

## MONITORING OF HIGH POWER DIODE LASER SHEET METAL WELDING

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### Abstract

Welding thin sheet metal in the 1 mm range with high power diode lasers closes the feed rate gap between conventional techniques like TIG- or plasma-welding and CO<sub>2</sub>- or Nd:YAG-laser welding. This was presented by Fraunhofer IWS at former ICALEO events. Applying sheet metal welding with high power diode lasers for industrial manufacturing raises the question of monitoring full penetration. Two sensor principles have been investigated concerning their suitability at welding nickel base alloy sheets in a controlled shield gas atmosphere. A special shield gas chamber for high power diode laser applications has been applied to avoid any oxidation of the weld. Optical emission spectroscopy and an infrared sensitive camera delivered promising results each. Both sensor principles are an approach for future optimized welding sensors.

### Introduction

Reliability of welding processes and monitoring becomes necessary for production of safety relevant parts for automotive industry and aircraft industry. At laser beam welding processes with their typical butt joint or overlap welds often full penetration is a required quality criterion. The optimum would be a closed loop control that could detect a failure in the becoming and change process parameters immediately. But for a first step a reliable sensing method must be developed to detect those failures. Discharge of poorly welded parts becomes possible in automated production lines if the response time of the sensing system is in the range of the cycle time. A closed loop control becomes possible, if the detecting of insufficient penetration is much faster. Industrial background of the presented work are housings of



Figure 1 Experimental setup with Rofin DL025S high power diode laser, special gas chamber and different sensors

aircraft engines. Therefore the used material has been the nickel based alloy Inconel 625. This alloy recommends itself as an alloy for exhaust systems due to its excellent strength, corrosion resistance and fabricability. This alloy also exhibits high creep and rupture strength, outstanding fatigue and thermal-fatigue strength, as well as excellent weldability.

### Experimental setup

The Inconel 625 sheets had a thickness of 1 mm. The edges have been shear cut and the welding geometry has been a butt weld joint. To avoid any oxidation and to inhibit any other influences from atmosphere a special gas chamber where the oxygen content could be controlled via lambda probe became a necessary equipment. This chamber is able to slide on a table where the specimen are clamped. It has a large fused silica window on top for the laser beam and different optical sensors (fig. 1). From the root side of the weld Helium has been applied, because it is lighter than air and therefore provides a better cover of the seam. Argon or Corgon (Ar + 18% CO<sub>2</sub>) have been the filler gases in the chamber.

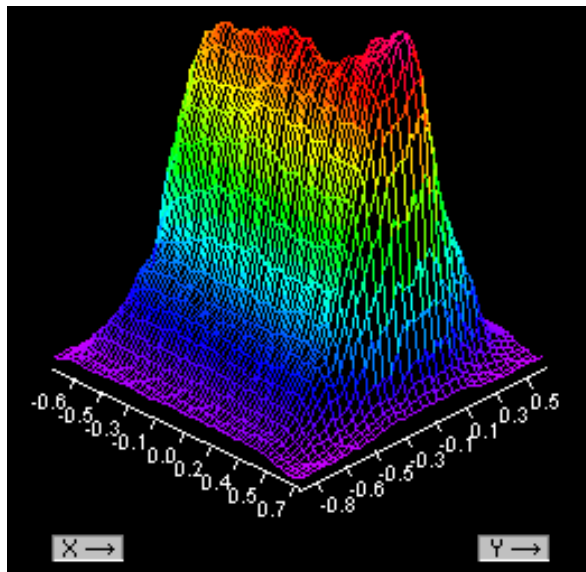


Figure 2 Beam profile of focus of Rofin DL025S, 66 mm focal optics, working distance 42 mm

