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# High-performance welding: One catchphrase, four alternatives

## How do these processes benefit users?

Joining-technologies in general are reckoned to be a growth sector. Industry insiders expect the highest growth rates of all to come from laser welding. However, there is also still growth potential for the GMA (gas metal arc) welding processes among manufacturers and research institutes. Manufacturers also agree on the likely significance of hybrid processes. "65% of respondents see laser-hybrid welding as the predominant process-combination in future, with the greatest potential being accorded to the laser-MIG process." [1)]

In the face of global industrial competition, some of the central demands being made of production operations are for shorter cycle times and higher productivity. This is in line with two trends found in practice: 1. higher output; 2. increasing large-scale production. In the welding technology field, these tasks are increasingly being solved by high-performance processes. Both joining rates and deposition rates are on the rise. This is mainly true in the case of large production lots, as found in the automobile and allied vendor industries, but also when joining large-volume weldments that have big joint cross-sections, or when performing overlay welding on large areas. Various solutions are now available, catering for the different overall conditions applying to the application and the user.

### State of the art: A high level has been reached

An often turbulent developmental process, with marked innovation "spurts", is what has characterised both the past few years in the development of welding-technology in general, and of high-performance welding in particular (see Fig.1). Users' three main demands nowadays are: High-capacity power sources, simple operator guidance and the very highest welding-system availability. In the arc-welding field, Fronius offers e.g. the tandem process and two types of single-wire process with large wire cross-sections. Rounding off the spectrum is the fourth process, LaserHybrid (a combination of laser and GMA welding).

What all high-performance welding processes have in common is that they are - as a minimum - mechanised, although in most cases they will be automated and - increasingly - also robot-assisted.

### Fully digitised power sources: Flexible, fast process control

The four processes have one major feature in common: The digitisation of their hardware and software. Without digitally controlled welding currents, digital process-control and digitised welding know-how, the performance delivered by today's equipment, the results of the processes and the quality of the welded joins would all be quite unthinkable.

### Data and values tell you a lot, but...

... when it comes to defining performance, hard figures are what counts. Above all, it is potential users who will be looking for hard-and-fast data to assist in their decision-making. Deposition rates and/or welding speed will be at the top of the list here. However, the final welding parameters will depend upon numerous boundary conditions. For this reason, the graphic (Fig. 2) shows only the basic interrelationships and tendencies with respect to the welding speed and deposition rate. For examples of data on the maximum values that can be achieved, see Table A) "High-performance arc-welding processes: An overview"

The reference examples include values derived from real-life applications. These examples are aimed at helping users to get their own idea of the state of development, perspectives and suitability of high-performance welding for their own particular tasks.

### Welding with large wire cross-sections

In principle, enhanced deposition rates are possible by increasing the wirefeed speeds. However, the "cutting effect" sets an upper limit here. This happens particularly often with aluminium; the limit-values are approx.18 m/min with ø 1.2 mm wire, and around 11 m/min for ø 1.6 mm wire. This means that increases in performance beyond this limit are only possible using larger diameters and/or cross-sectional areas of wire. This is accomplished by round-wire welding with wires of between ø 2.0 mm and ø 3.2 mm, and by strip-wire welding with e.g. a 4.0 x 0.5 mm cross-section.

A common feature of both processes is their low penetration and improved gap bridgeability. In terms of equipment, both processes run on a high-performance power source. In order to reach the desired amperage and/or duty cycle, this power source is made up of two single power sources working in power-sharing mode. In this way, for instance, two TPS (TransPulsSynergic) 5000's - working in concert as a TPS 9000 - supply a welding current of 900 A at 60% duty cycle and an ambient temperature of $40^0$C.

