Laser Welding Parameter Variations and its Application for Plastic Adhesion

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Abstract - a parametric investigation was conducted to evaluate the effect of the laser beam for plastic adhesion. To determine the best condition for plastic adhesion, the co_2 (wavelength 10.6μm) and nd:yag (wavelength1.06 μm) laser were experimented with. From the experiment results obtained, the nd:yag laser was revealed to be the most suitable for plastic adhesion.
In this study, three adhesion parameters such as input power level, working time of laser beam and pps (pulse per second) were systematically adjusted for suitable adhesion. From these experiments, it was observed that the target plastic melted and was evaporated by the nd:yag laser. Furthermore, the relationships between adhesive surface by laser beam and above three parameters were discovered.

Keywords: Input power level, Nd:yag laser, Plastic adhesion, Pps, Working time of laser beam

1. Introduction

Lasers provide a high intensity, controllable source of heat for material processing. [1] Especially, heat treating and welding based on laser technology is very significant. Successful applications are performed by unique advantages such as precision, excellent product quality, high productivity, low manufacturing cost and easy automation [2 - 4].

The brief feature of the laser welding technique that seals plastic food-packing is described by Robert Perkins [5].

He claimed that it is flexible and it could permit multiple packing-shapes to be made in a single production line, providing a major advantage over conventional heat-sealing and pressure-sealing systems.

Hyong-kewn Lee at al. made a small titanium tube sealing system based on the Nd:YAG laser. The titanium capsule containing Iodine-125 is inserted close to cancer cells by an operation, and the effects of the Nd:YAG laser welding parameter on the melting behavior of the titanium end is studied [6].

In underwater laser welding, the weld quality was very dependant on the shielding conditions of the local cavity when other welding parameters were fixed. Xudong Zhang et al. [7] researched the relationship between weld quality and optical emission in underwater Nd:YAG laser welding. The effect of water on the laser welding was studied first by conducting direct underwater welding, which was performed without any method to exclude the water from the welding zone.

A CO_2 laser plastic welding procedure was developed by J.P. Coelho [8]. In his experiment, welding with several beam-focus offsets (defocusing distances) was tested. Also, the CO_2 laser plastic welding system with thermal diffusion cooling process has been proposed by Yasuo Kurosaki [9]. It was confirmed by applying the overlapped same plastic films with a combination of infrared radiation absorption.

Generally speaking, many organic materials present a high surface absorption for the wavelength (10.6 μm) typical of the CO_2 laser whereas they are transparent at the 1.06 μm wavelength of a Nd:YAG laser [10].

In this study, the laser beam entered in one transparent plastic and then adsorbed another plastic material. In this case, the Nd:YAG laser was the proper choice to perform plastic adhesion as compared to the CO_2 laser.

The change of plastic adhesion was observed when the Nd:YAG laser beam was absorbed in a plastic contact surface. It was found that the plastic melting and evaporation area were changed by adjustment of the parameters such as input power level, working time and PPS.

2. Experimental Procedures

For the study of plastic adhesion, the CO_2 and Nd:YAG laser were used. The CO_2 laser system consisted of four parts, the CO_2 laser cavity, power supply, control part for laser level variation and focal lens. The laser beam was

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focused on the center position of the target plastic. The focusing lens with a focal length of 100 mm was used. CO_2 laser power level was adjusted from 8 up to 20 [W]. The CO_2 laser system is shown in Fig. 1. Using the CO_2 laser, the surface change was examined.

