Journal of Materials Processing Technology 170 (2005) 403–411

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Application of artificial neural network in laser welding defect diagnosis ☆

Hong Luo [a,*], Hao Zeng [a], Lunji Hu [b], Xiyuan Hu [b], Zhude Zhou [b]

[a] *Singapore Institute of Manufacturing Technology, 71 Nanyang Drive, Singapore 638075, Singapore*
[b] *Huazhong University of Science and Technology, Wuhan 430074, PR China*

Received 30 April 2003; received in revised form 2 February 2005; accepted 3 June 2005

Abstract

In this paper, audible sounds during keyhole and conduction laser welding were analyzed. The characteristic signals representing good welding quality was from 10 to 20 kHz. The more the welded metal vaporizes, the higher the plasma temperature and the stronger the acoustic signals. Furthermore, keyhole shape also affected the acoustic signal intensities.

Then time domain, frequency domain and wavelet analysis methods were used to analyze the acoustic signals. It was proved that frequency distributions are a better way to identify welding defects. The wavelet analysis results showed that the intensity of low frequency (<781 Hz) components of the sound signals decreased dramatically when welding defects occurred.

At the end, an artificial neural network (ANN) was constructed to diagnose welding faults. Features extracted from the acoustic signals were input into the ANN. After training, the ANN could be used to identify between normal and abnormal welds.

Keywords: Laser welding; Fault diagnosis; Laser-induced plasma; Audible sound; Wavelet analysis; ANN

1. Introduction

There exist a lot of factors and interactions during laser keyhole welding, for example: the melting and vaporisation of materials, keyhole formation and Fresnel absorption of incident laser at the keyhole wall, laser–plasma–material interaction and energy coupling through inverse Bremsstrahlung in the plasma. These phenomena make the process very complex. However, they also provide many sources for monitoring the welding process itself.

Typical signals used to monitor laser welding include acoustic emission [1,2], audible sound [3,4], weld pool infrared emission [5], voltage difference between work-piece and nozzle [6,7], visible light [8–10] and ultraviolet emissions [11,12] from laser-induced plasma. Fig. 1 summarizes various sensing methods for real-time laser welding monitoring.

It has been proved that keyhole formation and stability plays an important role in laser welding. The behaviour of laser-induced plasma is closely related to the formation of keyhole, and thus it can be seen as a good indicator of laser welding quality. Among the various monitoring methods, audible sound from the laser-induced plasma is one of the most promising signals and has been explored extensively. However, the problem is that acoustic emissions from the plasma are not analysed thoroughly to obtain the characteristic signals representing the behaviour of the plasma. There is also a lack of theoretical foundation for this monitoring method.

In the present study, the objectives are, firstly, to investigate the acoustic emissions from the laser-induced plasma in order to obtain the characteristic signals. Secondly, find a theoretical relationship between these signals with the laser welding quality. Thirdly, analyse the signals when welding defects occur by various signal-processing methods, such as FFT and wavelet analysis. Lastly, an artificial neural network will be set up and trained to identify welding quality.

☆ The work presented in this paper was carried out at Huazhong University of Science and Technology. Dr. Luo and Dr. Zeng are currently with Singapore Institute of Manufacturing Technology. They used to work at Huazhong University of Science and Technology.

* Corresponding author. Tel.: +65 67938294.
E-mail address: hluo@simtech.a-star.edu.sg (H. Luo).

