Analysis of Welding Stability Based on Plume Images during High-power Disc Laser Welding

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Abstract. During the high-power disc laser welding, metal vapor plume is the important phenomenon and contains a lot of information that related to the welding quality. This paper researches a method for analyzing the welding stabilty by monitoring the plume during the welding of stainless steel 304. In the high-power disc laser welding, a high-speed camera was used to capture the ultraviolet band and visible band meal vapor plume images. The information entropy and area ratio were defined as the characteristic parameters of plume to determine the stability of welding. Image algorithms such as Wiener filtering, dynamic threshold segmentation, mathematical morphology were applied to obtain the characteristic parameter curves in the welding process. Welding experimental results showed that the proposed characteristic parameters could accurately reflect the welding stability status of high-power disc laser welding process.

Introduction

Disc laser welding is one of the most advanced welding technologies with advantages such as high power laser, large depth-to-width ratio, good beam quality and extremely high utilization of laser [1,2]. During the high-power disc laser welding, while all kinds of welding control parameters were constant, lots of welding disturbances still exist to impair the stability and quality of welding[3]. So how to monitor the stability and quality of the welding is important. Metal vapor plume is the important phenomenon in the process laser welding. In this paper, we took stainless steel 304 as the experimental specimen and used a high-speed imaging system to capture the ultraviolet band and visible band metal vapor plume images in the high-power disc laser welding. The information entropy and area ratio of metal vapor plume were defined as the characteristic parameters of plume. Some image recognition processing algorithms were applied to process the plume images and obtain the characteristic parameters in order to extract of characteristic parameters changing curve during the welding. It could provide the information for welding stability analysis.

Experimental conditions

The experimental setup was composed of a Motoman 6-axis robot, a TruDisk-10003 disc laser welding equipment and a welding workbench equipped with a high-speed imaging system. Shielding gas was argon. The specimen was austenitic stainless steel 304 used for bead-on-plate welding with dimensional size of 150mm×100mm×10mm. The diameter of laser spot was 480μm, the wavelength of laser was 1030nm and welding velocity (v) =4.5m/min. The NAC high-speed camera captured the ultraviolet band and visible band metal vapor plume images at 2000f/s by 512×512 pixels [4].The welding experimental setup is shown in Fig.1.

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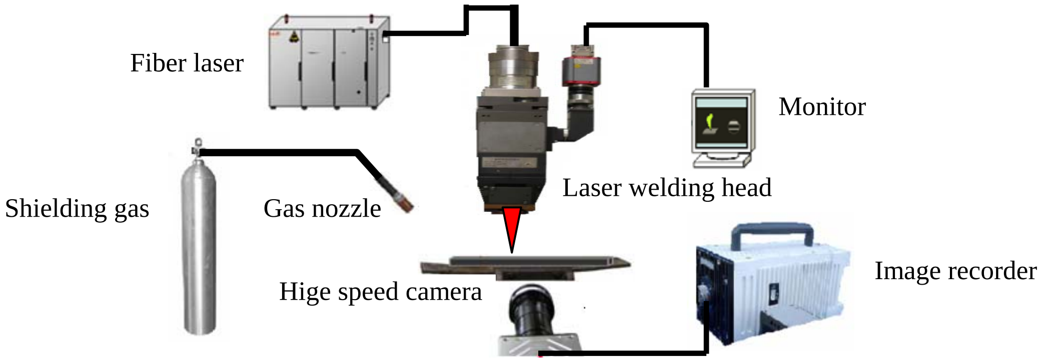
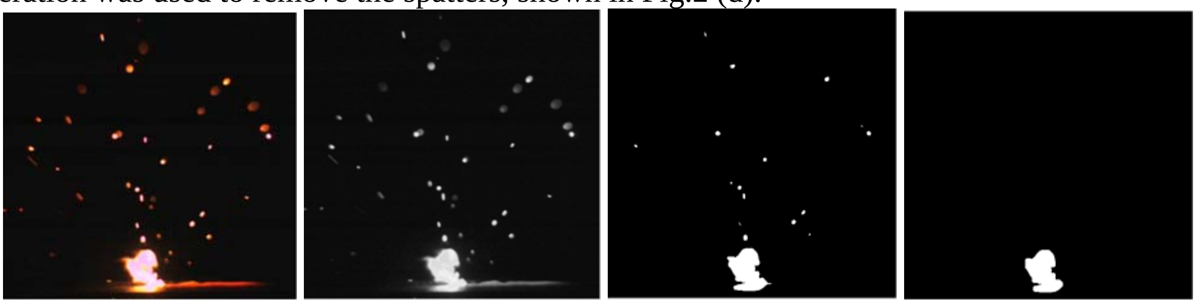


