LASER WELDING USING OPTICAL COHERENCE TOMOGRAPHY

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Nowadays the laser is a conventional tool used in industrial manufacturing for a wide variety of applications, from subtractive to additive, from cutting to welding. A major topic in production today is digitalisation and Industry 4.0. In this context the laser is playing a dominant role, because it is possible to produce a part directly from a digital model by contactless processing. This unique feature allows monitoring processes with smart devices, which is a key issue of Industry 4.0.

Sensor technology in particular is a leading component of a Smart Factory and predictive maintenance, and even process control. Transforming machine elements into intelligent cyber physical systems involves the integration of smart sensors for condition and process monitoring. Developing sensor systems especially for this industrial area is one of the main business units at Precitec and the use of Optical Coherence Tomography (OCT) in laser materials processing has become a substantive element of today's process monitoring and control activities.

OCT technology is basically an imaging technique based on low-coherence interferometry (LCI). It is a long-established medical examination procedure. An interferometer with a light source of low coherence length is used to measure distances and the composition of human tissue, e.g. the cornea. The low coherence length is achieved through the use of light sources that emit broad spectrum light. The applied light sources are typically super luminescent diodes (SLDs) with a range of some 10s of nanometers.

In contrast to sensor technologies which are typically used in laser materials processing, and which determine the process status by utilising the emissions emerging from beam-material interaction, OCT uses a dedicated light source which is coupled into the beam path of the processing laser. This allows the measuring position to be set individually, coaxially or with a slight offset to the processing beam or by using a deflection unit fully independently. The extremely high measuring frequency enables the use of this technology even with high speed laser processes. OCT technology is also called low coherence interferometry which describes the basic layout of the method, consisting of a reference and measuring path. The difference

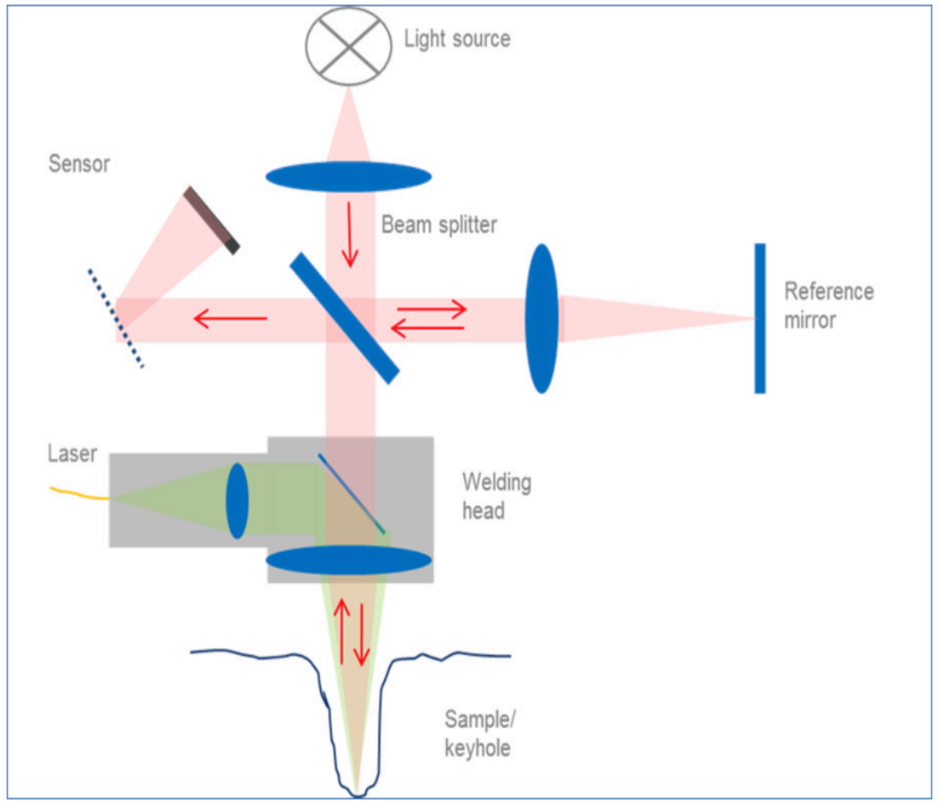

Figure 1: Schematic description of OCT adapted to a standard laser processing head.

between both paths can be precisely measured and as the reference path is fixed, the value derived from the system exactly matches the path difference, which is for example, depth of a keyhole or surface topology in LPBF or in surface ablation processes (see Figure 1).