A Rofin DL025S high power diode laser has been applied with the two wavelengths 808 nm and 940 nm simultaneously. With a 66 mm focal optics the minimal focus is 1.0 x 1.5 mm<sup>2</sup> at a working distance of about 42 mm measured from the last cover slide. The beam spot is asymmetrically formed and has a top-hat-like shape in one direction whereas the shape of the

perpendicular direction is more Gaussian (fig. 2). The direction of the laser spot for all experiments has been the long axis cross the feed direction. (fig. 3) The laser power was fixed at 1000 W. By variation of the feed rate full penetration welds and bad welds have been generated. At those conditions in Argon atmosphere a reliable full penetration weld could be achieved at 600 mm/min feed rate, whereas at 1200 mm/min a reliable bad weld was the result. In between that the quality was dependent on the clamping conditions and on the laser beam alignment. In Corgon atmosphere those feed rates shifted up to 1000 mm/min and 2000 mm/min respectively.

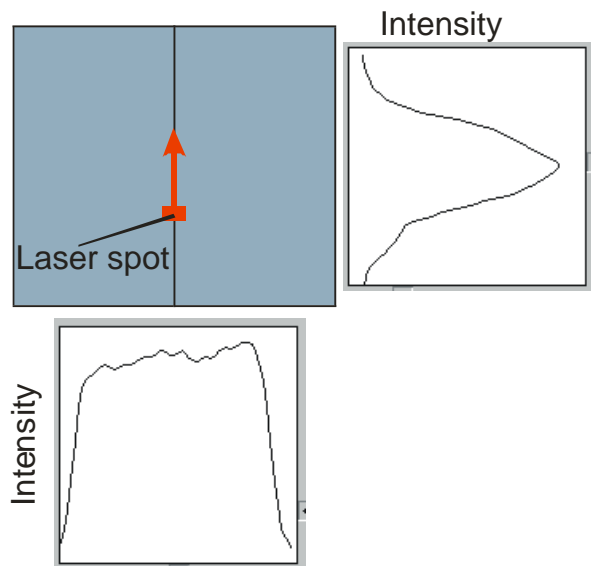


Figure 3 Beam Profile and relative position of laser spot and weld seam

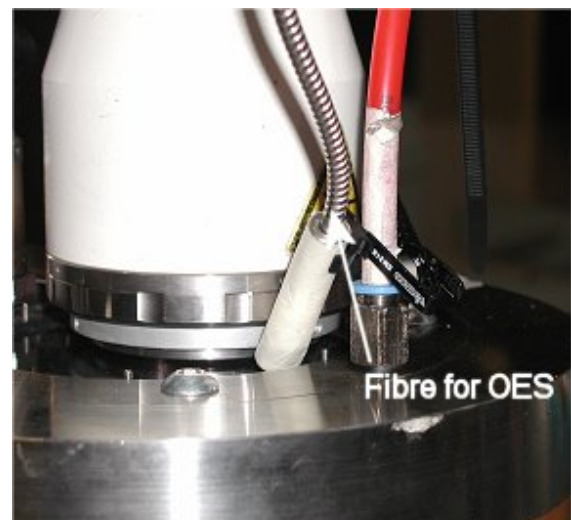


Figure 4 Laser optics and process gas chamber with fibre optic cable for OES

Two optical methods have been tested successfully for detecting full penetration and insufficient penetration. For the optical emission spectroscopy a fibre optic device was mounted to the gas chamber viewing at the process through the glass window (fig. 4) . The camera for the infrared picture recording had a direct view through this window as well (fig. 5).