### Strip-wire has many advantages

Under certain circumstances, a flat strip-wire can be fed even better than a round wire with the same cross-sectional area. This applies when the wire is deflected by its wider side. In comparison with strip-wires, circular steel wires are relatively stiff; this is particularly true of high-alloy steels. Aluminium wires of the same diameter, on the other hand, have lower stability and a tendency to kink, meaning that they are not very good to feed. Steel strip-wires are commercially available with a cross-section of e.g. 4.5 x 0.5 mm, as are aluminium ones measuring 4.0 x 0.6 mm. These can be supplied in all customary types and grades of material.

On strip-wire, the ratio of the narrow side to the wide side is very important; it determines the rigidity of the wire and thus its feedability. Moreover, different welding results will be obtained, depending on whether the strip-wire is fed parallel or at right angles to the direction of welding (Fig.3). In the case of strip-wire, this results in a significant process-engineering advantage over round wire. The wider arc goes hand in hand with a lower arc pressure, resulting in decreased penetration. This has particularly advantageous effects in overlay welding, for example.

The maximum deposition rates are 11 kg/h for steel and 4 kg/h for aluminium. For higher outputs than this, round-wire welding is the process of choice:

### Round wires for higher output

This statement relates primarily to the deposition rate. To give one example, in applications trials conducted in its Technology Centre for customers from the heavy-plant and construction machinery industries, Fronius has obtained deposition rates of 25 kg/h for steel. In aluminium-welding, the company has achieved up to 5 kg/h. Round wires are available in diameters of up to 3.2 mm. The market for such thick round wires is currently still developing.

The preferred applications are found with larger seam cross-sections, for which two or more passes would be required using conventional techniques. Some additional aspects - all highly interesting from the metallurgical and process-engineering points of view - are offered by flux-cored wires. Alloying elements which are not contained in the metal of the wires as such can be introduced into their flux cores. This can have a desirable influence on the metallurgical properties of the seam. In process-engineering terms, the components of the flux powder can enhance the stability of the arc, and with it the quality of the seam.

**Tandem: Two wires can achieve more than one**

There are various different approaches and solutions for simultaneous welding with two wires in one weld-pool. In both constructional and process-engineering terms, a distinction should be made between "double-wire" and "tandem" welding.

In double-wire welding, both wire electrodes run through a shared contact tube, and always have the same electric potential. In tandem welding, there is a separate contact tube for each electrode. Both these contact tubes are electrically insulated from one another. In this way, each electrode can have a different electrical potential. Fig.4 shows the functional principles of the two processes.

**The individual solution with TimeTwin digital**

TimeTwin digital is a special Fronius-developed welding system for the tandem process. The power of both electrodes' arcs can be individually regulated here, as can various other parameters. The most important of these are the arc length and the type of arc. With reference to the arc length, the control system produces a stable arc which makes for perfect droplet detachment - and thus low spatter. In terms of arc types, both standard and pulsed arcs can be selected. Combining each of these in turn results in four possible variants, three of which are particularly interesting in practice.

- The commonest application is a pulsed arc on both electrodes. In this case, the metal transfers are mostly phase-displaced by 180°; i.e. while the background current is applied to one electrode, the other is in the pulsed-current phase, and vice-versa (Fig.5).
- If the emphasis is on maximum welding speed and gap bridgeability, the leading electrode will weld with a pulsed arc, and the trailing electrode with a standard arc.
- For deep penetration, a standard arc is recommended for the leading electrode and a pulsed arc for the trailing one.

By combining the tandem process with total digitisation, TimeTwin Digital gives the user a further benefit: Each of the electrodes can either have the "leading" or "trailing" function, as desired. This does away with the need to reorientate at the end of the seam in multi-pass welding, greatly reducing cycle times and improving accessibility. Users will especially appreciate another aspect of digitisation as well: For everyday welding practice, Fronius already offers some 60 programs for different base and filler metals. These represent around six years' worth of welding know-how.

The maximum welding speeds with TimeTwin Digital are two to three times greater than with GMA single-wire processes, and still twice as fast as the T.I.M.E. Process. Speeds of up to 7 m/min on steel are entirely realistic. The deposition rates can be as high as 30 kg/h here.

