Fraunhofer IWS Dresden

FRAUNHOFER-INSTITUT FÜR WERKSTOFF- UND STRAHLTECHNIK IWS

LASER BEAM WELDING IN THE ENERGY SECTOR

Laser-MPNG - laser-multi-pass-narrow-gap welding (MPNG) – multiple, efficient, scalable

Motivation

The energy turnaround, meaning the transition from fossil fuels and nuclear energy towards renewable energy sources, is one of the most demanding challenges our society faces. Here, greater efficiency in energy utilization is as important as the fundamental restructuring of the power supply systems to provide sustainable power generation.

The combination of solar energy, wind power and fossil fuels calls for new strategies in power generation, energy conversion and storage. Germany has to address this situation to ensure that its great value adding potential in power generation and power station operation will be maintained in the future.

Weld joints that are loaded with high stresses are typical in the energy sector. These weld seams increasingly require innovative, highly efficient and reliable welding procedures. At Fraunhofer IWS Dresden, a laser-based joining technology has been developed that focuses particularly on structures with very thick walls: laser-multi-pass-narrow-gap welding (Laser-MPNG).

Laser-MPNG welding is a key technology to produce large-sized power plant components. Furthermore it enables to perform flexible repair solutions in the energy sector. The technique can be applied to classical structural steel engineering, heat resistant steels and nickel-based materials as well as for special aluminum alloys.

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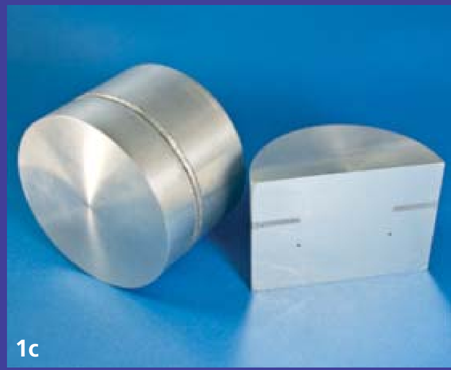

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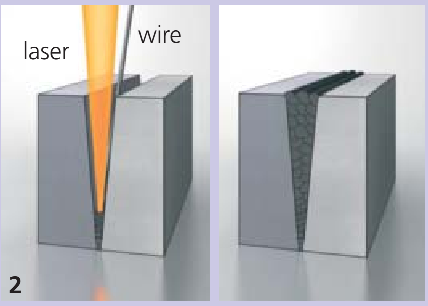
Laser-multi-pass-narrow-gap welding in structural steel engineering

Welding of large-sized cross-sections, providing significant part tolerances and welding under difficult-to-access conditions are typical issues in structural steel engineering. They have previously been only conditionally dealt with by using the laser beam welding technique. Now, with the innovation of the laser-multi-pass-narrow-gap welding technique, the requirements mentioned above can be fulfilled and the level of automation in production can be increased.

The performance is based on a 10 kW diode laser with an approximately 3 mm spot diameter and a high-quality laser beam of about 150 mm mrad. The minimal opening angle of the welded joint can be reduced from 40° to values less than 15°, depending on the laser beam caustic, without melting off the flanks in the upper region of a 120 mm double-bevel groove weld (DHV weld). The beam is statically guided through the welded joint to fill the gap – either with one welding pass or two to three passes per layer of weld.

Laser-multi-pass-narrow-gap welding with diode laser applied to structural steel engineering (principle view)



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Advantages of the technique

- reduced volume to be filled in the welded joint
- less distortion, minimal rework
- preconditioning of steel bars by means of plasma cutting sufficient
- low investment cost per kW laser power
- high filler wire deposition rate
- bridging a gap of + 2 mm
- increase in efficiency and cost reduction

Weld (microsection) after laser welding using the10 kW diode laser

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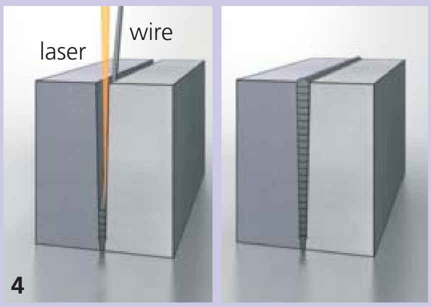
Laser-multi-pass-narrow-gap welding for highest precision

Employing solid state lasers (such as fiber or disk lasers) with the highest beam quality for laser-multi-pass-narrow-gap welding offers the particular advantages of laser beam welding e.g. minimal, limited energy input into the part, reduced part distortion - even for welding thick sheets. The limits typically imposed on the laser welding of very thick sections are significantly exceeded.

