Trends in Aluminum Welding

Diode lasers in the automotive industry

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Since 2001, diode lasers are used in automotive series production. Today, all major Original Equipment Manufacturers (OEMs) are using diode lasers. Typical applications are welding and brazing of zinc coated steel, welding of aluminum and cutting. Due to significant weight saving potentials, the OEMs focus on aluminum welding applications.

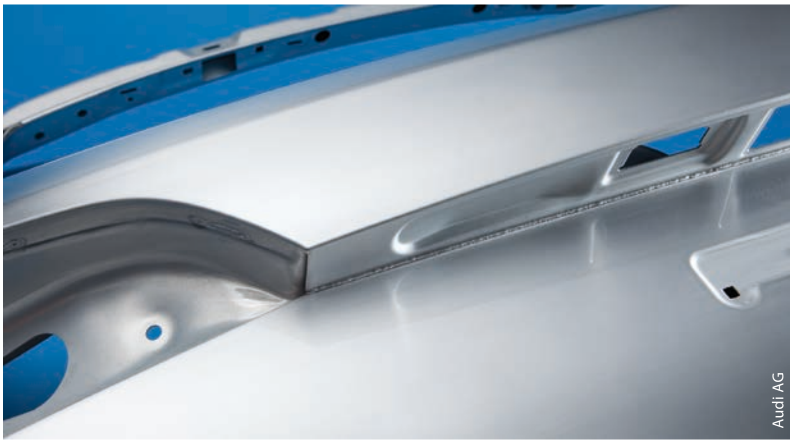

Fig. 1 Audi Q5 aluminum tailgate with weld seam in visible area

Compared to steel, aluminum has limited deepdrawing capabilities. Therefore more parts and joints are necessary in body-in-white (BIW) construction. A laser has multiple advantages in aluminum welding. In outer skin roof or tailgate joining applications, laser aluminum welding leads to a better appearance of a car. In structure weld flanges can be shortened. Due to limited spot welding capability, the laser is the method of choice for aluminum welding. During the last years, processes were improved to a large extent. Less heat input with tailored spot geometries and higher speeds without shield gas and filler wire were achieved.

Besides brazing, welding of aluminum is the second most common application for diode lasers. Within the last five years several dozens of diode laser systems with 4 to 6 kW were installed in this field. Today's standard in BIW aluminum welding series production is a tactile optical system like Scansonic's ALO_3 with AlSi (6xxx) or AlMg (5xxx) filler wire and shielding gas. The filler wire accounts for guiding the process head along the seam and reduces hot crack susceptibility by alloying up with silicon. Typical wire diameters are 1.2 to 1.6 mm, thus, similar seam geometries as in laser brazing are achieved. Aluminum has a high reflectivity in the typical laser wavelength range around 1 µm. Diode lasers are less sensitive toward back reflections than other laser systems, thus, the output power is constant and the welding process is not affected.

Fig. 1 shows an example of welding on the exterior of tailgates. Part geometry, clamping technique, and process are similar to laser brazing on the exterior. However, welding of aluminum requires a smaller focal diameter. Laser welding is often used in structural parts. After welding, the seam is directly coatable. Another application is producing step welds in an aluminum car door made of two deep-drawn inner parts with very short flanges in the window frame (**Fig. 2**). An increased strength of the weld seam leads to higher stiffness in all components joined by laser welding [1]. Depending on sheet thickness, spot diameter and laser output power, process speeds between 2 and 5 m/min can be achieved.

Application report

The typical spot for the aluminum welding process is characterized by a round spot with 0.6 to 0.9 mm diameter (**Fig. 3b**). The laser light is delivered through a fiber with a 600 µm core and focused onto the workpiece through a tactile process optic with a magnification of 0.9 to enable keyhole-welding. **Fig. 4a** shows a cross section of a lap joint fillet weld with 1.6 mm AlSi filler wire which is typically applied in the structure or non-visible areas of hang-on parts. A strong bonding with almost no porosity is achieved on a properly cleaned workpiece (no oil and particles). Gaps up to 0.3 mm can reproducibly be bridged, i. e., tolerances of deep-drawn parts can be compensated to a large degree. In order to achieve robust incoupling, 2.7 to 3 kW of laser power are at least required.

If welding through or excessive root convexity should be avoided, tailored spot geometries can be utilized to optimize heat input and the cross-section of the seam. **Fig. 3** shows the results of linear welds on 6xxx aluminum test coupons with round or tailored double spot geometry made at the Laserline application lab. Parameters like wire feed rate and robot velocity are identical for both geometries. The test coupons welded with double spot profile have a smooth and tight seam while the results with the clas-

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Fig. 2 Stitch and fillet welds in the Audi A6 aluminum door

sical round spot are characterized by waviness in the radii and a more uneven surface. Compared to the single spot, the process window for a given robot and wire speed almost doubles, ranging from 3.4 to 3.8 kW at a velocity of 4 m/min.

