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Research paper

Assessment of laser weld width based on time and frequency domains of ultrasonic testing signals

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ABSTRACT

The ultrasonic test is used for evaluating the laser weld width and the direction perpendicular to the laser weld is adopted for the scan. In the frequency domain analysis, the frequency spectrum characteristic curve shows that the change of the main frequency is in good agreement with the position of the probe. The boundary of the weld width is evaluated using amplitude changes of the main frequency in the base metal and fusion zones. The tested values have larger errors compared to the actual values when the weld width is small. A mathematical model of calculating small weld widths is established based on the time domain signal. The results after correction fit the actual values well, and most of the relative errors are within 0.1 mm. From an analysis of the error statistics, the accuracy and stability after correction meet the requirements of engineering applications and provide an important basis for the quality evaluation of laser welds.

1. Introduction

Hong and Shin (2017) reported that laser welding has advantages including no indentation, small deformation after welding, high positional accuracy and high strength compared with traditional resistance spot welding. However, Ao et al. (2015) stated that the highly dynamic process and energy transferred from the laser beam to the material are extremely unstable during the laser welding. Sathiya et al. (2012) believed that it is significant to find an effective method to evaluate the quality of laser welds. Weld width, which is an important geometric parameter of laser welding, can be used to evaluate the quality of a weld combined with welding parameters according to the study by Chen and Gao (2014). They used the infrared imaging during high-power fibre laser welding to detect the weld width as a process inspection method. For a lap joint, Gu et al. (2013) considered that the formation of the weld requires the fusion of two plates at the interface and the width of the fusion zone at the interface (weld width) is closely related to the quality of the weld. They claimed that a key problem with testing the weld width at the interface is performing a rapid evaluation of the weld quality.

For the laser welding, destructive inspecting with low efficiency and high cost has often been used. It is of great importance to implement online non-destructive inspections and quality evaluations for laser welds. Chertov et al. (2007) and Zhou et al. (2016) described how the ultrasonic nondestructive testing is popular because of its convenience, efficiency, reliability, security and economic efficiency. As ultrasonic signals in base metal and fusion zones have different characteristics in the time and frequency domains, as studied by Chen et al. (2009), the weld width can be determined by extracting these characteristic values. In this paper, ultrasonic nondestructive testing technology is used to accurately evaluate laser weld width for actual production needs during fabrication of stainless steel railway vehicles body. Weld widths are tested by a frequency spectrum characteristic curve and calculated by the model established over the time domain signal. Its accuracy completely meets the requirements for engineering applications.

2. Materials and experimental procedure

2.1. Specimen preparation

The SUS301L austenitic stainless steel is used as the base material, with the chemical composition and mechanical properties shown in Tables 1 and 2, respectively. A Trudisk 4002 disk solid laser welding machine is used for the welding, with the parameters shown in Table 3. Thicknesses of 1 and 1.2 mm are chosen and a lap joint is used. Fig. 1 shows a welding diagram for the stainless steel railway vehicle bodies. The stainless steel skin covers outside of the frame and the laser beam welds the inside of the frame. Taskin et al. (2009) showed that different

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Table 1
Chemical composition of the SUS301L austenitic stainless steel (wt.%).

C	Si	Mn	P	S	Ni	Cr	N
≤0.03	≤1.00	≤2.00	≤0.045	≤0.03	6.00–8.00	16.00 − 18.00	≤0.20

Table 2
Mechanical properties of the SUS301L austenitic stainless steel.

Tensile strength (N/mm^2)	Yield strength (N/mm^2)	Elongation%	Hardness HV
≥930	≥685	≥20	≤218

Table 3
Parameters of used for the Trudisk 4002 disk solid laser welding machine.

Rated power	Laser beam wavelength	Laser beam quality	Optical fibre diameter	Lens focal length
4 kW	1.06 µm	8 mm·mrad	0.6 mm	250 mm

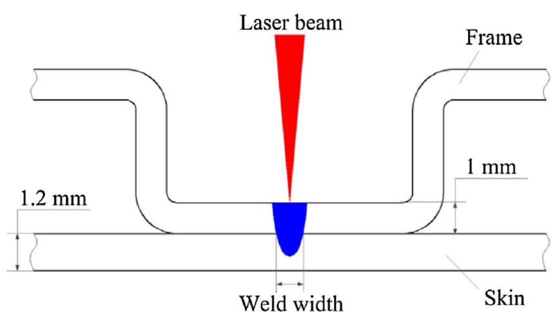

Fig. 1. Diagram of the laser welded joint in the stainless steel vehicle bodies.