For multiple-conducted welds, very small melt pool volumes, customary in classical laser beam welding, are maintained. As a result, the shrinkage stresses are low, and it is frequently no longer necessary to preheat the parts. The high power intensity of the laser beam in the focus is utilized for both melting off the filler wire

Laser-multi-pass-narrow-gap welding using the solid state laser, applied to highly stressed parts (principle view)



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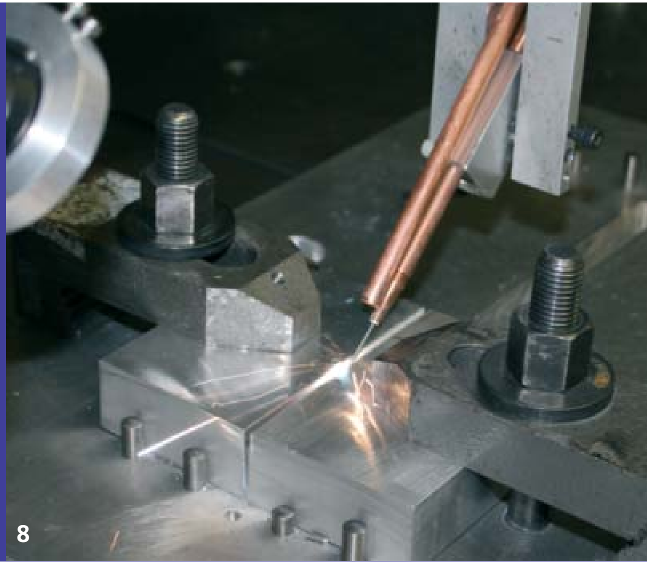

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material and local melting of the part flanks. Consequently, lack of fusion can be avoided.

The machined flanks of the parts are characterized by an extremely narrow opening angle of approximately < 4°. Laser-multi-pass-narrow-gap welding provides a weld seam which has a high aspect ratio (high depth to width) and is free of cracks and lack of fusion. The welding is characterized by homogeneously connected passes.

Advantages of the technique

- extremely low energy input
- significantly reduced weld melt pool volume
- welding joint of high aspect ratio, free of cracks and lack of fusion
- highest weld quality (no cold cracks, negligible part distortions, low residual stresses)
- scalable as desired in part thicknesses from 15 to 50 mm
- efficient and low cost method

Laser-multi-pass-narrow-gap welding used to weld thick aluminum layers

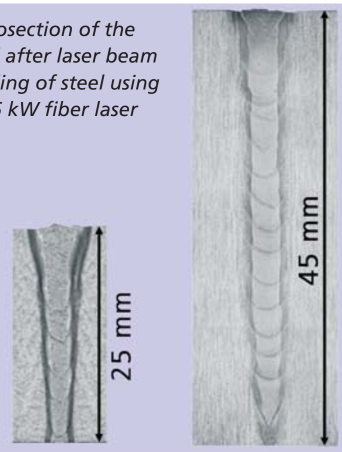
Laser-multi-pass narrow gap welding using solid state lasers with the highest beam quality (beam parameter product approximately 0.4 mm mrad) is particularly suitable to weld thick aluminum plates. It is possible to fully irridiate the almost ideally focusable laser beam down to the joint ground into a joint of 2 to 3 mm width and up to 50 mm depth.

Laser-multi-pass-narrow-gap welding with a beam 2D-beam oscillation assists to obtain a homogeneous composition of the alloying elements from the joining metal. Thus the beam can intentionally transversely oscillate at high scanning frequency inside the joint. As a result, the part flanks can homogeneously melt off, and the melt is homogeneously mixed thoroughly with the joining metal AlSi12.