0924-0136/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.jmatprotec.2005.06.008

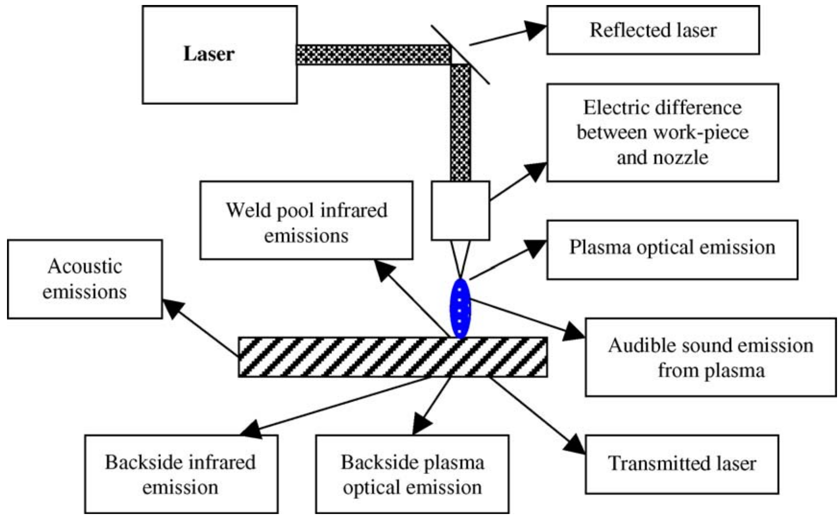

Fig. 1. Various signals used for real time laser welding monitoring.

2. Experimental system

The formation of keyhole and laser-induced plasma is an indicator of deep penetration welding. In order to investigate the audible sound emitted from the laser-induced plasma during keyhole laser welding, sound level meter (SLM) was used to analyse the acoustic emissions. A diagram of the system is shown in Fig. 2.

For audible acoustic signals, an electrets microphone (CZII-65), which is directionally sensitive (60 degrees), was used to capture audible sound (0 Hz–20 kHz) and to eliminate noises coming from other directions.

The data acquisition system had an A/D card (AdvanTech PCL-818HD) with a 12-bit accuracy and a maximum sampling rate of 100 kHz. The signals were pre-processed by a band-pass filter (10–20 kHz) and then the signal intensities were fed into the data acquisition system. (During spectral analysis, original sound signals were used without band-pass filtering.)

All the experiments were carried out under the following conditions:

- Axial fast flow CO_2 laser with the maximum power of 1500 W.

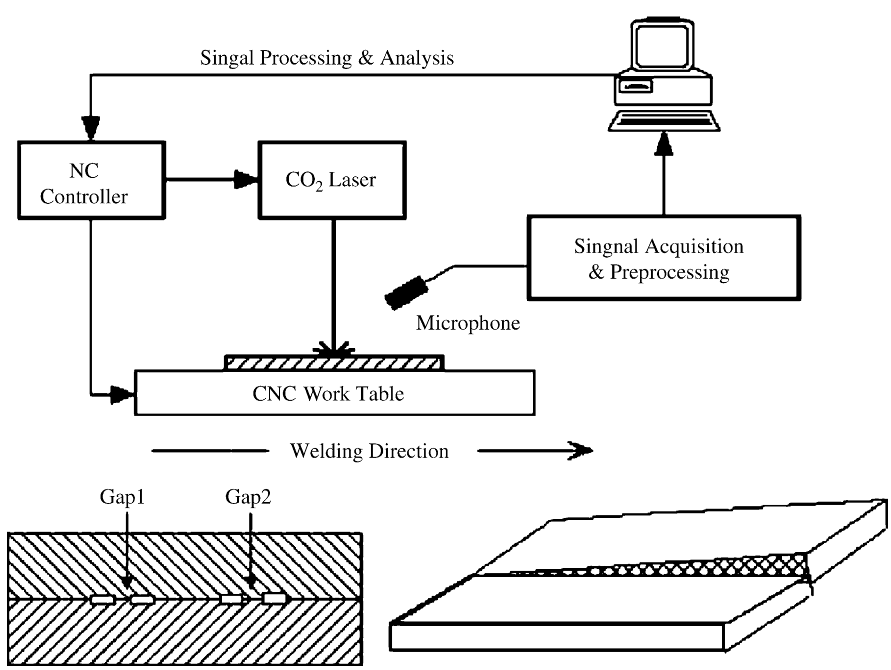

Fig. 2. Acoustic signal analysis system and test samples with gap and misalignment.