is applied in addition to MIG welding and laser welding. One door includes seven MIG seams, eleven laser seams and 48 LaserHybrid seams. The seven MIG seams comprise 380 mm, the eleven laser seams comprise 1,030 mm and the 48 hybrid seams are 3,570 mm long.

The LaserHybrid welding is used for welding the extruded sections, castings and sheets made from aluminium in the doors of the Phaeton. The seams are mainly fillet seams on the lap joint, partially also butt seams.

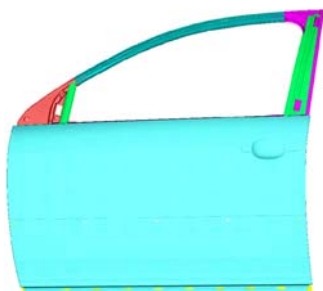


Fig. 4: LaserHybrid welded door of the Phaeton of VW [13]

To be able to meet the rigidity requirements of the doors and to save weight at the same time, it would be necessary to have a tailor-made combination of sheet, casting and extruded material. At different spots these parts can only be joined by the LaserHybrid process due to the required speeds and the tolerances given. Without the hybrid process VW would have had to use heavy casting material.

The fact that the hybrid process is not applied to all 4,980 millimetres of weld seams in the Phaeton door, can be put down to the characteristic feature of the respective seams: if the gap width is excessive, the laser of the LaserHybrid process will not be useful either – in this case the pure MIG process is advantageous. And vice versa: for very small gap widths the pure laser process with its low heat input and the high welding speed can be considered the best possible solution. However, the LaserHybrid process disposes of a large ability to adapt. By varying the share of laser welding and MIG welding, the process can be adapted to the different welding requirements. This means that it is of course possible to carry out a pure laser process or a pure MIG process by means of the LaserHybrid system, however, one part of the processes would have to be switched off. Depending on the welding job the speeds can also vary considerably. By the example of a butt weld in the Phaeton door the range is as follows: speeds between 1.2 and 4.8 meters per minute are possible, wire feed speeds of four to nine meters per minute and laser powers on the workpiece between two and four kilowatt. The process was finally optimised for a welding speed of 4.2 meters per minute, for a wire feed speed of 6.5 meters per minute and a laser power of 2.9 kilowatt.

A LaserHybrid system is also employed in the case of the new Audi A8.

“By combining both jointing processes we are now able to achieve diverse synergetic effects. We are expanding the limits of the today’s thermal jointing processes with regards to productivity, price, seam quality and process safety“, Stephan Helten emphasises, who is responsible for laser beam technology in the “Aluminium Zentrum in Neckarsulm“ and who played a dominant role in the development of the hybrid welding process for the new top model of Audi.

Each vehicle comprises a total of 4.5m of weld seams. In the case of the A8 the LaserHybrid welding is used in the area of the lateral roof frame that is equipped with various functional sheets.



Fig. 5: Laser beam Hybrid welding at Audi: OEM in Ingolstadt applies the process for 4.5 m of weld seams in the roof area of the new A8 and thus achieves higher welding speeds and stronger seams. Photo: Audi

The Fronius developments and production areas range from the power source to the arc and the integration of the optic components, which are applied in the VW and the Audi. The laser itself and the robot are purchased by Fronius or are provided by the customer.

6. Synergies by LaserHybrid:

The following benefits can be achieved by combining the arc and the laser beam:

Compared to the laser welding process the LaserHybrid process features the following advantages: high gap bridging ability in the case of a gap existing for a short period, wider and deeper penetration, significantly wider range of applications, lower investment costs by saving laser power, increased toughness.

LaserHybrid advantages compared to MIG: higher welding speeds, deeper penetration at higher speeds, lower heat input, higher strength, narrower seam.

By combining the laser beam and the arc a larger molten pool is formed compared to the laser beam welding process. Consequently, components with larger gaps can be welded.

The arc welding process is characterised by a low-cost energy source, a good gap bridging ability and a microstructure that can be influenced due to the filler material added. The laser beam process features a high penetration depth, a high welding speed, a low thermal load and a narrow seam. In the case of metal workpieces the laser light produces the so-called deep-weld effect as of a determined beam density, so that components with an increased wall thickness can be welded providing the laser power is sufficient.