With double spot, best results are achieved by using less power compared to the single spot. By reducing the power by 200 to 400 W, the cross section of the weld seam is smaller than welded with single spot. In addition, the melt pool is right where you need it: the molten material stays in the upper part of the seam improving the smallest effective cross section and mechanical properties. The double spot module can easily be integrated into Scansonic's ALO_3, only the TCP of the robot has to be adapted.

Aluminum remote laser welding

Remote laser welding is characterized by increased flexibility, high operational speed and a reduced cycle time and therefore complements all advantages of laser joining. Laserline's diode laser with active converter fiber achieves 4000 W at a beam parameter product of 6 to 8 mm mrad and therefore enables all common remote applications. In remote laser welding, the combination of high power, high beam-quality diode laser, scanner unit and robot system is essential. The scanning unit consists of focusing optics with a long focal distance combined with galvanometer scanning mirrors. This setup enables high-speed focusing of the laser beam onto the workpiece. In most available scanning systems, the focus position is not limited to a 2D plane – an additional linear axis within the beam collimation enables any arbitrary 3D workpiece geometry.

This optical layout enables extremely fast switching in-between the desired weld joints resulting in a significant decrease in laser off-time. Additionally, the long working distance allows for simplified clamping techniques and protects the optics from weld spatter. To further improve workpiece accessibility and system flexibility, the scanning unit is attached to a 6-axis robot.

As aluminum is known to be a difficult material for welding, the availability of shielding gas for a smooth and solid surface and additional filler wire to improve the metallurgical composition of the weld and avoid hot cracks seem to be essential. In order to benefit from the advantages of remote welding, the lack of filler wire and shielding gas have to be compensated for.

Two different approaches have been developed for automotive series applications:

- aluminum alloy sheets with eutectic AlSi coating
- controlled heat management by 2D beam oscillation

Sheets with coating

This approach for joining aluminum of the 6xxx family in the absence of filler wire and shielding gas by means of remote laser welding features sheets coated with an eutectic AlSi composition. The Si component in the coating stabilizes the oxide layer on the melt pool and improves the weldability. Furthermore, the hot-crack susceptibility resulting from the low ductility of 6xxx aluminum is reduced significantly. OEMs and suppliers reported promising processes with high speed and weld seams close to the edges of the deepdrawn aluminum parts enabling short flanges and increased stiffness in doors, decklid and other structures [2]. However, until today, remote welding processes in automotive series applications have not been published even though the material is in use for one-piece aluminum doors at various OEMs. As

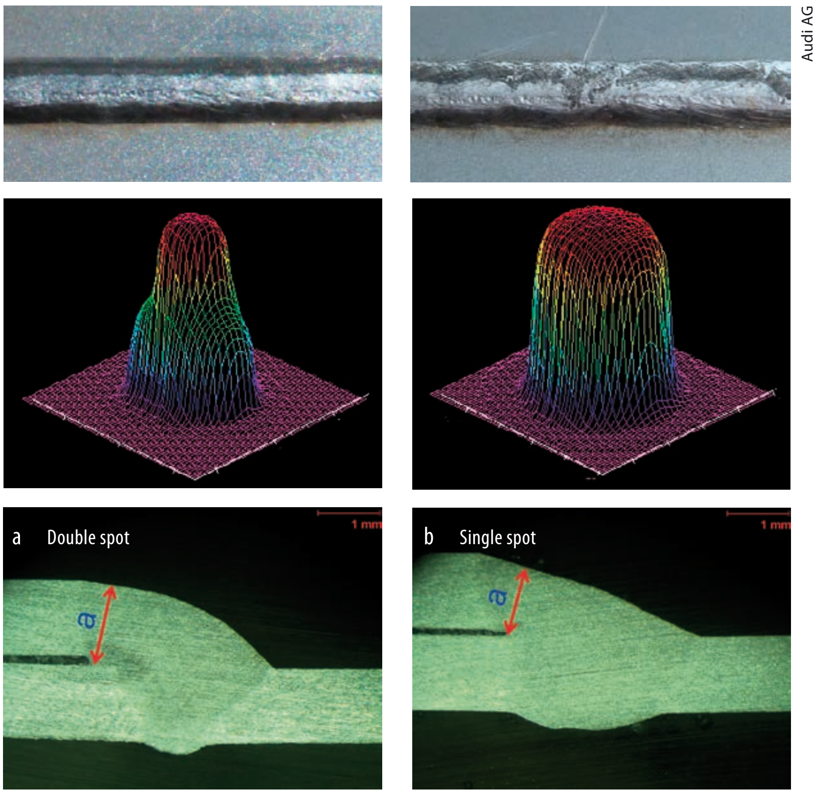

Fig. 3 AL 6xxx welding with AlSi 1.6 filler wire

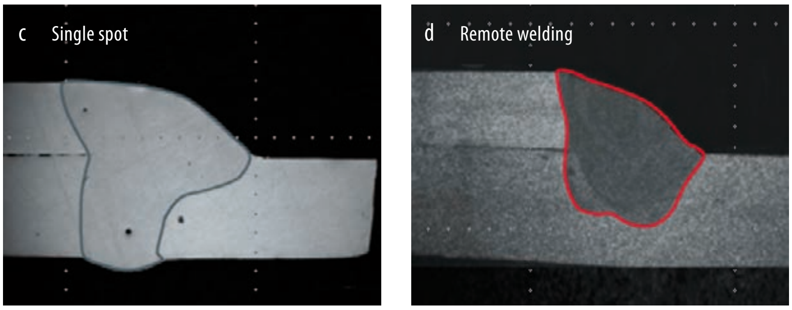

Fig. 4 Cross section of aluminum fillet weld lap joint

coated aluminum sheets are quite new, the availability of this material has to be considered. Furthermore, the aging effects on the sheets directly influence process stability.