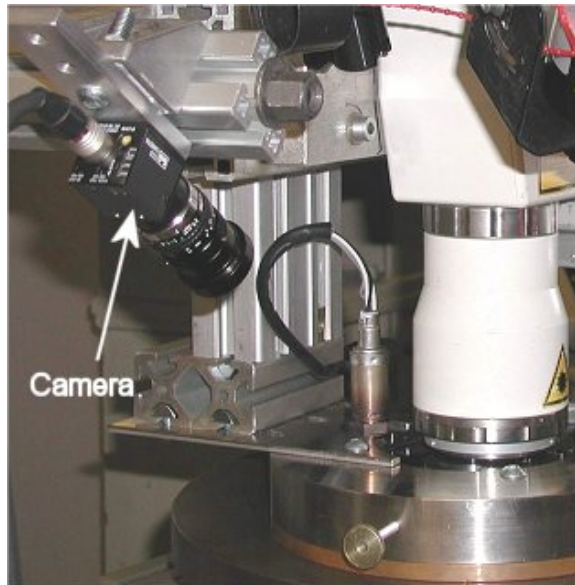


Figure 5 Laser optics and process gas chamber with infrared sensitive camera

### Optical Emission Spectroscopy

Optical emission spectroscopy uses characteristic spectra in the UV-/VIS range. The analysed radiation is caused by recombination of stimulated electrons. Stimulation can occur by absorption of radiation from the process or the laser itself and by following collisions of stimulated electrons with others.

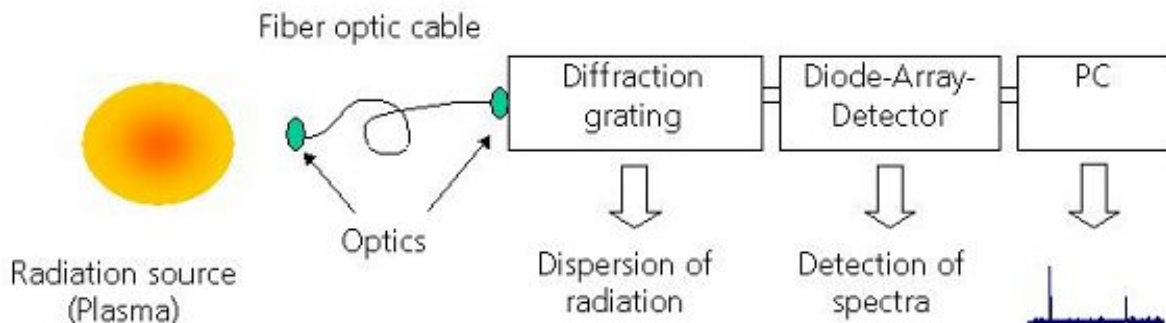
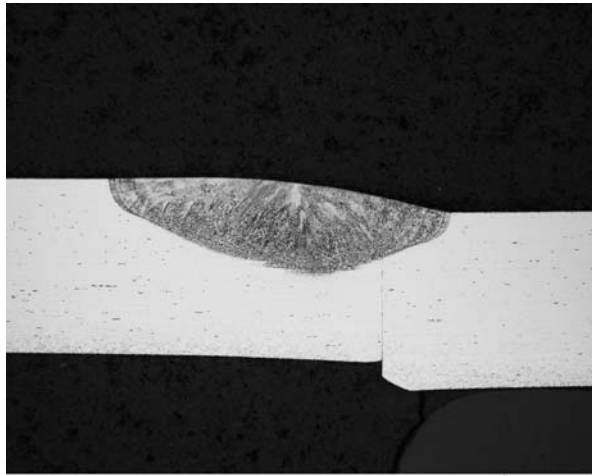


Figure 6 Signal scheme of optical emission spectroscopy

The optical signal is caught with a fibre optical system and delivered via a diffracting grating to a diode array detector. A PC samples the data and generates the typical spectra.

Systematic bad and good welds have been done in Argon and in Corgon atmosphere. The belonging typical cross sections are shown in figure 7 to 10. Corgon delivers a better penetration because of its influence on the convection and absorption of the laser beam. The influence of Corgon on the plasma signal is significant. Whereas welding in Argon atmosphere does not show any difference between a full penetration weld and an insufficient weld, the typical spectra of welding in Corgon atmosphere differ very much (fig. 11 and fig. 12).