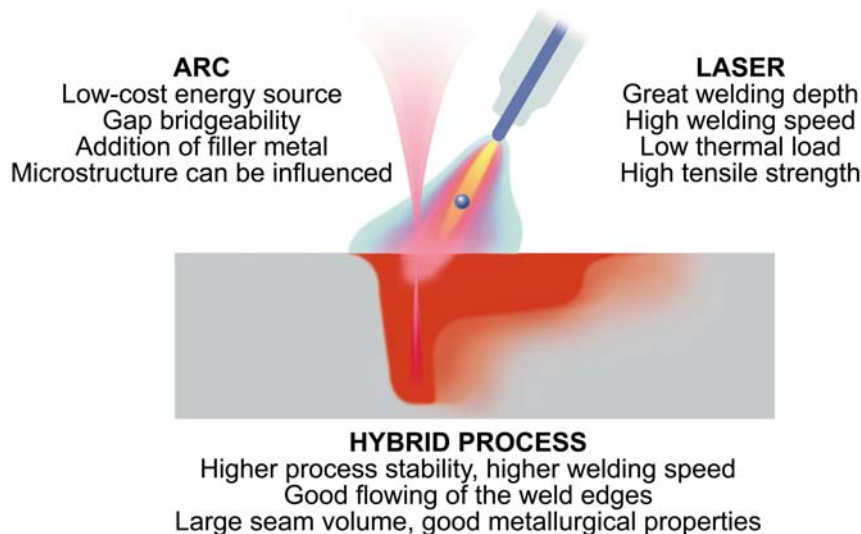


Fig. 6: Advantages by combining the processes

The LaserHybrid welding allows therefore higher welding speeds, a process stabilisation due to the interaction between arc and laser light, and a neutralisation of tolerances. The smaller molten pool compared to the MIG process results in a lower heat input and thus in a smaller heat-affected zone, which reduces distortion and consequently the subsequent straightening work. In the event that two separated molten pools are available, the laser-beam-welded area – especially in the case of steel – is tempered due to the subsequent heat input via arc and furthermore it is possible to reduce hardness peaks. Figure 6 shows a summary of the advantages of combining the processes. The higher welding speeds allow reducing fabrication times and hence fabrication costs [13].

7. LaserBrazing:

In contrast to laser welding a large focused spot on the workpiece is required for simultaneously heating up the joining partners. Zinc starts melting at approx. 420° Celsius

and evaporates at 906° Celsius. These properties have a negative impact on the welding process, as the zinc already starts evaporating when the arc is ignited. The zinc vapours and oxides can cause pores, lack of fusion, formation of cracks and arc instability. Therefore, for galvanised plates it is more useful to use jointing processes with a low heat input into the molten pool.

The electrolytically galvanised plates normally have a thickness between 3 and 20 µm. Zinc forms an efficient corrosion protection for steel. This results from the barrier effect of the cover layer; and what's more, the electric corrosion protection of the zinc layer in the case of damages. This way it is possible to protect both the coated cut edges of plates and also the microcracks that form during cold reduction. Also subsequently cut edges profit by this electrochemical protection. While during the welding of galvanised steel plates the coating in the area of the weld seams is damaged or destroyed, and thus the joining area is accordingly susceptible to corrosion, the brazing seam itself, however, does not corrode. Due to the low heat input a narrow evaporating zone of a few tenths of a millimetre only is formed right next to the brazing seam, which remains protected against corrosion due to the distant cathodic effect of the zinc without any problems.

Based on the properties and advantages shown the LaserBrazing process is certainly an interesting alternative jointing technology especially compared to the conventional welding process, even if the filler material is still significantly more expensive than a conventional welding wire. Figure 7 shows the schematic representation of the LaserBrazing process. With the new brazing process it is now possible to joint this type of coated material by meeting the high requirements. Usually, a copper-based brazing filler metal is used as filler material. Different alloys are available. In line with the Cu-Si two-component phase plot there is a melting range between 950°C and 1050°C for SG-CuSi 3. Other filler metals on the basis of low-melting-point copper-based alloys are also SG-CuAl 8 and SG-CuSn. The goal of the latest developments in the field of filler metals is reducing the melting point or achieving special metallurgical properties [12].

By preheating the wire (which is the so-called laser hot-wire process) the brazing speed is increased so that an improved flowing of the brazing filler metal is achieved.