**Eliminating disadvantages + adding together advantages = LaserHybrid?**

Instead of competition, co-operation can also be a royal road to success. Laser and GMA welding each have their pros and cons. Laser welding is characterised by a small focus diameter and a very narrow heat-affected zone, with a large ratio of weld penetration depth to weld-seam width. The high welding speeds that can be obtained are offset by a low ability to bridge gaps. In contrast, the energy density of the arc process is significantly lower, the weld-pool on the material distinctly larger and the gap bridgeability considerably better. What is special about the synergy of both processes is that their respective disadvantages largely disappear, at the same time as their advantages complement one another. Another characteristic feature is that both processes act on the same process zone at the same time. Although the theoretical advantages of combining the two processes have been known since the 1970's, it was not until the beginning of this century that institutes and manufacturers developed industrially viable processes. Fronius can claim the distinction of having developed and commercially launched the first such system to weld successfully in industrial production - "LaserHybrid". The LaserHybrid welding head plays a particularly significant rôle here.

Some important features of the process are shown by the seam geometry: When seams welded with the same penetration depth and at the same welding speed are compared, the arc-welded seam (in GMA welding) has a pronounced overfill and is much wider than the concave termination of the laser-welded seam (Fig. 6). To achieve the same depth of penetration with the LaserHybrid process as in GMA, half the wirefeed speed is sufficient. The weld terminates here with a (desirable) slightly convex reinforcement.

Among the striking advantages of this combination of processes are:

- concentrated heat input with great welding depth and speed
- high gap bridgeability
- higher process stability
- better wetting to sidewalls
- great weld depth / deep-weld effect
- large weld volume
- better metallurgical properties
- high weld strength and toughness
- lower fabrication times and costs
- wider spectrum of utilisation, including (when needed) "pure" arc or laser welding, on one and the same installation.

The LaserHybrid welding head is designed for current loads of up to 250A and a laser power of 4 kW, at 100% duty cycle. In the two years in which it has been in use in industry, it has proved itself with flying colours. When welding aluminium assemblies, the maximum speed is 9 m/min; on steel, 4 m/min can be achieved.

### Summary and outlook

High-performance welding processes have come to occupy important positions in a relatively short time. Given that higher productivity constitutes a crucial factor for succeeding in the face of global competition, it will continue to spur higher performance and flexible, innovative solutions in the welding sector as well. Various objectives are apparent here.

From the point of view of robot and handling systems, higher speeds mean that existing welding-technology resources are better utilised. The goal of all current high-performance welding processes is to achieve higher deposition rates. Manual welding is also deserving of attention, however. A highly desirable development here would be of manually usable systems for the LaserHybrid process. The "laser" component is also capable of further development. The signs are that higher performance is on the way, yet with lower specific investment costs, as well as technical progress in solid-state lasers.

In principle, tremendous opportunities are available here to those who can take a holistic approach. In concrete terms, these opportunities may be found in timely collaboration among all partners involved. When the partners all contribute their widely varying know-how, this collaboration bears fruit in terms of optimum choice of materials, designing workpieces with welding in mind, harmonising the process parameters, the machine technology itself (including clamping and robot systems) - and ultimately, of course, in terms of the welding result. This is true in terms of quantity, quality and efficiency. In this way, the individual solution can move ever closer to the optimum of zero gap-width and maximum welding speed.

[1)] "Equipment-technology research needs in the materials-joining technology field, as seen by medium-sized machine manufacturers or system suppliers"; study conducted by the Institute of Production Engineering & Welding Technology at the Technical University of Chemnitz on behalf of the Research Association of the German Federation for Welding and Allied Processes; Chemnitz and Düsseldorf, March 2003.

