Journal of the Optical Society of Korea, Vol. 7, No. 3, September 2003, pp. 193-196

Laser Welding Quality Monitoring with an Optical Fiber System

Dohyoung Kim
Dept. of Applied Photonic Eng., Grad. Sch., Chosun University, Gwangju 501-759, KOREA

Jin-Tae Kim*
Dept. of Photonic Eng., College of Eng., Chosun University, Gwangju 501-759, KOREA

Chin-Man Chung, Sung-Hoon Baik, Seung-Kyu Park, and Min-Suk Kim
Lab. for Quantum Optics, Korea Atomic Energy Research Institute,
Daejeon 305-301, KOREA

(Received March 25, 2003)

We have developed a laser welding monitoring system to monitor laser welding process conditions such as sample feed rate, laser focal position, and laser power. A 2 kW Nd:YAG CW laser beam has been applied to the welding of a stainless steel plate (SUS306) to investigate the welding monitoring. The radiation signal from the weld pool was guided back through the focusing optics and the laser delivery fiber, and measured by a photo detector. By changing the focus of the laser beam along the z-direction, the penetration depth of the welding material has been measured. That shows the penetration depth depends on the frequency fluctuations of the plume signals which can be used in welding quality control.

OCIS codes : 060.2370,120.0280,120.4570.

I. INTRODUCTION

Laser welding has advantages for welding materials more precisely. It differs which is different from the conventional welding methods due to the precise focusing of the laser beam and the small heat affected zone (HAZ). Laser welding technology has developed rapidly with respect to the developments of high power lasers such as CO_2, Nd:YAG laser, etc.

Laser welding has been applied to safety related parts in the automotive industry. It is necessary to investigate the welding quality in car bodies with 100% absolute confidence for safety checks. In the case of checking the welding quality by using a collected specimen after welding the car body, quality investigation of the entire welded car body can not be assured with 100% absolute confidence. Also, it wastes expensive welding materials although welding defects can be found after welding. Thus, the development of a real time welding monitoring system is urgently required.

A high power laser beam can be transported through an optical fiber so that it is much easier to detect the radiation signal from the welding zone by guiding the radiation back through the optical fiber and delivery optics. There are many ways for laser welding quality monitoring such as the capacitance change measurement between the welding surface and a bundle of optics for focusing the laser beam, and using acoustic waves generated during laser welding, and generated X-ray in real time [1-6]. There are various ways for checking optical welding quality monitoring such as chromatic filtering, etc. [7]. However, these are very complex and expensive ways. In previous welding monitoring similar to our method, the reference welding signal of welding material was generated by using the envelope curve technique [8]. Those signals at defined upper and lower distance limit to the signal were compared with the current welding signals. Thus, the error signal between the current and reference signal can be controlled through PLC. In this work the frequency components in optical signals are correlated to the penetration depth for welding monitoring. However, that frequency dependence is quite different from the welding sample due to the welding characteristics of the samples. Thus, different samples should be carefully analyzed in intensity, frequency, etc. for the good evaluation of the welding.

In this work we chose stainless steel (SUS306) welding specimen and a real time welding quality monitoring system using thermal radiation, plume spectra, etc. generated during the laser welding has been developed. We realized that laser power change, focal length change, and frequency components of photodetector signals due to plasma, and plume are correlated well to the penetration depth of the welding.

II. EXPERIMENT

The welding monitoring system by using thermal radiation, the plasma, etc. generated during laser welding has been described in the previous article [8]. Our experimental setup for welding monitoring is shown in Fig. 1. After a laser beam is focused through the optical fiber and collection lens, the thermal, plume, and plasma radiation signals are transported back to a single element photodiode detector through the collection lens, optical fiber, the band pass filter, and collection lens. The obtained photodiode detector signals are digitized and analyzed in the PC based oscilloscope (SDS-200).

To select the appropriate bandpass filter for our experiment we illuminated a halogen lamp on the welding plate to obtain the spectra of the light reflected back from the plate through the mirrors and optical fiber. Analyzing the obtained spectra by using a spectrometer (K-Mac Co.), we could ascertain the wavelength absorbed due to the coated mirrors for a 1.06 μm laser wavelength.