Besides all the effort in mechanical and optical integration of the sensor components, the real innovation achieved with the adapted technology is as follows. The accuracy of the interferometric measurement is not affected by electromagnetic emissions from the vapor capillary or their adjacent areas, neither in deep penetration welding nor during laser surface modification. Only the specific light emitted from the low coherent light source leads to interference between the reference and the measurement path. These benefits of the sensor principle led Precitec to focus on this technology more than 10 years ago. Thus, with accurate positioning of the measuring point, a measurement of the depth of the keyhole is possible coaxially to the processing laser, regardless of weld geometry and material, the topography of a structured surface can be exactly determined independent of the surface condition. The only limitations are the dimension of the measurement point relative to the spot size of the laser processing and the size of the measurement range in the axial direction.

This technology opens new horizons for manufacturing with lasers, particularly with respect to:

- reduced manufacturing costs for an existing product
- improved quality in an existing product
- new product design
- reduced process costs
- shorter development lead time
- improved quality assurance
- detection and correction of defects during early production stages
- real-time controlled processes

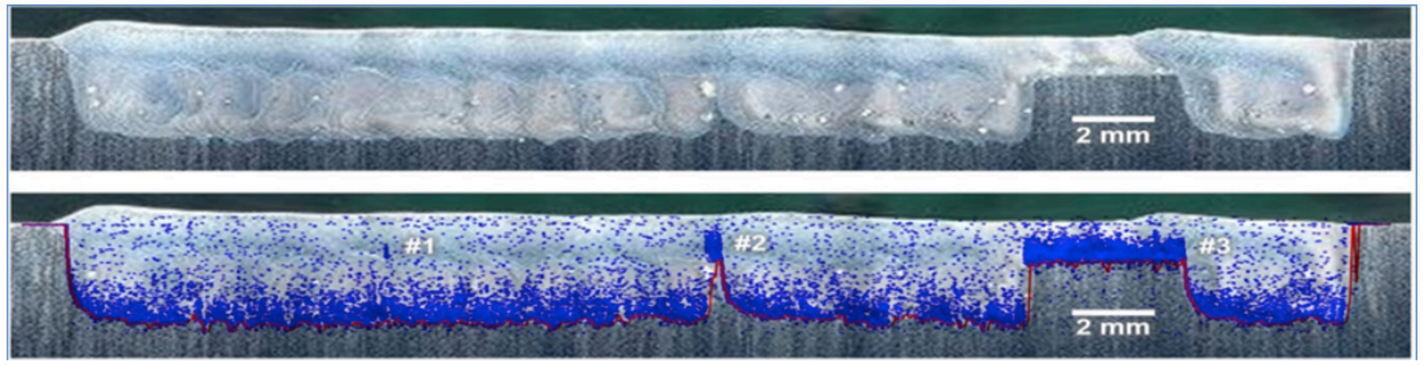

Figure 2: Application example: IDM signal extraction for a weld in stainless steel and three intentional interruptions of the laser power (#1: 1ms; #2: 10ms; #3: 100ms).