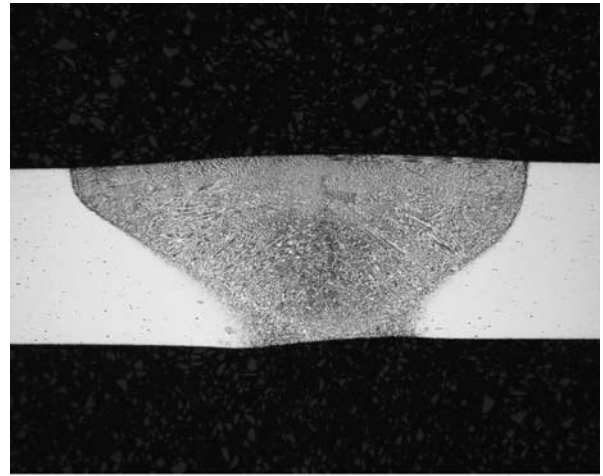
Welding of IN625 in Corgon atmosphere delivers at full penetration a typical Argon spectra. Several emission lines of characteristic Argon electron transitions are observed. The reason, why this is only observed at full penetration and only in Corgon atmosphere and not in pure Argon is not completely understood so far. Maybe there is an absorption effect that goes via the CO<sub>2</sub> in the broadest sense. Analyzing the cross sections, maybe at this process the temperature of the molten metal is over a certain level what enables electron transitions in Argon. The investigation of what originates that observed effect will be done in future. For that purpose variations of the materials and of the CO<sub>2</sub> content of the welding gas will be done among others. For an application of welding 1 mm thick IN625 sheets this method can be developed. Using a simple optics for visible light and applying a fast 3-point-measurement analyzing the peak-to-noise ratio an online weld monitor or even weld control should be possible for less than 10 k\$.



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500 μm

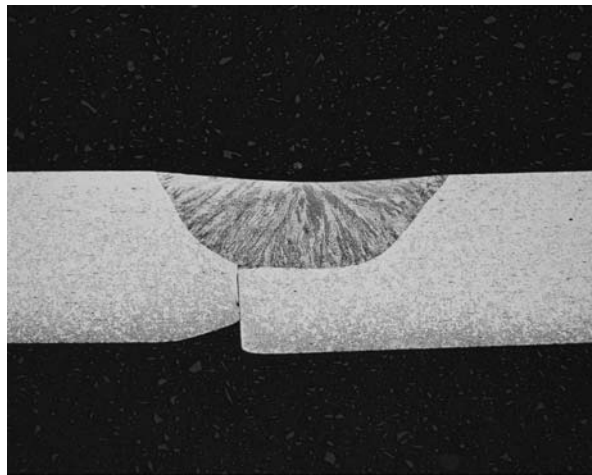
Figure 7 Cross section of IN625, welded in Argon, HPDL 1 kW, 1200 mm/min



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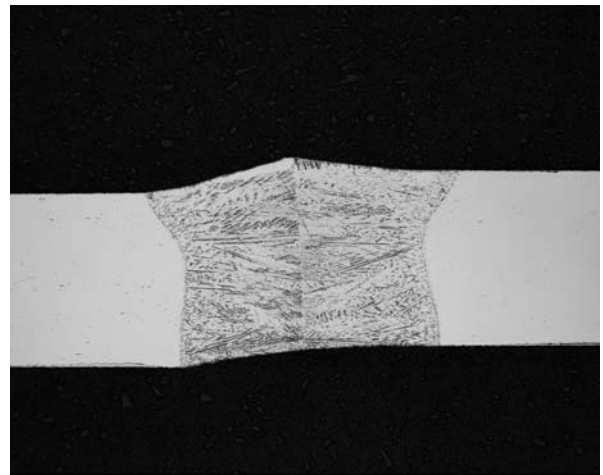
Figure 8 Cross section of IN625, welded in Argon, HPDL 1 kW, 600 mm/min



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Figure 9 Cross section of IN625, welded in Corgon, HPDL 1 kW, 2000 mm/min



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Figure 10 Cross section of IN625, welded in Corgon, HPDL 1 kW, 1000 mm/min