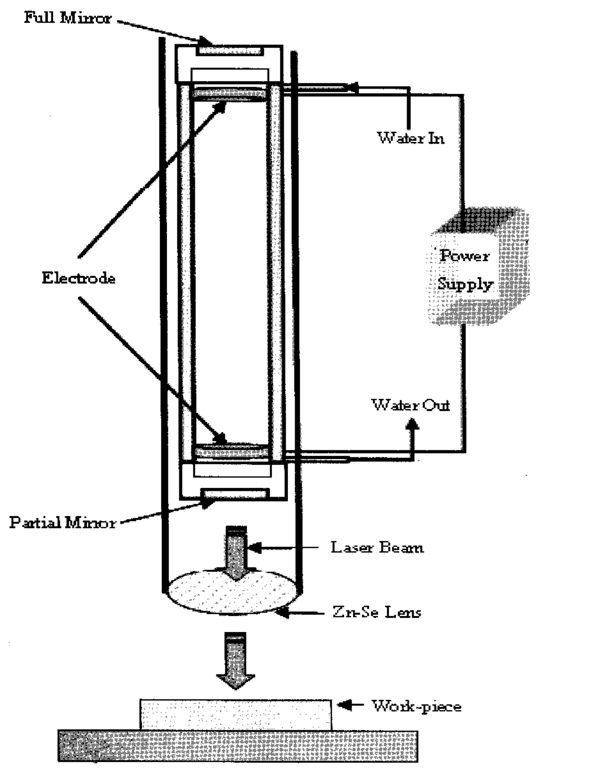


Fig. 1(a). Schematic CO_2 laser system for plastic adhesion.

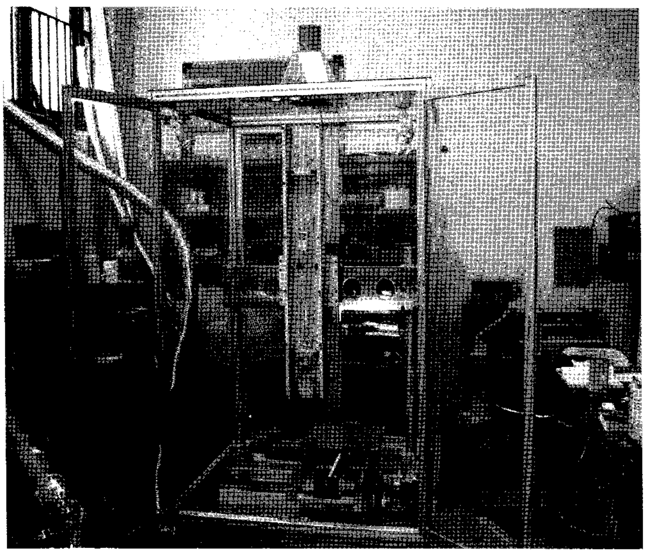


Fig. 1(b). The CO_2 laser system for plastic adhesion.

The Nd:YAG laser system and its circuit configuration are presented in Fig. 2 while a photograph of it can be seen in Fig. 3. It is composed of a pulsed Nd:YAG laser cavity, water circulation part for cavity cooling, power supply for input power level variation and moving part for laser working time control. Input voltage level was adjusted from 450 up to 750 [V], by increasing the step voltage of 50. The working time of Nd:YAG laser absorption in a plastic target was controlled within the range of 1 to 10 seconds by one axis moving table. One axis moving table was controlled by PLC (MITSUBISHI ELECTRIC MR-C Servo system). The output laser beam was regulated at 5, 10, 15 and 20 PPS.

The plastic target used was PP (Polypropylene) and its melting point was 165.5^{0}C. The incident direction of one was transparent and the other was dark plastic for laser beam absorption.

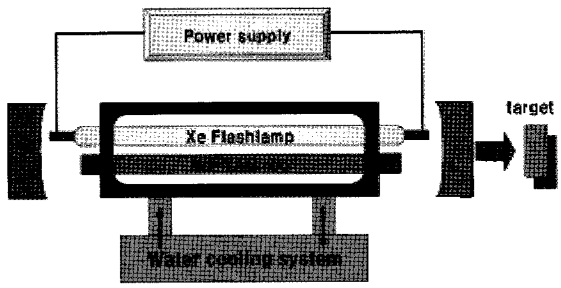


Fig. 2. The schematic diagram of the Nd:YAG laser system.