### Illustrations

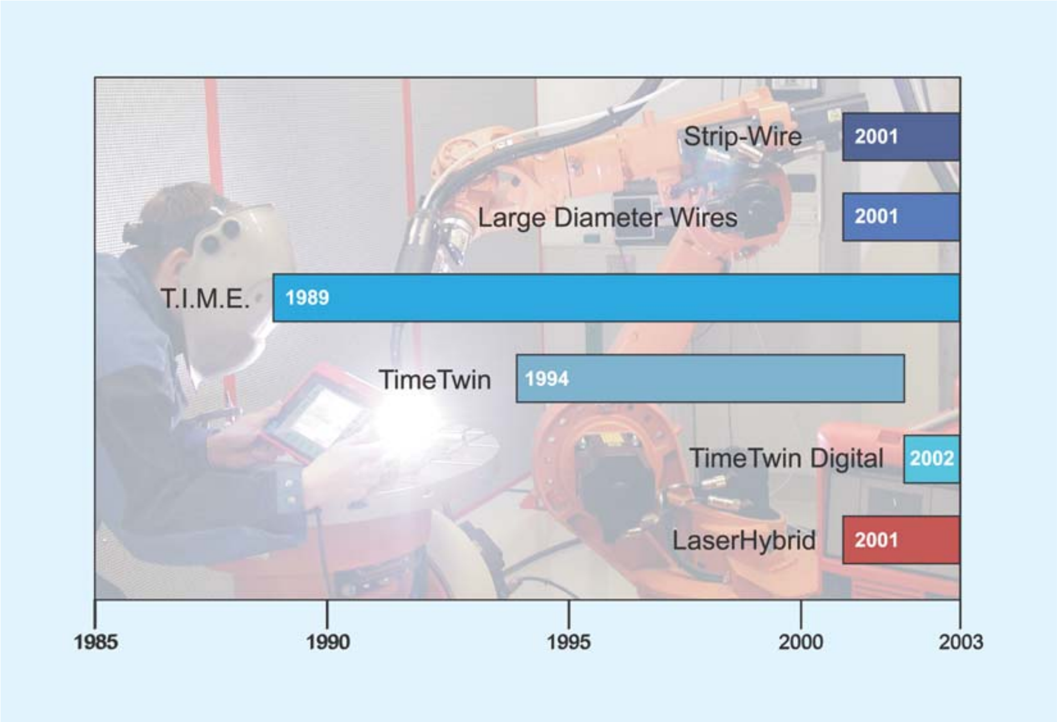


Fig. 1: Chronological development of high-performance welding.