Controlled heat management

With remote welding, non-productive time between weld seams is minimized and laser utilization is maximized. By using remote welding in applications like welding the inner structure of doors with a big amount of weld seams, this high utilization results in a significant decrease of equipment and investment costs. Additionally, single-sided access, a facilitated clamping process and smaller weld flanges enable a completely new part design with regard to material mix, geometry and weight.

Audi AG introduced a novel approach for aluminum remote welding of doors with Laserline's LDF 4000-6. This diode laser with active beam converter technology delivers 4 kW output power through a 150 µm fiber and works alongside of Precitec's Scantracker based on the WeldMaster platform. The small-field scanning optical system is utilized for the exact positioning of the laser beam on the workpiece and enables controlled heat management in the process zone. While the Scantracker is responsible for spatial modulation, ensuring a defined connection width, the laser outputs a temporally modulated beam to control the heat input. Thanks to fast-switching power supplies, the output power of the laser can be precisely modulated within each oscillation of the scanner allowing for selective partial penetration welding rather than deep penetration welding. As the energy input is significantly reduced by almost 50 %, hot crack susceptibility is efficiently eliminated despite the lack of filler wire and shielding gas. **Fig. 4** shows a cross section of the fillet weld lap joint with tactile laser beam welding and laser remote welding. A closed-loop control system based on a triangulation sensor in the scanner guarantees gap-bridging up to half of the sheet thickness.

Audi reported time savings of 53 % and a reduction of CO_2-emission by 24 % due to a decrease in process time, increased welding velocity and reduction of laser power. By eliminating the need for filler wire, shielding gas, wearing parts and an increased lifetime of the optical system due to larger working distance, running costs are cut down to 5 % compared to tactile laser beam welding. The described setup is used in the Audi A8 series production (**Fig. 5**) since 2014 and has proven its advantages.

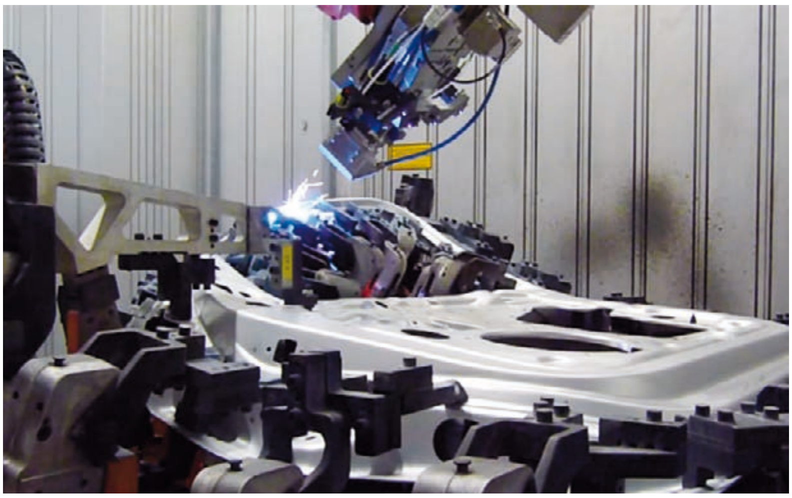

Fig. 5 Remote welding of Audi A8 doors

Conclusion

The dimensions of the heat-affected zone are largest when using a conventional round spot. When utilizing a tailored double-spot, the intensity is heterogeneously distributed across the seam with a peak in the center where the filler wire is molten. The laser power surrounding the wire accounts for localized heat input and stabilizes the process. By means of spatial and temporal beam oscillation, the heat-affected zone is reduced even further when applying a laser remote welding process without additional shielding gas and filler wire.

Today the fundamentals of laser aluminum welding are understood to a large extent and, therefore, further improvements tend to occur in details. For example, spot geometries can be changed to rectangular- or double-spot shapes and scanning systems lead to a higher average utilization of laser systems in production. Thanks to Laserline's experience in all major automotive applications, diode lasers help to create added value in modern production lines. They are robust, easy to operate and highly modular. If customers wish to optimize their process parameters and spot geometries, they are always welcome to visit Laserline's application lab in Mülheim-Kärlich.

[1] *M. Shome* and *T. Muralidhar,* Welding and Joining of Advanced High Strength Steels: The Automotive Industry, Elsevier (2015) p. 115ff

[2] Innovative Aluminum Alloy for Remote-Laser-Welding; Laser Joining of Aluminum Technical Symposium; *C. Bassi* (Novelis Switzerland SA)

