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Vision and spectroscopic sensing for joint tracing in narrow gap laser butt welding

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ABSTRACT

The automated laser beam butt welding process is sensitive to positioning the laser beam with respect to the joint because a small offset may result in detrimental lack of sidewall fusion. This problem is even more pronounced in case of narrow gap butt welding, where most of the commercial automatic joint tracing systems fail to detect the exact position and size of the gap. In this work, a dual vision and spectroscopic sensing approach is proposed to trace narrow gap butt joints during laser welding. The system consists of a camera with suitable illumination and matched optical filters and a fast miniature spectrometer. An image processing algorithm of the camera recordings has been developed in order to estimate the laser spot position relative to the joint position. The spectral emissions from the laser induced plasma plume have been acquired by the spectrometer, and based on the measurements of the intensities of selected lines of the spectrum, the electron temperature signal has been calculated and correlated to variations of process conditions. The individual performances of these two systems have been experimentally investigated and evaluated offline by data from several welding experiments, where artificial abrupt as well as gradual deviations of the laser beam out of the joint were produced. Results indicate that a combination of the information provided by the vision and spectroscopic systems is beneficial for development of a hybrid sensing system for joint tracing.

1. Introduction

Robotized laser beam welding (LBW) is one enabler for manufacturing industries to produce efficient joining of metal parts with high quality. One of the main advantages of LBW is the possibility to focus the energy of the laser beam into a small spot. This allows an efficient energy transfer onto the material resulting in high aspect ratio seams with narrow widths, and therefore a high level of precision in the welding process. One down side related to the resulting narrow fusion zone is that the process requires strict fit up tolerances as well as accurate joint preparation, robot motions and fixturing. Furthermore, LBW is also susceptible to joint deviations caused by heat induced distortions that occur during welding. Especially in the case of laser butt welding, these problems are key issues because even a small offset of the laser spot from the joint may result in lack of sidewall fusion within the seam. Fig. 1.1 shows a cross section of a weld, where the laser beam spot had hit the work piece with an offset of 1 mm aside from the joint. The result is a clearly seen lack of sidewall fusion. This type of defect can hardly be noticed by ocular inspections, since they are often hidden by fused metal both on the top and root side of the weld. It is furthermore problematic to detect such defects by non-destructive testing since the voids caused by lack of sidewall fusion are typically very flat and oriented in such a way that e.g. ultrasonic testing fails in detection. One commonly used way to avoid this problem is to apply systems for joint tracing and/or joint tracking. Existing joint tracking devices often use structured light constituting laser triangulation to get a distance profile of the parts to be welded. Several commercial systems are available using this method, examples can be found in [1–3]. Although these systems work well in many joint configurations such as V-groove, fillet- and lap joints, they are not robust enough in the case of narrow gap butt joints (situations with machined parts, when tolerances for gap size and mismatch between the parts are small) where the gap size is close to zero (<0.1 mm).

Various methods for joint tracking during narrow gap butt welding have been addressed by several researchers. Different concepts and principles regarding sensors for joint tracking are presented in [4], where a multi sensor concept is introduced, using a CMOS camera and low power laser source for illumination, for tracking and also for measuring the displacement between the

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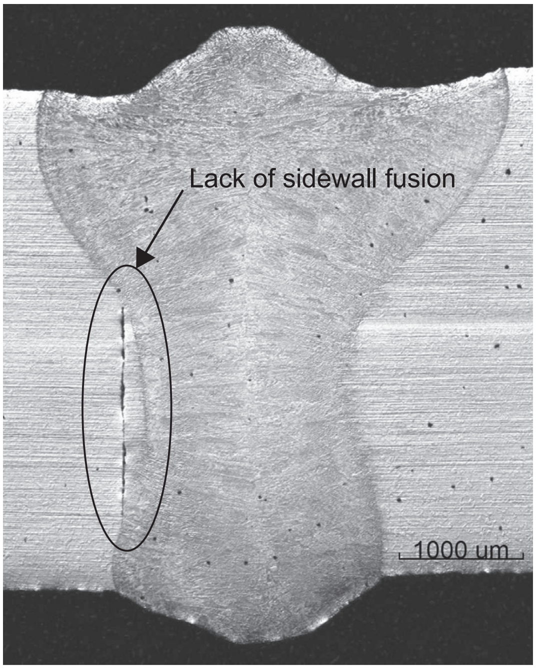

Fig. 1.1. Cross section of a welded butt joint when the laser spot was offset 1 mm from the joint.