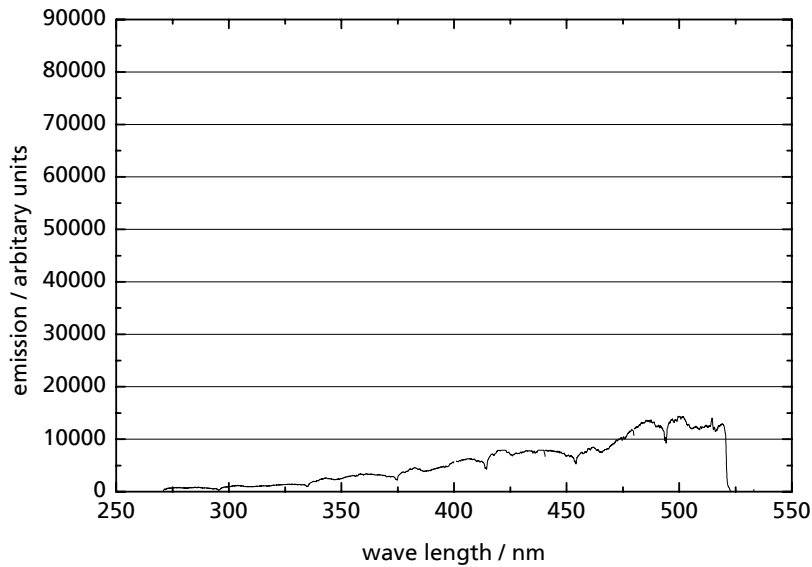


Figure 11 OES-diagram, welding of 1 mm IN625 in Argon atmosphere, similar diagram for full penetration and insufficient weld, HPDL 1kW

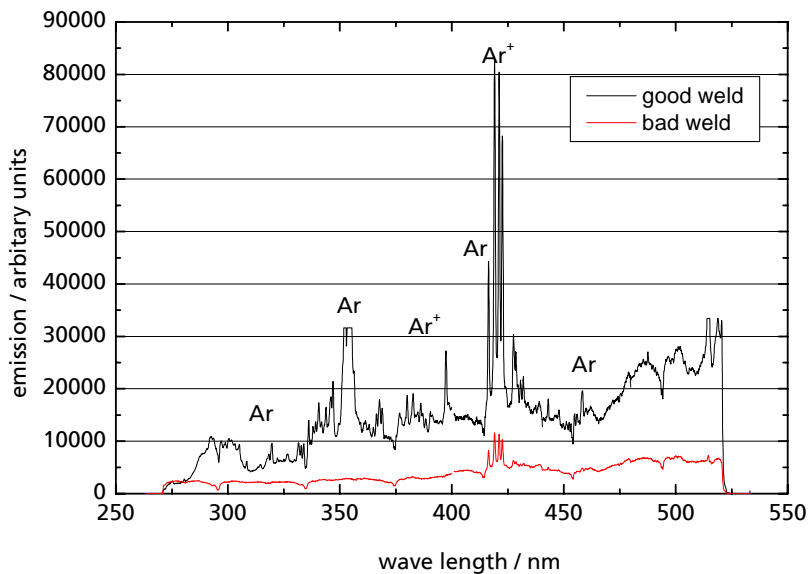


Figure 12 OES-diagram, welding of 1 mm IN625 in Corgon atmosphere (Ar + 18% CO<sub>2</sub>), comparison full penetration versus insufficient weld, HPDL 1kW

### Infrared Sensitive Camera

A CCD camera which is sensitive in the near infrared has been applied in combination with a notch filter around 760 nm and a conventional framer grabber running on a PC. They grabbed grey scale pictures show the temperature distribution in and around the weld during the process. For the first tests no calibration was done, because the aim was to “see” just

differences between full penetration welds and insufficient welds. A typical picture of a welding process is given in figure 13. Because there are just 256 grey scales the grey scale – intensity - assignment for the picture starts again from 0 (black) if 255 (white) has been achieved. From this follows that the hot spot in the middle of the weld looks darker than the surroundings. For the investigation of the method 20 single pictures have been shot during a welding

process. For a later process monitoring a faster picture acquiring is possible. The exposure time was in the range of 1/100 second. Two different methods of analyzing the pictures have been examined. The first has been the simple determining of the maximum pixel temperature. This was completed by a determination of the temperature spreading. Using a camera instead of a pyrometer, which gives just an average value measured over a larger area than a single CCD pixel is, enables to measure a value which is closer the real temperature within the hot spot. Therefore a better contrast between different welds becomes possible. On the other hand it is independent of the exact measurement position. This is important because the hot spot has a fluctuating position.