Fig. 1 High-power disc laser welding experimental setup

Welding Experiments and Discussions

Image preprocessing. An original metal vapor plume image including spatters is shown in Fig.2 (a). First, it was transferred into the gray scale image, shown in Fig.2 (b). Wiener filtering was used to eliminate the noises. Through repeated experiments analysis, it was found that the morphology of the metal vapor plume was the same with the original one when a global threshold 160 was applied to the filtered image, and it could meet the calculation requirement of information entropy and area ratio of plume, shown in Fig.2 (c). In the process of laser welding, a large amount of spatters were produced and would influence the extraction of metal vapor plume. Therefore, the morphological open operation was used to remove the spatters, shown in Fig.2 (d).



(a) Original image (b) Gray image (c) Binary image (d) Metal vapor plume

Fig. 2 Image preprocessing of plume during disk laser welding

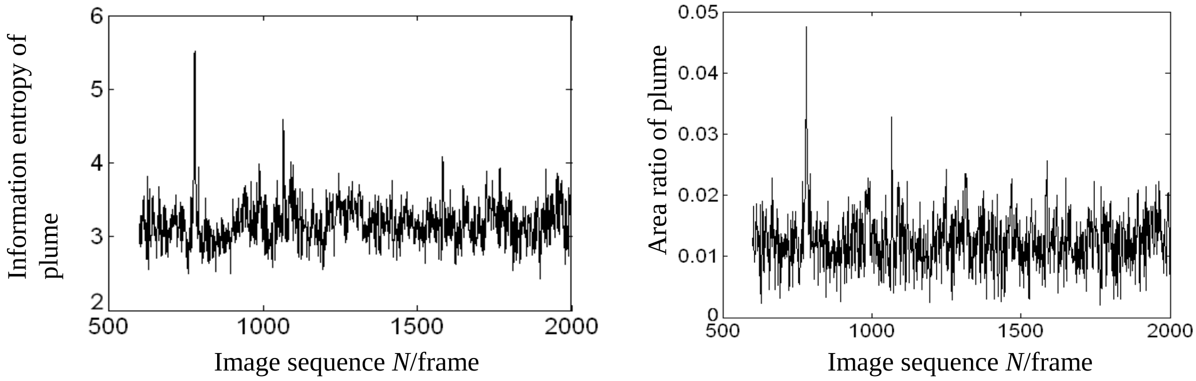
Characteristic parameters extraction. Set {F (*x*, *y*); *x* = 1, 2...M; *y* = 1, 2...N} is a two dimensions image pixel matrix, F (*x*, *y*) indicates the brightness of the pixels at (*x*, *y*). The pixel luminance of the image has a set after quantization, and this set of entropy was defined as the statistical average of the self-information, namely the information entropy of image. For binary image, F (*x*, *y*) = 0 represents the background pixel, F (*x*, *y*) = 1 represents the image pixels, so the information entropy of binary image can be written as [5]:

$$H(p_0, p_1) = -\log p_0 - p_1 \log p_1 \tag{1}$$

where p_0 is the occurrence of gray level 0, and p_1 is the occurrence of gray level 1. According to Eq.1, the information entropy of a metal vapor plume binary image can be acquired.

Because only metal vapor plume gray level was 1 in a metal vapor plume binary image, so the method of calculation area ratio of plume was to calculate the number of pixel with which the grayscale value was 1, and then was divided by the total number of the pixel (512×512) in a metal vapor plume binary image.

The experiments totally got 2480 images, selecting the No.600-2000 images to calculate the information entropy and area ratio of metal vapor plume with the above image preprocessing and calculation method. The information entropy of plume is shown in Fig.3(a). The area ratio of plume is shown in Fig.3(b).



(a) Information entropy of plume (b) Area ratio of plume.

Fig. 3 Information entropy and area ratio of plume images

Characteristic parameters analysis. For analyzing the stability of welding, the welded workpiece was divided into three areas of A, B and C. The surface of welded workpiece is shown in Fig.4. Area A and C with large and stable welding seam widths were good welding quality parts, which corresponding to the No.600-800 and the No.1800-2000 plume images, respectively. Area B with narrow welding seam widths was poor welding quality part, which corresponding to the No.1100-1300 plume images.