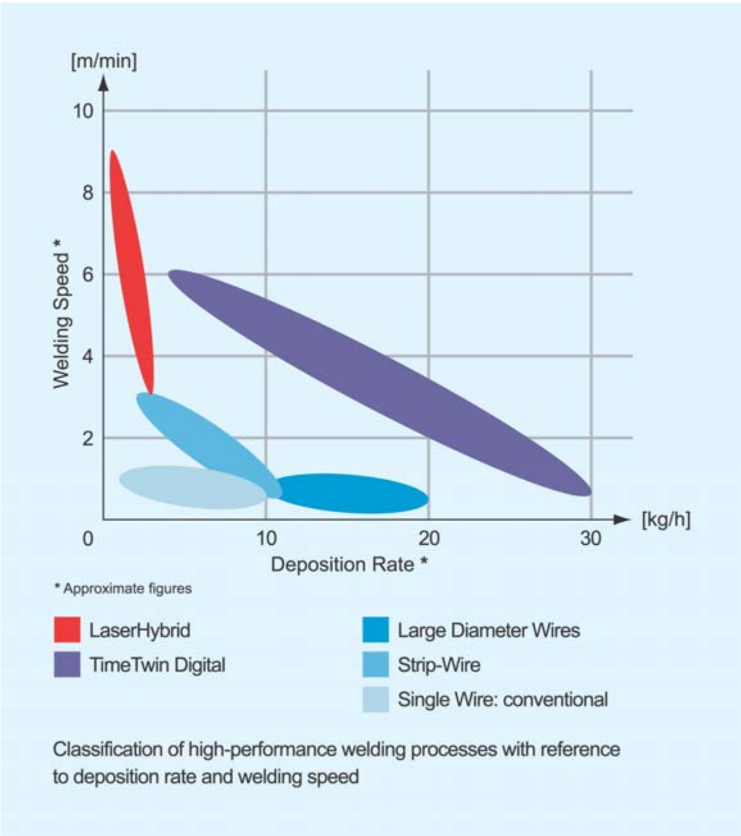


Fig. 2: High-performance welding processes with reference to deposition rate and welding speed.

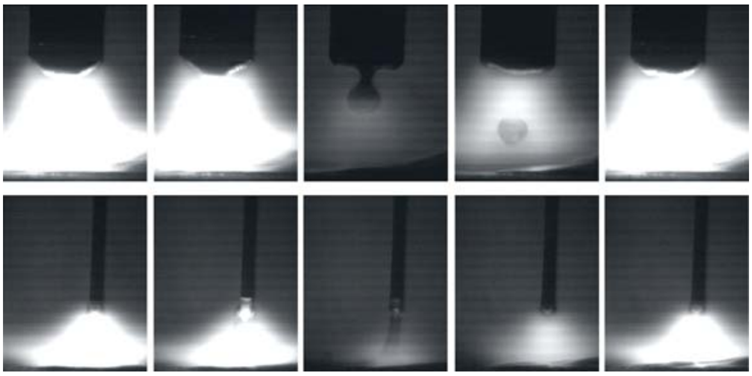

Fig. 3: Metal transfer from an A1Si5 strip-wire in a pulsed arc (wirefeed speed 5 m/min), shown by a high-speed video camera in longitudinal and transverse views.

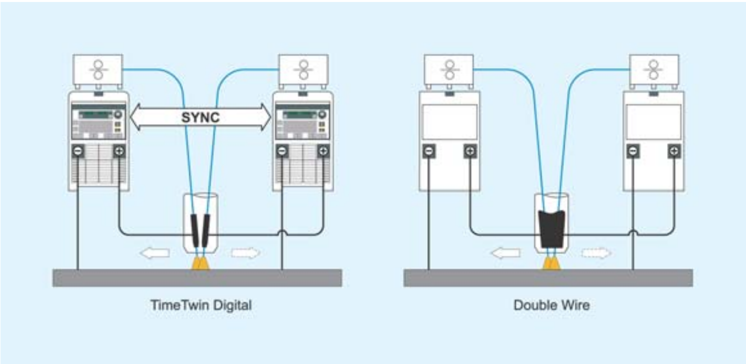


Fig. 4: There are significant differences between the double-wire process and the TimeTwin Digital process.