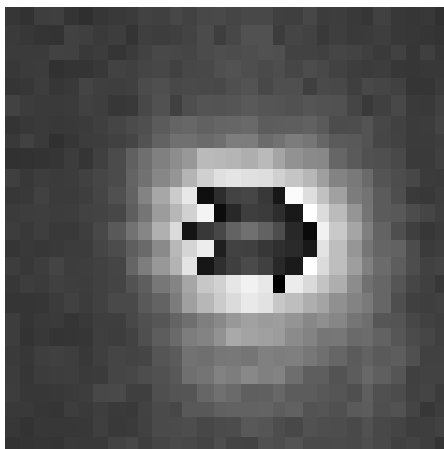


Figure 13 Typical picture of a full penetration weld at IN625, grey scales not calibrated, HPDL, 1 kW

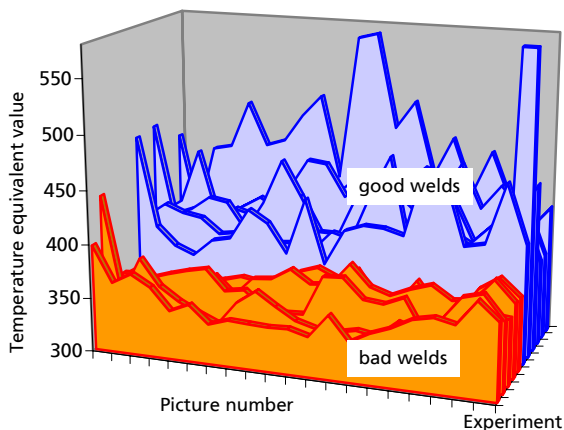


Figure 14 Temperature equivalent values over picture number and weld number, welding in Argon, conditions referring to fig. 7 – fig. 10

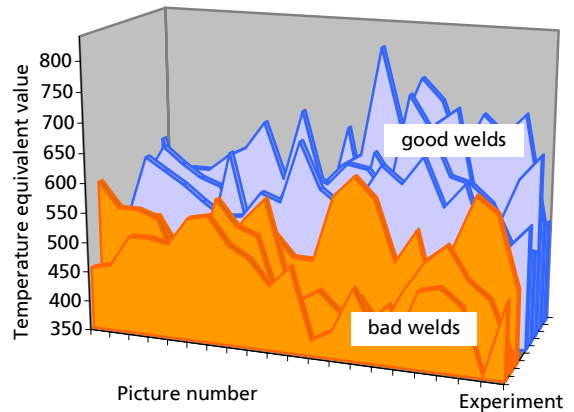


Figure 15 Temperature equivalent values over picture number and weld number, welding in Corgon, conditions referring to fig. 7 – fig. 10

All measurements show strong fluctuations, but there is obviously a significant contrast between full penetration welds (good welds) and insufficient welds (bad welds). And this is independently if the process runs in Argon or in Corgon (fig. 14 and fig. 15). Looking at the average values of each process the contrast becomes more explicit (fig. 16). These results deliver a hopeful base for a later weld monitor development. It means that full penetration leads to higher temperatures of the liquid metal because of more or less overheating. As long as the cross section is not completely molten the temperature of the melt is kept lower.