In this experiment we used a bandpass filter transmitting 633 nm wavelength. We used a CW Nd:YAG laser made by the Trumph company with the 1.06 μm wavelength, four step amplification resonator, 10 mm rod diameter, 150 mm rod length, and 2 kW average power. Laser beam was transported from the oscillator to the welding pool using an optical fiber with 600 μm diameter and 0.22 numerical aperture (NA). The laser beam was focused on the welding area by using a lens with 200 mm focal length. The diameter of the lens is 60 mm so that the f-number is 3.3. The laser beam waist size on the welding area was controlled by adjusting z-axis distance from the stage holding the welding sample to a focusing optics. We changed z-axis distance by varying the distance between a focusingl optics and the stage with the programmable CNC machine code. Diode laser beam with an equal path to that of Nd:YAG laser beam was illuminated on the welding surface to check the welding position. The laser beam size focused on the welding surface was approximately 800 μm and the moving speed of the stage was 40 mm/s. High speed DET100 silicon single element photodiode detector from the Thor Labs Co. was used to detect the radiation signal.

III. OBSERVATIONS AND DISCUSSION

We used a stainless steel (SUS306) sample for the welding. The two plates with different thickness were welded together by a laser. We have tried several welding sample sets with 2 mm+ 2mm, 1 mm + 1 mm , 2 mm +1 mm, 1 mm + 2 mm thickness to obtain the correlation between the penetration depth and the reflected radiation signal. In a set with 1 mm + 1 mm thickness the welding was done well by using a 2 kW CW Nd:YAG laser. The different sets were not good for the welding because the thickness of the plates was too thick.

In a set with 1 mm+ 1 mm thickness the welding was done well by using a 2 kW Nd:YAG laser. Fig. 2 shows the radiation signal and the back surface of the welded plates with 1 mm + 1 mm thickness with respect to the focal length change of the laser. The laser beam was defocused from +6 mm to -6 mm distance on the surface of the welding sample during the welding. Thus, at the center of the traveling distance the laser beam was quite well focused on the surface. Welding distance was 70 mm and welding speed 40 mm/s. In Fig. 2 the horizontal axis is welding time

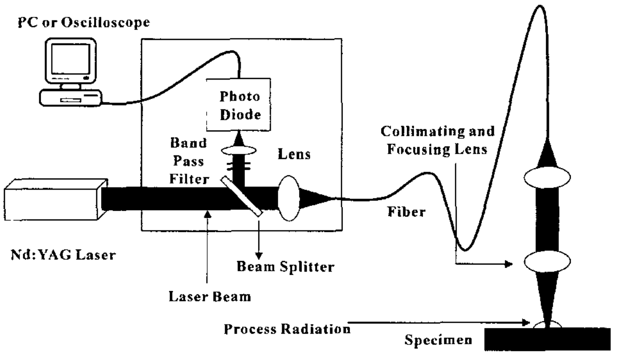

FIG. 1. Experimental setup for real time welding monitoring.

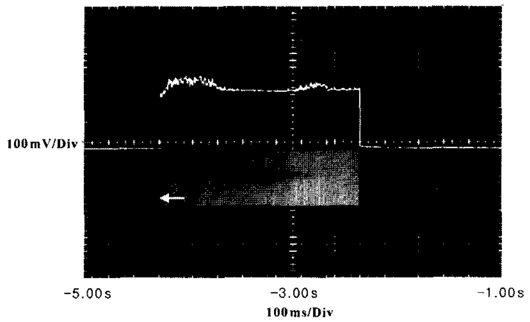

FIG. 2. Radiation signal from welding pool and the back surface of the welded plates with respect to the change of the focal length.

in seconds and the vertical axis is radiation intensity. Also, the back surface of the welded sample is below the radiation signal in Fig. 2. The arrow on the sample surface represents the welding starting point. The welding starting and ending points in the welding sample were set to be equal for the welding starting and ending time in the radiation signal. The penetration depth with respect to the change of the laser defocusing length was measured. The back surface of welded plates in Fig. 2 shows that in the beginning of the welding two plates were not joined well so that there was no change of plate back surface in color. But the two plates were welded well near the center of the traveling distance.