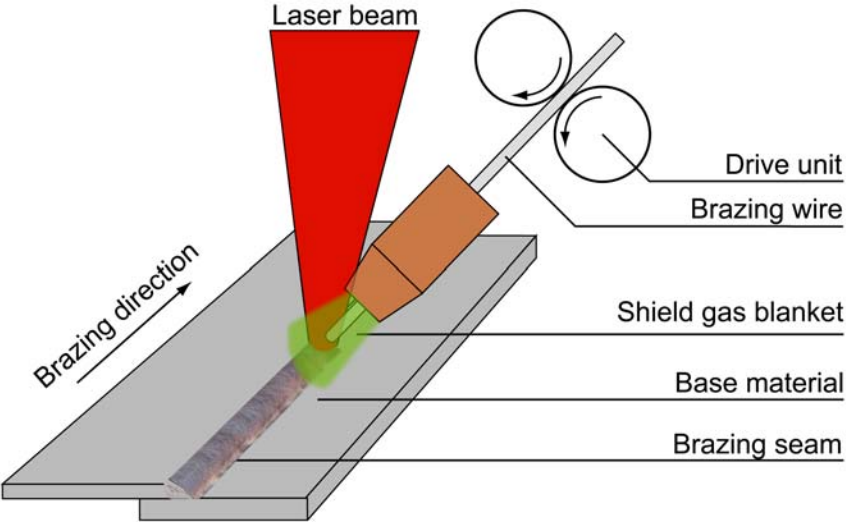
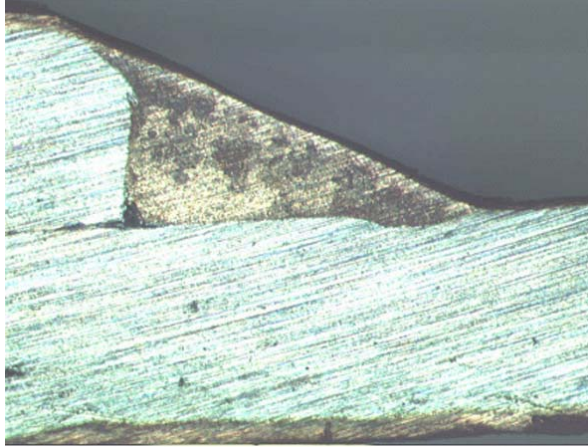


Fig. 7: Schematic representation of the LaserBrazing:

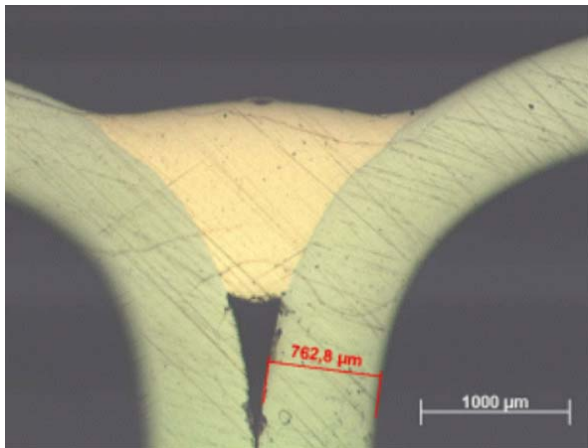
The figures 8 and 9 show the macrosections of a fillet weld on the lap joint and of a fillet weld at the flanged joint. The base material with a material thickness of 1.5 mm is an electrolytically galvanised cold-rolled steel, grade DC04ZE+25/25, with the material number

1.0338. This material is coated on either side with a zinc layer of 18g/m² and corresponds to a zinc layer thickness of approximately 3 μm. The tensile strength of the base material amounts to 270 to 350N/mm², at a yield point of 220 N/mm² and an elongation after fraction of 37%. SG CuSi3 with a wire diameter of 1.6 mm was used as filler material in line with DIN 1733.



| | |
|------------------|--------------|
| Base material: | DC04+ZE25/25 |
| Plate thickness: | 1.5 mm |
| Filler material: | SG CuSi 3 |
| Brazing speed: | 3 m/min |
| Current: | 206 A |

Fig. 8: LaserBrazing; fillet weld on the lap joint



| | |
|------------------|--------------|
| Base material: | DC04+ZE25/25 |
| Plate thickness: | 0.8 mm |
| Filler material: | SG CuSi 3 |
| Brazing speed: | 3 m/min |
| Current: | 210 A |

Fig. 9: LaserBrazing: fillet weld at flanged joint

8. Welding head for LaserHybrid welding and LaserBrazing:

The most important requirement made on the welding head (figure 10) is that it shall have the smallest possible dimensions in order to ensure accessibility to the components to be joined, especially in car body construction. Furthermore, the welding head is designed in a way that it can be rotated by 180° - thus can be mounted as a mirror image – and allows a wide vertical adjusting range compared to the robot mounting so that an improved accessibility to three-dimensional components can be achieved.