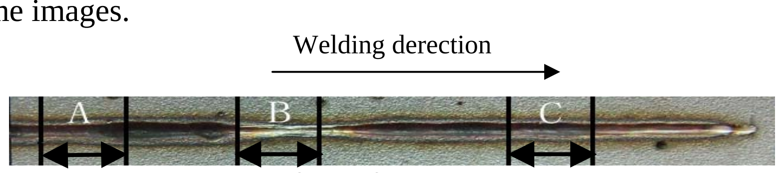
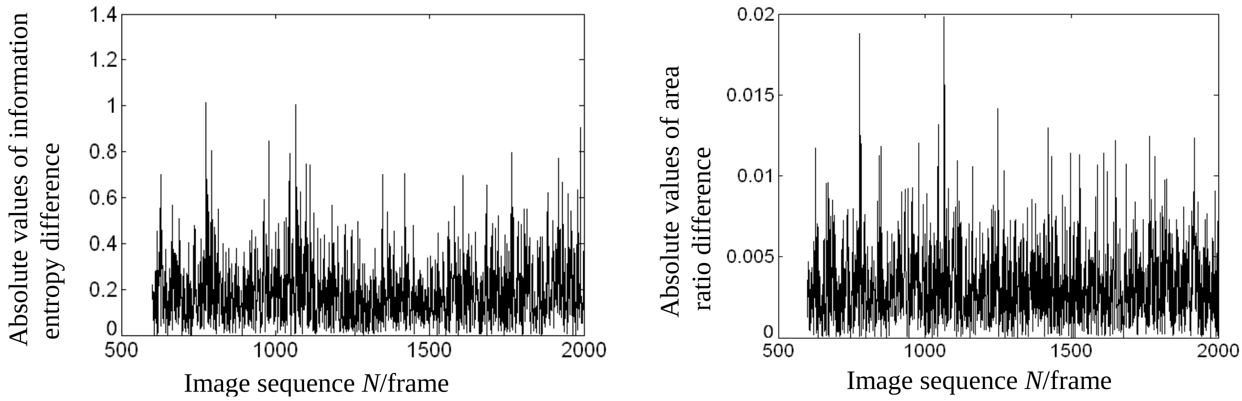


Fig.4. Surface of welded workpiece



(a) Absolute values of information entropy difference (b) Absolute values of area ratio difference

Fig. 5 Absolute values of the information entropy difference and the area ratio difference

The area A, B and C were studied in the purpose of exploring the relationship between the metal vapor plume and the laser welding stability. Respectively calculating the changing of information entropy difference and the changing of the area ratio difference of the adjacent images, and then the absolute values were calculated. Finally the absolute value of the information entropy difference and the area ratio difference of metal vapor plume were obtained. The absolute values of the information entropy difference are shown in Fig.5 (a). The absolute values of the area ratio difference are shown in Fig.5 (b).

In order to evaluate the changing extent of the absolute values of the information entropy difference and the area ratio difference, we calculated the average absolute values in area A, B and C. The calculation results are shown in Table 1.

Table 1. Statistics of characteristic parameters of plume

	Area A [600-800]	area B [1100-1300]	area C [1800-2000]
Average values of the information entropy difference	199.5989	159.1680	211.9468
Average values of the area ratio difference	3.2150	2.9979	3.4090

It can be seen from Table 1 that the average value of the information entropy difference and the average value of the area ratio difference in area B are apparently smaller than those of A and C. According to the above analysis, it is noted that area B was a bad welding stability and relatively poor welding quality, the results were consistent with the actual welds. The experimental results showed that the changing of the absolute value of the information entropy difference and the changing of the absolute value of the area ratio difference of metal vapor plume could evaluate the quality and stability of welding effectively in the high-power disc laser welding process.

Conclusions

In the high-power disc laser welding process, application of a high speed imaging system for taking metal vapor plume images can obtain the information of the instantaneous changes of plume and welding quality.

Application of image processing technology such as gray level transformation, adaptive Wiener filtering, binarization and mathematical morphology for processing the plume images, can obtain the characteristic parameters of plume correctly and effectively.

The changing of the absolute value of the information entropy difference and the changing of the absolute value of the area ratio difference of metal vapor plume can evaluate the quality and stability of welding effectively in the high-power disc laser welding process.

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References

[1] X.D.Gao, L.Mo, X.G.Zhong, D.Y.You and S.Katayama: Acta Physica Sinica. Vol.60 (2011), p.088105-1-8.

[2] Q.Wen and X.D Gao: Advanced Materials Research. Vol.532-533(2012), p. 330.

[3] W.W.Duley: *Laser Welding* (John Wiley Sons Inc, New York 1998).

[4] X.D.Gao, W.X.Lv and D.Y.You: Transactions of China Welding Institution. Vol.32 (2011), p. 5.

[5] H.P Jiang and Z.K Shen: Signal Processing. Vol.22 (2006), p. 678.