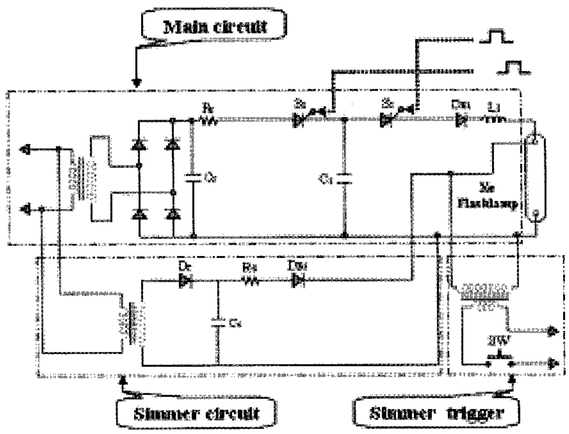


Fig. 3. The electrical circuit configuration of the Nd:YAG laser system.

3. Results and Discussion

Using the CO_2 and Nd:YAG lasers, the change of plastic junction area was examined. In the case of the CO_2 laser, the laser beam was absorbed in all laser levels from 8 to 20 [W]. It wasn't penetrated inside of the transparent plastic material. Its laser energy was absorbed on the contact surface and transfered around it. In the incident surface, a hollow in the figure of an upside-down Gaussian curve was made. It is shown in Fig. 4. Using SEM (Scanning Electron Microscopy), its surface is indicated in Fig. 5.

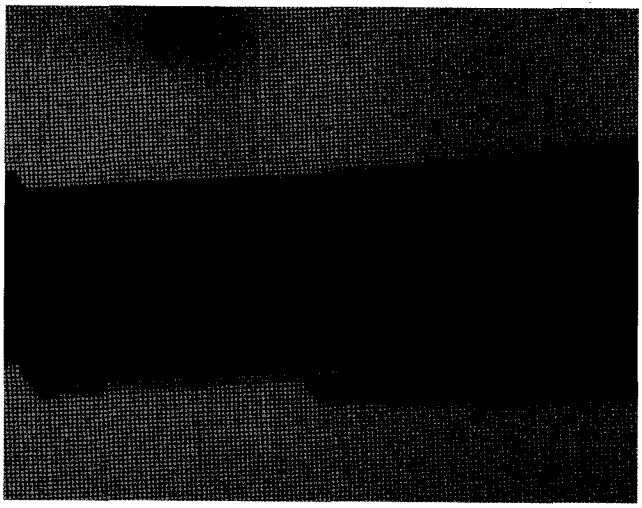


Fig. 4. Gaussian profile of upside-down surface after CO_2 laser beam incident.

From the general theory, the laser beam was normalized by Gaussian distribution. Equation (1) showed the relationship between P_0 and I_0 [11]. When the laser beam has Gaussian distribution, about 85% of the laser beam was concentrated on spot size ($2w'$).

$$\frac{I(x,y)}{P_0} = \frac{1}{2\pi w'}\exp\{-\frac{(x^2+y^2)}{2w'^2}\} \quad (1)$$

(I: intensity, P: Laser power, ω' : standard deviation)

The shape of the hollow was also satisfied with equation (1). It was concentrated deeply at the center because of its Gaussain distribution. The more distant from the center it receded, the less hollow the depth was. From the above result, it was not appropriate for plastic adhesion by the CO_2 laser. For the plastic adhesion based on the CO_2 laser, a special cooling part for surface refrigeration was necessary.

In comparasion with the result of the CO_2 laser, the laser beam of the Nd:YAG passed the transparent first plastic and absorbed the second plastic as well. Accoring to the former research, the wavelength of the Nd:YAG laser beam was permeated in material as well [10]. Therefore, the Nd:YAG laser was determined to be the proper choice for plastic adhesion. The laser beam passed the transparent plastic and also absorbed the second one. It was performed by variation of parameters. At the condition of fixed input power level, the relationship of working time and PPS were examined. Input voltage level was adjusted from 450 up to 750 [V], by increasing step voltage of 50. Working time of Nd:YAG laser absorption in the plastic target was controlled within the range of 1 to 10 seconds by one axis moving table. Pulses per second were regulated at 5, 10, 15 and 20 PPS.