Thanks to the integrated adjustment device with scanning unit the variation of the wire with respect to the laser beam is possible in any Cartesian direction. The jointing process can hence be adapted to suit the various seam preparations, powers, wire types, wire qualities and jointing jobs.

The formation of spatter during the jointing process causes an increasing contamination of the protective glass. The quartz glass made from a double-coated anti-reflection material is installed to protect the laser optics from being damaged. The deposits on the glass cause a reduction of the power that impinges on the workpiece down to 90% depending on the degree of contamination. Excessive contamination normally destroys the protective glass,

since a high share of the radiation is absorbed on the protective glass and causes thermal stress in the glass. To prevent all that, a cross jet is used to deflect the weld spatter by up to 90° and to extract the spatter before it touches the protective glass. The corresponding cross jet nozzle was designed in a way that the speed is increased at the outlet end. Thus, an ultrasonic flow can be achieved and the welding spatter is deflected more easily. In order to prevent the air of the nozzle from flowing into the area to be welded, it is extracted through an air outlet pipe. What's more, the machining cell is not contaminated by welding fume or spatter so that you can always work in a clean environment. The torch is equipped with a two-cooling-unit cooling system and designed for a current loading of 250A at a 100% duty cycle and 4 kW laser power.

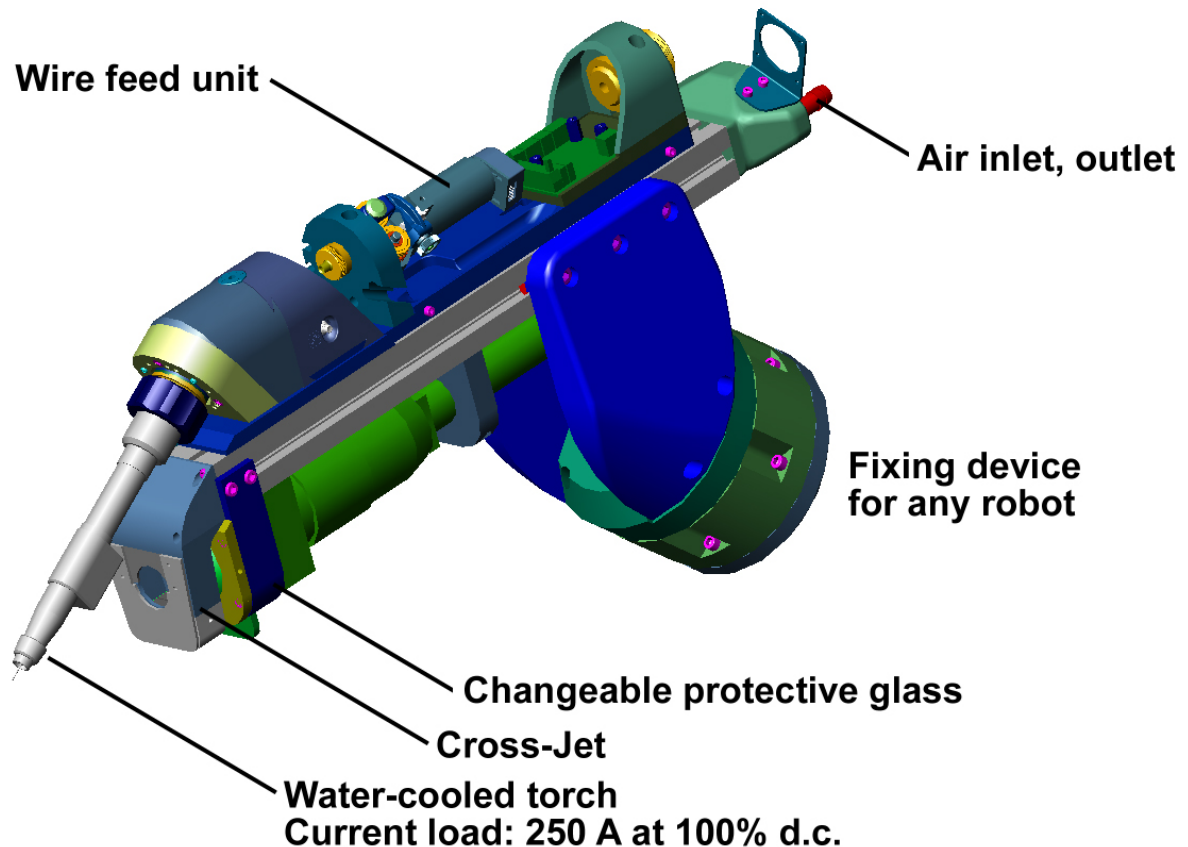


Fig. 10: LaserHybrid welding head

Summary:

The synergetic effects achieved by the absolutely new LaserHybrid technology open up a wide field of application in the jointing technology, especially where the tolerances of the jointing parts required for laser beam welding cannot be met or can only be met incurring high costs. Thanks to a considerable extension of the field of application and the efficiency of the combined process it is possible to reduce investment costs, fabrication time and fabrication costs as well as to increase productivity. An increase in competitiveness is the result. The design is being offered new possibilities through narrower joint geometries .