The radiation signal fluctuates during 600 ms at the beginning of the welding, stabilizes 750 ms after that like the DC signal, fluctuates again, and stabilizes 300 ms after that like the DC signal. Each welding radiation signal shows similar behavior so that final DC-like signal may be due to a detecting problem. As shown in Fig. 2, the penetration depth is at the maximum when the welding signal is like the DC signal, but the radiation signal is at the minimum. In other words we can conclude that the welding quality is best when the radiation signal is like the DC signal as shown in the back surface of the welded plate which shows the penetration depth of the welded plate. To truly understand such a penetration depth better, the welded plates should be cut and inspected carefully. Also, the fluctuation should be more carefully examined with more data sample points to investigate the welding quality more clearly. The radiation signal is reduced because the radiation signal is not reflected well and is absorbed inwards and transmitted to the welding sample because the welding pool is deeper. Due to this phenomenon the welding beads can be observed on the back surface of the welded sample instead of the welding's front surface. This is due to the pushing of the welding pools by the laser. In addition to the laser pushing the collected radiation signal can be reduced due to the plasma and plume shape distribution change with respect to the change of the welding depth and laser power. Also, the fluctuated signals in the beginning and ending of the welding should be more carefully examined by using a discrete Fast Fourier Transform (FFT). Some argue that keyhole geometry changes can cause the fluctuated signals [9].

Also, we expect that a high speed camera can be used to trace the stage of the keyhole geometry formation in real time and correlate the frequencies of the fluctuated signals with the keyhole geometries. We may check the spectra carefully near the welding pools instead of measuring spectra obtained through the fibers and mirrors. So, we do not miss spectral signal due to the absorption and the plasma. Also, plume frequencies can be checked in detail. We may understand the dynamics of the welding pool with the combination of an optical method with an acoustic method.

IV. CONCLUSIONS

The radiation signals generated during the welding are more stable and smaller where the welding depth and the frequency fluctuation is much stronger when the welding depth is shallow. This may be due to the geometry of the welding pool, the laser pushing of the welding pool, etc. It is necessary to conduct the discrete FFT analysis of the radiation signals for the quantitative analysis of these frequency fluctuations. Also, the systematic correlation parameters for welding quality monitoring can be obtained by confirming the real time form of the welding pool with the high speed camera so that the systematic data for the closed loop control of welding quality monitoring can be obtained.

ACKNOWLEDGEMENTS

This study was supported in part from Chosun University.

*Corresponding author : kimjt@chosun.ac.kr.

REFERENCES

[1] S. Postma, R. Aarts, J. Meijer, B. Jonker, and W. M. Zweers, "Penetration control in laser welding of sheet metal using optical sensors," in *Laser Material Processing*, X. Chen, Ed., Proc. ICALEO, vol. 81e, pp. 1083-1092, 2001.

[2] M. Watanabe, H. Okado, and T. Inoue, "Features of various in-process monitoring methods and their applications to laser welding," in *Laser Material Processing*, D. Farson, Ed., Proc. ICALEO, vol. 80e, pp. 553-558, 1995.

[3] J. Beersiek, R. Poprawe, W. Schulz, H. Gu, and W. W. Duley, "On-line monitoring of penetration depth in laser beam welding," in *Laser Material Processing*, R. Fabbro, Ed., Proc. ICALEO, vol. 83e, pp. 30-35, 1997.

[4] H. K. Tonshoff, L. Overmeyer, and J. Schumacher, "Process and quality control for automotive laser welding applications," in *Laser Material Processing*, D. Farson, Ed., Proc. ICALEO, vol. 80e, pp. 45-55, 1996.

[5] H. K. Tonshoff, L. Overmeyer, and F. V. Alvensleben, "Closed-loop control of material processing with high power CO_2 lasers," in *Beam Control, Diagnostics, Standards, and Propagation*, L. W. Austin, Ed., Proc. SPIE, vol. 2375, pp. 109-117, 1995.

[6] H. K. Tonshoff, A. Ostendorf, R. G uttler, and W. Specker, "Online monitoring and closed-loop control of

laser welding processes," VDI Berichte Nr. vol. 1405, pp. 603-612, 1998.

[7] C. -J. Kim, S. -H. Baik, M. -S. Kim, C. -M. Chung, and K. -J. Kim, "Auto-focus control by chromatic filtering in laser welding," *J. Opt. Soc. Korea*, vol. 4, no. 2, pp. 94-100, 2000.

[8] 4D GmbH, "WeldWatcher operating instructions", ver. 2.41, pp. 2-11, 2000.

[9] I. Miyamoto, E. Ohmura, and T. Maede, "Dynamic behavior of plume and keyhole in CO_2 laser welding, " in *Laser Material Processing*, M. Beck, Ed., Proc. ICALEO, vol. 83e, pp. 210-218, 1997.