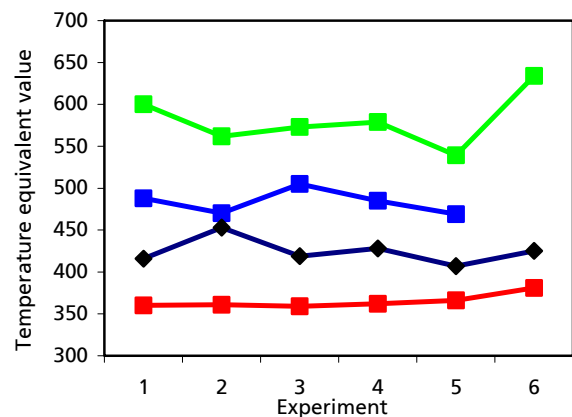


Figure 16 Average temperature equivalent values over picture number and weld number, welding in Corgon, conditions referring to fig. 7 – fig. 10

Looking at the results of the temperature spreading analysis the signal contrast is less obvious (fig. 17). The FWHM values do not deliver a definite result. The

width at a certain temperature level shows a contrast which is strongly connected to the information concerning the maximum temperature value. In the beginning was the hope, that full penetrations welds show a different width of a certain temperature level comparing to insufficient welds. But this could not verified reliably. The temperature spreading around the maximum value is rather less suitable for detecting full penetration. But maybe this information can be applied for some other monitoring objectives.

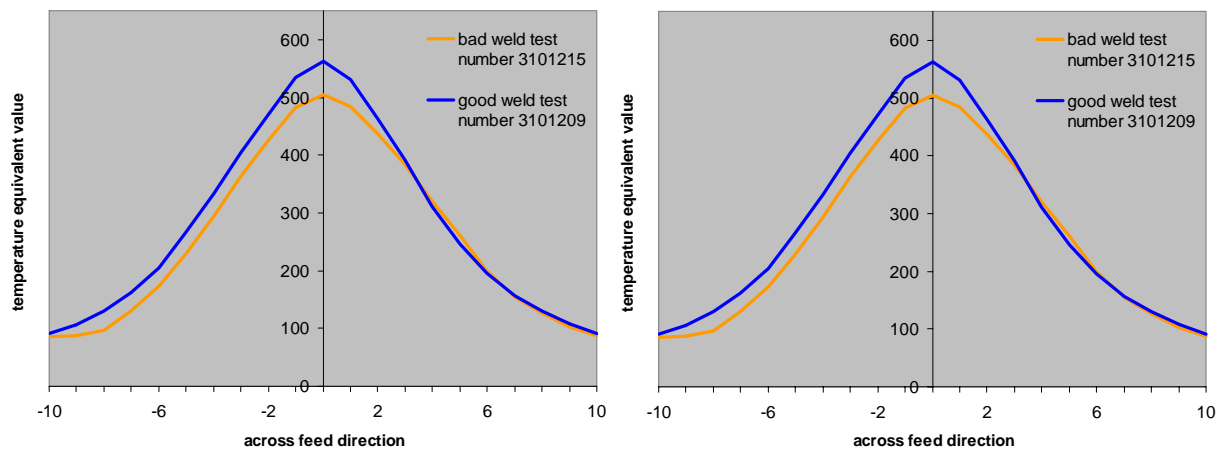


Figure 17 Temperature spreading during a welding process of IN625, HPDL, 1 kW, conditions referring to fig. 7 – fig. 10, left: Argon, right: Corgon

### Summary

Two different optical methods have been tested for monitoring the welding of IN625 sheets with high power diode laser. Optical emission spectroscopy gives an significant signal at full penetration welds only in Corgon atmosphere, Whereas the infrared sensitive camera system measures a different maximum temperature for full penetration welds in contrary to insufficient welds in Argon atmosphere as well as in Corgon. Both methods have the potential to be developed to a reliable monitoring or even controlling system for high power diode laser welding.

### Acknowledgements

This work has been done on behalf of the MTU Aero Engines GmbH, Munich, Germany. It has been supported by the European Union within the project “MMFSC - Manufacturing and Modelling of Fabricated Structural Components”.