LBW tool and the work piece. A method using a CCD camera and a vision algorithm to track narrow joints is described in [5] with promising results shown for an arc welding application, but not for LBW. In [6] a CMOS camera is used to capture images during LBW. A texture based algorithm is suggested where the difference in surface texture of the two work pieces is used to find the joint position. The method shows good results, but a teaching procedure is required for each test case, and the algorithm is expensive in terms of computational power, which makes it unsuitable for real-time applications. A combination of 2D feature extraction and 3D laser triangulation measurements were used in [7] to find narrow weld joint gaps. However, the system is only evaluated for 0.1 mm joint gaps, not for smaller gaps. In [8] an infrared camera, placed off-axis, was used for joint tracking during fiber LBW. The method showed promising results, but integrating a bulky camera system off-axis may not be an option in an industrial implementation. A novel approach, using a magneto-optical sensor, was used in [9] to detect "micro gaps" (<0.1 mm) during laser butt joint welding. Good results are shown, however the method requires integration of an electromagnet on the root side of the work piece. This is not possible in general industrial applications, i.e. when complex parts are to be welded. Although showing promising results none of the referred systems prove to be a robust enough solution for joint tracing of narrow gap butt joints. This applies especially for LBW of complex geometries with limited access, which requires the sensor to be integrated into the LBW tool.

In view of the complexity of the task to trace the position of a narrow gap during the LBW process, combining the information acquired by different sensors could constitute a more effective approach instead of relying on just one sensor. An online measurement system based on multiple sensors, i.e. embedding photodiodes, spectrometers, visible imaging and X-ray imaging has been proposed in [10] in order to monitor the welding status. Among the available sensing technologies that could be usefully implemented in a novel hybrid solution for narrow gap LBW joint tracing, vision based systems and optical spectrometers have shown great potential. In [11] camera images of the plasma plume were captured during CO_2 LBW of T-joints, and image parameters and descriptors were extracted to detect beam offset from the joint. In [12] a vision system was used, developing an image processing algorithm to monitor the joint width. As regards optical sensors based on plasma spectroscopy, in [13] a correlation was demonstrated between the LBW plasma electron temperature and the weld quality. A correlation analysis of the welding plasma emission spectra revealed that the dynamics of the plume is strictly related to the stability of the process [14]. Based on these results, several signals, like e.g. the correlation coefficient between lines of different elements [15] or the plasma electron temperature [16], have been extracted from the optical spectra to detect in real time the occurrence of weld defects. The influence of the laser beam power and the travel speed on the electron temperature signal in relation with the joint width and penetration depth has been investigated [17], as well as alterations of the gas shielding conditions leading to defects like weld oxidation or porosity revealed by abrupt changes of the plasma emission and thermodynamic features [16,18]. Although it has been successfully demonstrated that such spectroscopic signals can be used to predict [19] and control [20] in real time the penetration depth during laser lap joint welding, by acting on the laser power, this kind of approach has not been investigated yet for joint tracing purposes. In [21] the welding plasma electron temperature was acquired together with high-speed images of the melt pool during narrow gap lap welding of AZ31B magnesium alloy sheets revealing a correlation of those data with the presence of oxide layers within the gap, which eventually led to porosities in the joint. Therefore, while showing promising results as stand-alone sensors to detect in real-time specific LBW issues and/or defects, a combination of optical spectrometers and vision based systems has not yet been deeply investigated to trace the joint during LBW of narrow gap butt joints.

In this work, we present experimental results from a dual-sensing approach including a calibrated CMOS camera and a miniature spectrometer for detection of deviations of the laser spot from the joint in LBW of narrow gap butt joints. Image and signal processing algorithms have been developed to extract information from the acquisitions by the two devices. This improves detection reliability by redundant information and detection capability by complementary information. The limitations of the two respective sensing methods in detecting deviations of the laser beam outside the joint are discussed together with their complementarities looking for the development of a hybrid sensing system combining data from both devices.

2. Material and methods

The welding equipment, sensor systems and experiments are described.

2.1. Robotized laser system setup and weld materials

An industrial robot, ABB IRB4400, is used for the LBW tool manipulation. The tool center point position is continuously recorded by the system during the welding experiments, and is used as a reference when evaluating the performance of the two tracing systems.

The robotized LBW cell is equipped with a 1070 nm wavelength IPG Ytterbium Fiber Laser (YLR-6000-S, 6 kW) together with a LBW tool from Permanova Laser System AB. By using a 600 μm optical fiber, a collimating lens with a 160 mm focal length and a focusing lens with a 300 mm focal length, a laser spot diameter of 1.12 mm and a Rayleigh length of 13.7 mm is obtained. The laser spot was focused on the surface of the work piece and the average power used during the experiments was 2150 W.