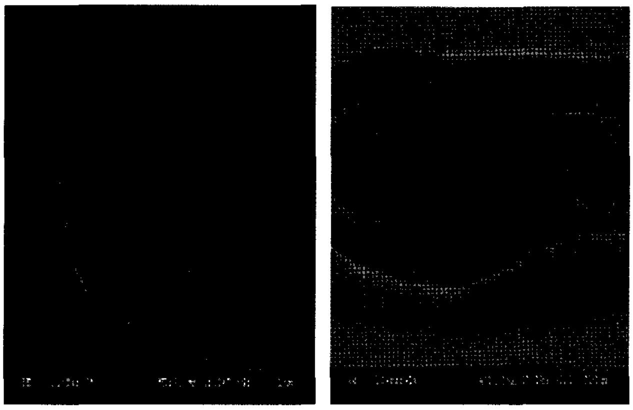
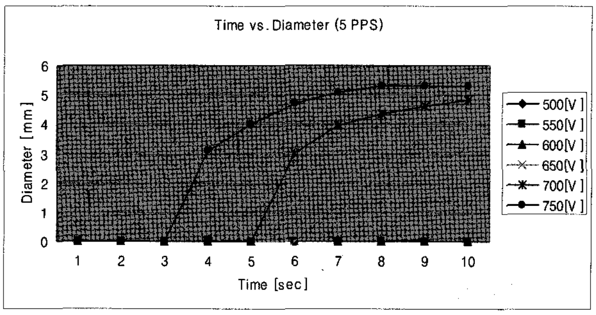


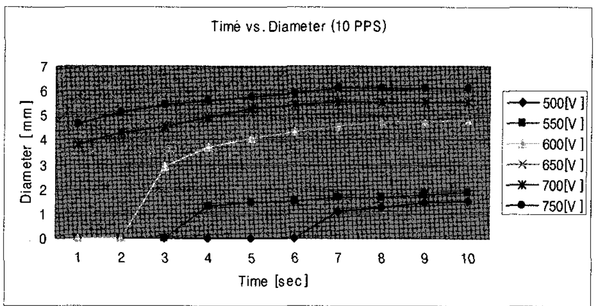
Fig. 5. SEM (Scanning Electron Microscopy) figure of surface after CO_2 laser incident.
(a) Top view (b) Surface at an angle of 45 degrees

Fig. 6 presents the relationship between adhesion area and parameters. In the case of 450 [V], adhesion of the plastic target was not occurred. When the discharge laser beam was fixed at 5 PPS (Fig. 6 (a)), adhesion was started at 6 seconds in the 650 [V] input voltage level. As time elapsed, the adhesion area increased. After 2 seconds, the area of 1.2mm was saturated.

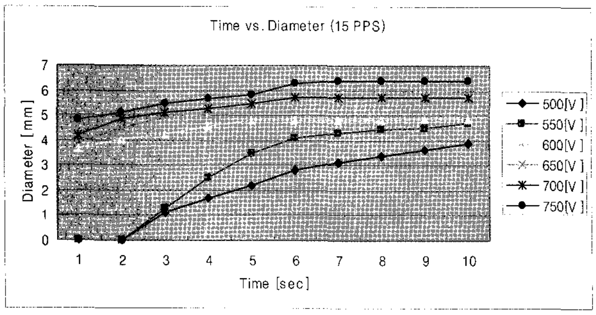
In the case of 700 [V] and 750 [V], adhesion was started 5 and 3 seconds after exposure to the laser beam. Its area of saturation was started at 5 and 4 seconds following adhesion. The saturated adhesion diameter was 4.8 and 5.3 mm. Fig. 6 (b) shows the relationship between working time and input voltage level at 10 PPS. Fig. 6 (C) and (d) also indicates the relationship between working time and input voltage level at 15 and 20 PPS, respectively.