Table 4
Welding parameters used during laser welding.

Group	Laser power (kW)	Welding speed (mm/s)	Defocusing distance (mm)
1	1.1	22	0
2	1.3	22	0
3	1.4	20	0
4	1.6	20	0
5	1.8	18	0
6	2	18	1
7	2.2	16	−1
8	2.4	15	0

weld widths are obtained by adjusting the welding parameters, including laser power, welding speed and defocusing distance. Table 4 lists the eight groups of welding parameters used in this work. The length of each weld is 100 mm and eight welds with different widths are fabricated.

2.2. Testing device

The ultrasonic testing device used in the study is composed of a 15 MHz focused ultrasonic probe, a 100 MHz ultrasound card, an *x-y* mechanical scanning platform, and a portable industrial computer. The ultrasonic probe is equipped a delay block with a diameter of 2.5 mm. The ultrasonic scanning test process operates automatically as defined by a set program in the computer. The accuracy of the scanning step size is 0.02 mm. During the scan, the ultrasonic probe collects data after each step of the stepper motor. From this, a two-dimensional A-scan data matrix is obtained, stored in the computer, and used for analysis.

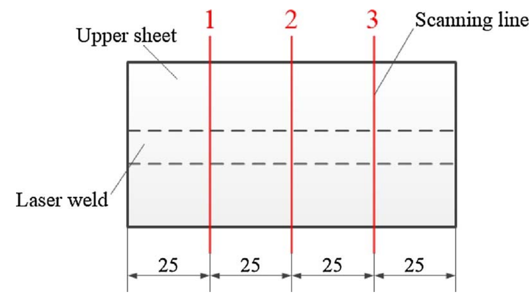

Fig. 2. Schematic diagram of the probe scanning path over the three scanning lines.

2.3. Experimental method

To avoid the influence that excess weld metal has on the ultrasonic scan, the opposite side of the weld is selected as the scanning plane. Water is used as the coupling agent between the ultrasonic probe and stainless steel sheet. As this work mainly studies the weld width, scans perpendicular to the laser weld are mainly used at a scanning step length of 0.08 mm. A total of 200 and 400 scanning and sampling points are chosen, respectively. Considering that the weld width always has a certain variation for constant welding conditions, three different scanning lines are used in each weld, as shown in Fig. 2. The probe moves along these scanning lines. After each scan, a series of A-scan data are obtained and used for analysis.

Fig. 3 shows the ultrasonic propagation path at different positions around the laser weld. At position 1 (in the base metal zone), the ultrasonic pulse incident to the bottom of the upper sheet is almost completely reflected. At position 2 (in the conjugation zone), the echoes contain a reflection from both the bottoms of the upper sheet and the lower sheet. At position 3 (in the fusion zone), the echoes are fully reflected from the bottom of the lower sheet for cases where the weld width is much larger than the diameter of the delay block. In an actual test, some weld widths are smaller than the diameter of the delay block. Thus, the echo reflected from the bottom of the upper sheet is often found when the probe is at position 3.

The actual values of the weld widths are measured using optical microscopy. Twenty-four weld specimens are cut along the scanning lines after the ultrasonic test using an end mill to produce a flat surface and leaving a certain allowance for sandpaper grinding. After polishing and etching, the specimen is observed using an optical microscope, as shown in Fig. 4.

3. Results and discussion

3.1. Time and frequency domain analysis

Ultrasonic A-scans and their corresponding frequency spectrum characteristic curves (determined via Fast Fourier Transforms (FFT) of

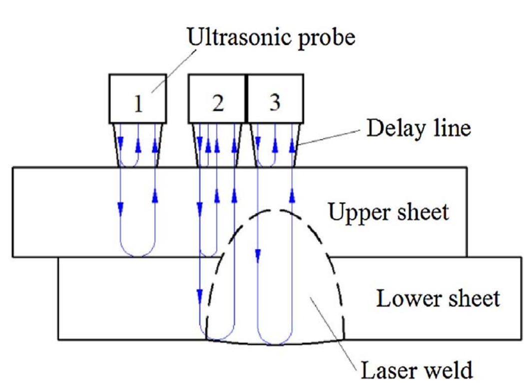

Fig. 3. Ultrasonic propagation paths over different laser weld positions.