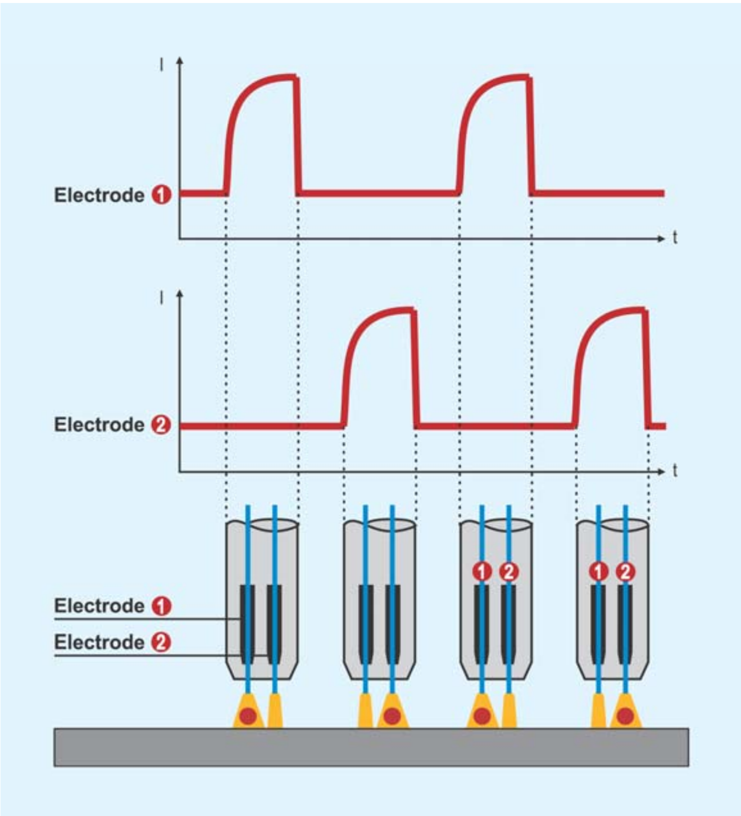


Fig. 5: The 180$^{o}$ phase-displaced pulsed arcs achieve optimum metal transfer.

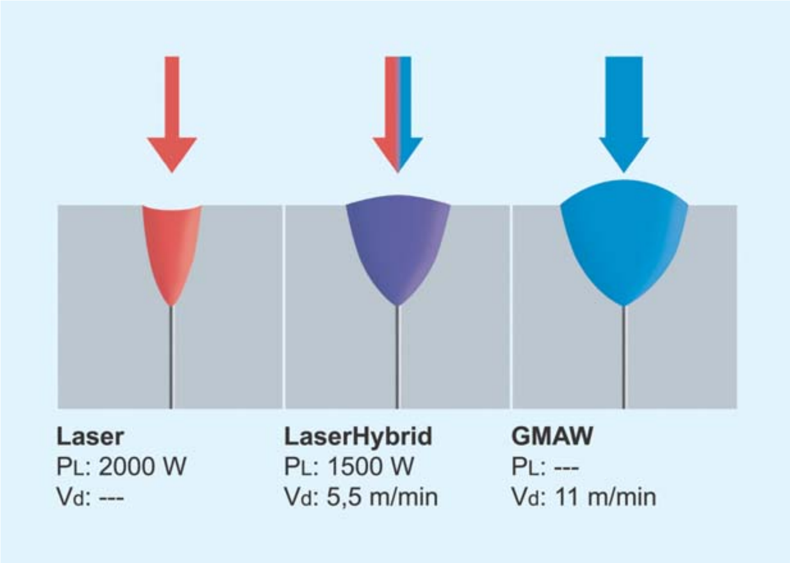


Fig. 6: In LaserHybrid, it only takes half the wirefeed speed to achieve the desired weld termination.

Fig. 7: Strip-wire welding is particularly suitable for joining large workpieces that can be moved by handling systems.

Fig. 8: From four hours per joint to only 20 minutes - these are the sort of welding-time reductions that the TimeTwin Digital system achieves in gas pipeline construction.


Fig. 9: The Fronius LaserHybrid welding head ensures good positionability of the laser beam and arc, both to one another and to the workpiece.

C: Reference examples and key data

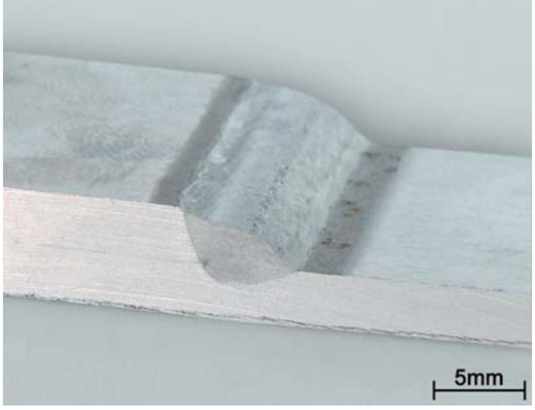

Fig. C.01 Macrosection Strip-Wire

| | |
|---|---|
| Feature/process | Strip-Wire |
| Seam-geometry | Lap-weld |
| Base metal | AlMg3 |
| Thickness | 3 mm |
| Filler metal | AlSi5 |
| Diameter | 4,0 x 0,6 mm |
| Wirefeed speed | 6,1 m/min |
| Deposition rate | 2,4 kg/h |