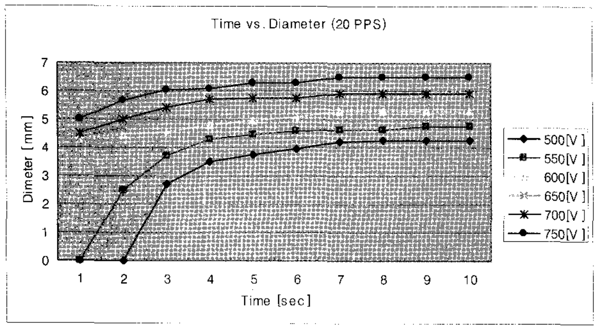
(a) 5 PPS



(b) 10 PPS



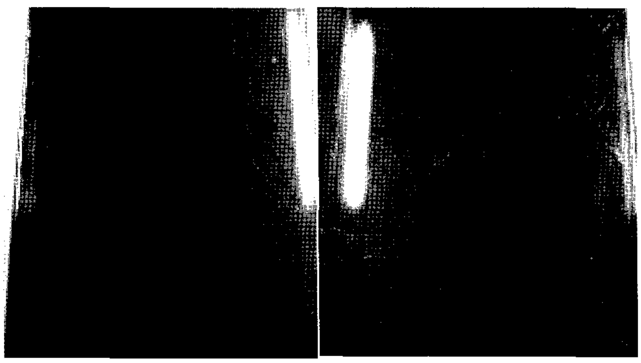
(c) 15 PPS



(d) 20 PPS

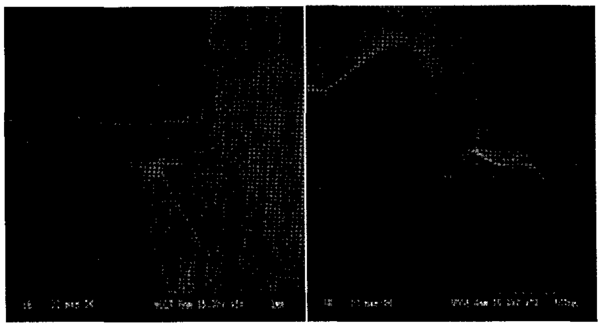
Fig. 6. The adhesion diameter change by variance of exposing time and input voltage level.

The photographs of the experimental results are presented in Fig. 7. Using SEM, the contact surface of two plastics is observed in Fig. 8. The incident Nd:YAG laser beam was absorbed in the second plastic surface. When the light penetrated, its energy was converted from light into heat. Therefore, the surface of the second plastic played the role of heat source. The heat energy was transferred to the adjacent plastic and melting phenomenon of the plastic material was initiated. From these photos, the input voltage level was proportional to the adhesion area. When PPS increased, adhesion time was declined at the lowest input power level. Also the saturation time for limited diameters was more rapid.



(a) 650V (b) 750V

Fig. 7. The state change of target plastic (At the same condition of 5, 10, 15 and 20 PPS, at 1 to 10 seconds).



(a) (b)

Fig. 8. SEM figure of contact surface after Nd:YAG laser beam incident (650V, 10 PPS).
(a) Side view (x50) (b) Surface at an angle of 90 degrees (x70)

According to the general theory, the laser beam had been normalized by Gaussian distribution. The energy of the incident laser beam was concentrated in the centre. As the time elapsed, its Gaussian curve was moved in an upper direction and the temperature of the centre was increased. When the temperature of the centre reached specific region, its region was not enlarged. Therefore, the dimension of energy absorption was saturated. In the middle of the adhesion region, plastic evaporation took place. It was due to the temperature of the evaporation point from melting. The result of the evaporation characteristic is shown in Fig. 9.

Its evaporation was observed at the input voltage level of 750 [V], 15 and 20 PPS. (The condition of 4 and 2 seconds and saturation at 9 and 8 seconds, respectively) According to these results, the higher PPS was, the faster saturation was occurred.

We carried out line adhesion with one axis moving machine. It was tested at the condition of 550 [V], 10 PPS and working time 5 seconds and 650 [V], 10 PPS and working time 5 seconds, respectively. Its results are shown in Fig. 10.

For the industrial application, the state change of melting to evaporating had to be avoided. Therefore, to get the proper width and diameter with plastic adhesion in each case, input power level and exposing time had to be selected properly.