Advantages of the technique

- significant application limits for thick layer welding of aluminum alloys that can be structurally hardened can be overcome
- AlMgSi alloys up to 50 mm layer thickness can be welded
- very high welding quality (no lack of fusion or cracks)
- high reproducibility
- homogeneously melted part flanks
- high aspect ratio, homogeneous composition of weld metal and filler wire material (AlSi12)
- only 2 to 4 kW laser power required for layer thicknesses up to 50 mm
- very low heat input into the part
- hardly any part distortion (distortion decreases with increasing layer thickness)
- low frequency of pores (B classification according to DIN 13919-2)
- no cracks in the weld metal
- very high tensile strength values
- high process reliability
- low investment costs

Microsection of the weld after laser beam welding of steel using the 5 kW fiber laser



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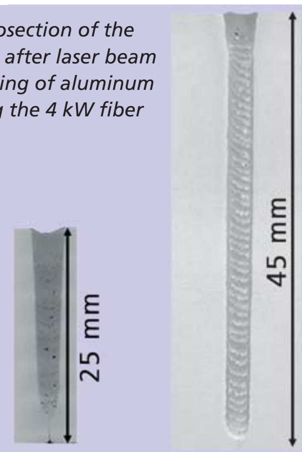
Microsection of the weld after laser beam welding of aluminum using the 4 kW fiber laser



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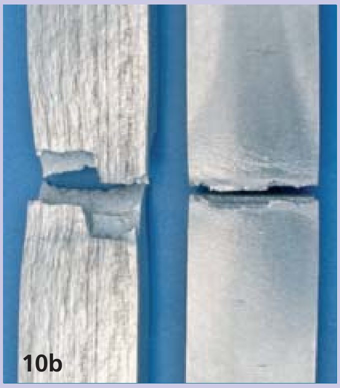
1a Structural steel engineering application, up to 90 mm weld
1b Aluminum plate 50 mm weld
1c Aluminum pipe socket 25 mm weld
5 Laser-MPNG welding head
8 Laser-MPNG welding process (example)

Structural characterization and mechanical testing of welding joints

At our institute, we provide our customers with a wide range of standard static tensile strength testing machines and offer comprehensive equipment for cyclical fatigue tests in order to characterize welds of thick-walled parts. They range from the very high cycle fatigue (VHCF) testing of the weld regions to the determination of voids that are critical for part failure. Moreover, analytical methods for material characterization are used, from metallographic analysis to transmission electron microscopy. To perform the structural testing of thick-walled components in a way that is suitable for the part, FE-simulations are first performed, in which the regions relevant for failures are predetermined. Afterwards, the simulation results are validated, for instance in experiments using a torsion and tensile testing machine.

Characterization of the samples that have been Laser-MPNG welded in the tensile test (10a), failure behavior of apparent material sample (10b left) and a welding seam obtained by Laser-MPNG welding (10b right)

10a



10b

Examples for the use of laser-multi-pass-narrow-gap welding

In comparison with the conventional laser beam welding, the laser-multi-pass-narrow-gap welding process has significant advantages. Using this method, it is possible to weld materials that are critical in terms of cracks and transitions with very low yield strength and thus low laser power. This way, investment costs can be reduced. Part distortion after welding is minimal and is reduced with increasing sheet thickness, thereby reducing the need for rework. As a result, the technique also provides a solution to weld thick-walled parts in the shipbuilding, crane and aircraft industries, on the one hand. On the other hand, it is also an economical alternative to conventional welding technologies for highly stressed parts in the energy sector, such as rotor shafts and tanks.

R&D services provided by Fraunhofer IWS

The »Laser beam welding« group deals with the engineering of innovative joining technologies applied in power train, aircraft, aerospace and power engineering industries, as well as in car body and steel construction. The research group has wide-ranging expertise in the execution of projects with public funding and / or with partners from the industry.

Our offer:

- development of laser-based welding processes for difficult-to-weld materials and mixed material joints
- design of joining points and characterization of joints
- support for and execution of feasibility studies
- implementation of R&D projects in cooperation with partners from industry and / or with public funding
- system design in cooperation with our partners
- technological support in launching processes, training for engineers and plant operators
- failure analyses

9 *Aluminum cooling element with seam that has been Laser-MPNG welded*