The employment of a stable process, however, has not been able until recently thanks to the available higher output power of the solid laser. Numerous examinations were carried out in the past with basic process information on laser-arc-hybrid welding processes. The hybrid welding process is the combination of the laser beam welding and the arc process with only one single process zone (plasma and weld pool). By selecting favourable process parameters the seam properties such as geometry and structural constitution can be purposefully influenced. The arc welding process increases the gap bridging ability due to the filler material added and determines the seam width and thus decreases the weld seam

preparations. Process efficiency can be considerably increased by the interactions of the processes.

Bibliography:

- [1] Matsuda, J.; Utsumi, A.; Katsumura, M.; Hamasaki, M.; Nagata, S.: TIG or MIG arc augmented laser welding of thick mild steel plate. *Joining & Materials* 1988.
- [2] Steen et al.: Arc-Augmented Laser Welding. 4th Int. Conf. on Advances in Welding Processes, Paper No.17 (1978) pp.257-265.
- [3] Cui, H.: Untersuchung der Wechselwirkungen zwischen Schweisslichtbogen und fokussiertem Laserstrahl und der Anwendungsmöglichkeiten kombinierter Laser-Lichtbogentechnik. TU Braunschweig, Dissertation, 1991.
- [4] Maier, C.; Beersiek, J.; Neuenhahn, K.: Kombiniertes Lichtbogen-Laserstrahl-Schweißverfahren On-line-Prozessüberwachung. *DVS 170* (1995) S.45-51.
- [5] Haberling, C.: Prozesstechnische Untersuchungen des CO₂-Laserstrahlschweißens mit Zusatzdraht und in Kombination mit dem MIG-Schweißverfahren. Diplomarbeit, RWTH, Lehrstuhl für Lasertechnik, 1994.
- [6] Dausinger, F.: Hohe Prozesssicherheit beim Aluminiumschweißen mit Nd: YAG-Lasern. *Bleche und Profile* 42 (1995) Nr.9, S.544-547.
- [7] Treusch, H.-G.; Junge, H.: *Laser in der Materialbearbeitung, Schweißen mit Festkörperlasern*, Band 2, VDI- Verlag, 1995.
- [8] Beyer, E.: *Schweißen mit Laser: Grundlagen*, Springer-Verlag, 1997.
- [9] Steen: *Laser Material Processing*, Springer Verlag, 1996.
- [10] Faißt, F.; Weick, J.M.; Fitz, R.; Kern, M.: Anwendungen der Twinfokus-Technik. *Stuttgarter Lasertage 19 99*. S.50-52.
- [11] Helten, S.: Qualifizierung und Implementierung des Lichtbogenunterstützten Laserschweißverfahrens in den Fertigungsprozess im Aluminiumkarosserieleichtbau. Diplomarbeit Audi, RWTH (ISF) Aachen 1999.
- [12] Haldenwanger, H.; Schmid, G.; Korte, M.; Bayerlein, H.: Laserstrahlhartlöten für Karosseriesichtteile in Class-A-Oberflächenqualität. *DVS 204*, S.191-196.
- [13] Graf, T.; Staufer, H.: LaserHybrid at Volkswagen. *IIW-Doc. XII-1730-02*