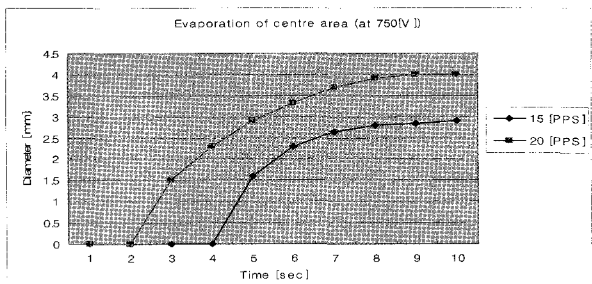


Fig. 9. Evaporation characteristics of plastic contact surface (750[V]).

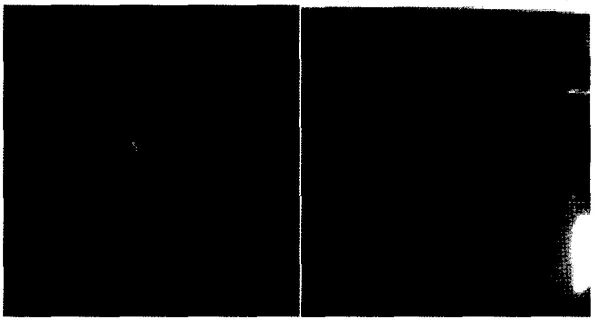


Fig. 10. The line adhesion of plastic target (10 PPS).

4. Conclusions

A parametric investigation was conducted to evaluate the effect of the laser beam for plastic adhesion. To determine the suitability for plastic adhesion, the CO_2 (wavelength 10.6μm) and Nd:YAG (wavelength1.06 μm) laser were experimented with. The experiment results indicate that the Nd:YAG laser is more suitable for plastic welding.

In this study, three adhesion parameters, input power level, working time and PPS (pulse per second) were systematically adjusted for adhesion. From these results, the change at which the target plastic was adhered and evaporated by the Nd:YAG laser was observed. Laser working time was directly proportional to adhesion area. However, its input voltage level and pulses per second had to be limited to avoid evaporation within these conditions, which were 750 [V], 15 PPS and 4 seconds and 750 [V], 20 PPS and 2 seconds. Also, adhesion width was proportional to input voltage level and PPS. However, it was saturated in specific conditions.

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References

[1] Oh Myong, Gang Min Ho. Laser Application Choung Moon Guak, 1983, pp. 59-75.

[2] Sidney S. Charschan. Guide to Laser Materials Processing, Laser Institute of America, 193, pp. 31-142.

[3] Gang Hyung Sik. Laser processing technique of electricity for new technique innovation. Proceedings of KIEE, Vol. 50, No. 5, May, 2001.

[4] Goo Young Duk at al. Laser application technique for steel sheets. KITI, 2004.

[5] Robert Parkin. "Laser-based welding system improves packing seals".

[6] Hyong-Ken Lee et al. Optimization of Nd:YAG laser welding parameters for sealing small titanium tube ends. Materials Science and Engineering A. 2006, pp. 149 – 155.

[7] Xudong Zhang et al. Relationship between weld in quality and optical emissions in underwater Nd:YAG laser welding. Optics and Laser in Engineering 2004, pp. 717-730.

[8] J.P. Coelho, M.A. Abrea, M.D. Pires. High-speed laser welding of platic welding process. Journal of Quantitative Spectroscopy & Radiative Transfer.pp. 25 – 41, 2005.

[9] Yasuo Kurosaki. Radiative heat transfer in plastic welding process. Journal of Quantitative Spectroscopy & Radiative Transfer, pp 25 – 41, 2005.

[10] P.A. Atanassov. CW CO2 laser cutting of plastics, SPIE, Vol. 3092. Edinburgh, 1997, pp. 772-775.

[11] R.S Sirohi, A course of experiments with He-Ne Laser, A Halsted Press Book, 1995. pp. 9-11.

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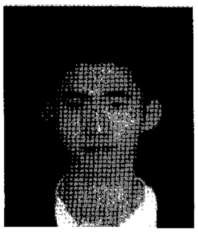

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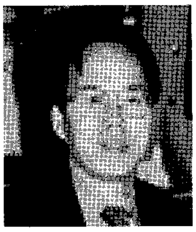

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