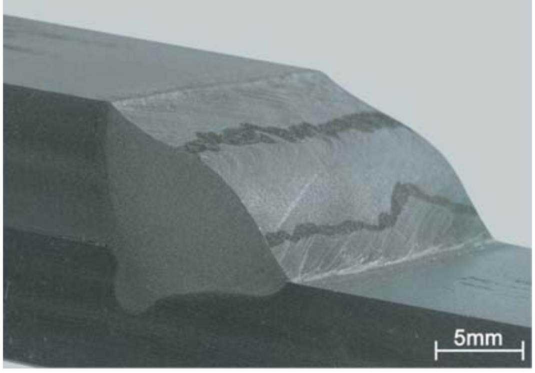

Fig. C.02 Macrosection Large diameter wires

| | |
|---|---|
| Feature/process | Large-diameter wires |
| Seam-geometry | Lap-weld |
| Base metal | AlMg3 |
| Thickness | 8 mm |
| Filler metal | AlMg4,5Mn |
| Diameter | 2,4 mm |
| Wirefeed speed | 7,5 m/min |

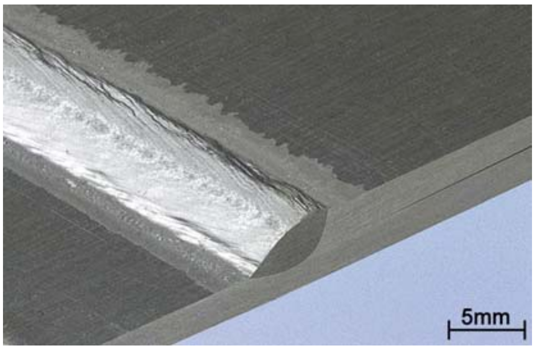

Fig. C.03 TimeTwin Digital

| | |
|---|---|
| Feature/process | TimeTwin Digital |
| Seam-geometry | Lap-weld |
| Base metal | AlMg3 |
| Thickness | 2 mm |
| Filler metal | AlMg4,5Mn |
| Diameter | 1,2 mm |
| Wirefeed speed | 19 m/min |
| Deposition rate | 3,3 kg/h |

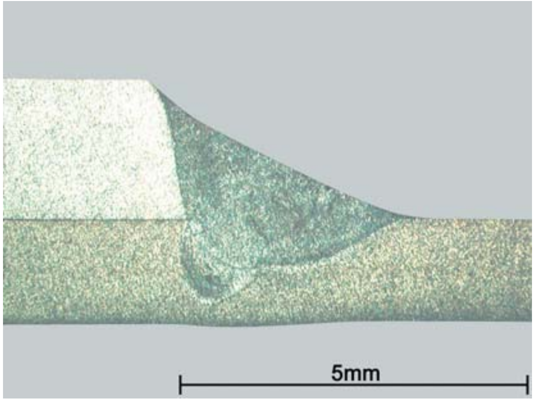

Fig. C.04 LaserHybrid

| | |
|---|---|
| Feature/process | LaserHybrid |
| Seam-geometry | Lap-weld |
| Base metal | AlMgSi1 |
| Thickness | 2 und 1,5 mm |
| Filler metal | A1Si5 |
| Diameter | 1,6 mm |
| Wirefeed speed | 5,5 mm |
| Deposition rate | 1,7 kg/h |

Boxes / overview:

(A) High-performance arc-welding processes: An overview

(B) Industrial sectors and fields of use for high-performance welding processes