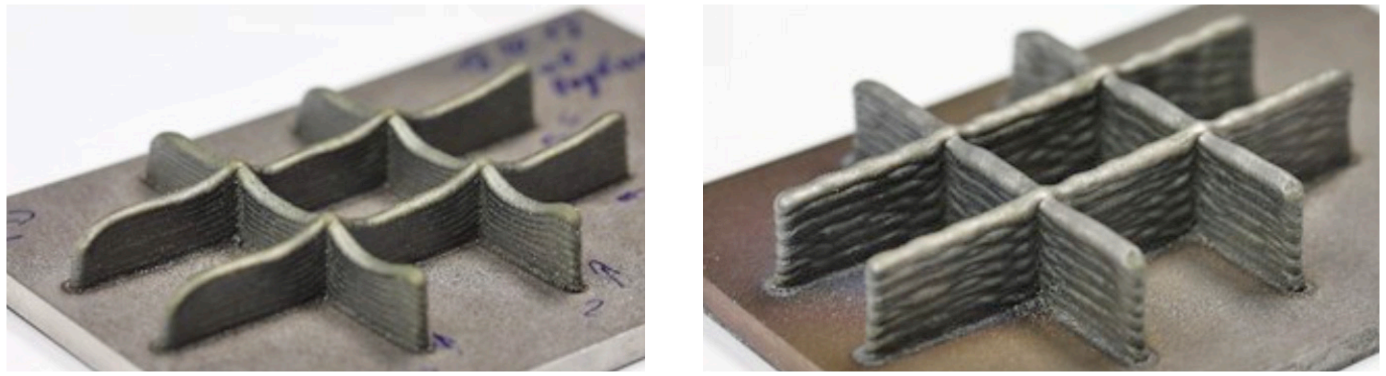

Figure 3: Results of the closed-loop-controlled process in comparison to a non-controlled.

All the statements listed above were proven to be true in an industrial application where the laser was used to weld safety-relevant parts for the automotive industry. This was the first application world-wide in which the measurement of an OCT sensor was taken to control the laser power and thus control the penetration depth of the weld seam during serial production. The measuring equipment suitability was proven by the customer. This effort and the costs for the sensor paid for itself after 3 months. In particular the dramatic reduction of destructive testing is one major reason for the customer's satisfaction.

It has been shown that the accurate positioning of the OCT measuring spot is a key element for successful industrial implementation. In order to to secure the correct spot position during production against various outside influences, e.g. thermal impact on optical components, Precitec developed a module named KeyholeFinder. All moving elements consist of industrially-proven parts which guarantee a static position of the measuring spot. The module KeyholeFinder also is the preferred solution to automatically adjust the OCT sensor during system setup.

With respect to demand for complete monitoring or even control, additive manufacturing processes like laser metal deposition (LMD) and laser powder bed fusion (LPBF) are not distinguished from other laser applications.

Precitec demonstrated in miscellaneous applications, that OCT is the most promising sensor technology to acquire the most comprehensive information regarding the topology of the processing result and, due to the coaxial adaptation, this is possible in-situ. Possible process error conditions in 3D printing with LPBF – for example pores, distortion, coating defects, layer offsets or even the so-called balling effect, will result in topography changes and therefore are picture perfect to be detected and measured with OCT technology.

Just recently this year Siemens and Precitec demonstrated a fully closed-loop controlled LMD process by integrating the OCT technology into the SINUMERIK control. What is true for other laser manufacturing processes also holds true for LMD, even the metal powder blown to the workpiece surface does not change the exact surface topology measurement and so the metered value can be used as input for a control loop. This work was carried out in a funded project by the European commission called PARADDISE - A Productive, Affordable and Reliable solution for large scale manufacturing of metallic components by combining laser-based ADDItive and Subtractive processes with high Efficiency (see Figure 3).

Looking back at the last 5 years from the first industrial version of an OCT sensor for the use in laser materials processing applications (presented by Precitec) until today, this sensor took scientific and industrial users by storm. It is unusual to find any laser conference without dedicated OCT sessions. There is a generation of young scientists growing up who cannot believe that there was a pre-OCT time. In many Universities and Research Institutes this sensor is used as a standard to set up laser processes or to evaluate the processing result, from cw laser to short and ultra-short pulsed processing.

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SEE OBSERVATIONS P29