Study of the characteristic of droplet transfer in laser-MIG hybrid welding based on the phase matching control of laser pulse and arc waveform

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Abstract

This paper puts forward an experimental program on accurate phase matching control between laser pulse and MIG arc waveform, and achieves continuous trigger control of the laser pulse. With the relationship between laser pulse, MIG arc and droplet, the effect of laser pulse on droplet transfer is studied by controlling laser pulse to act on the peak value and basic value of the MIG arc waveform respectively during laser-MIG hybrid welding process on aluminum alloy 6061. High-speed camera is used to acquire the droplet transfer. Experimental results show that the form of droplet transfer hasn't changed with the laser pulse acting. However, laser pulse can changes the necking form of droplet and the speed for droplet transfer by changing the electromagnetic force. The necking form of droplet changes from symmetrical necking to asymmetrical necking when the laser pulse acts on the peak value, however there is no significant change for the necking form when the laser pulse acts on the basic value. The speed of droplet transfer is faster than that without laser, and it improves with the increase of the laser power. The speed of droplet transfer with laser acting on the basic value is faster than that with laser acting on the peak value. Welding appearance with laser pulse acting on the basic value is better than that with laser pulse acting on the peak value. It is thought that this study can technically support the aluminum alloy welding with high speed and low thermal damage at small welding currents.

Keywords: Phase matching, Hybrid welding, Drop transfer, Welding appearance

Introduction

As an advanced method, laser–MIG hybrid welding has many advantages in increasing welding speed and improving drop transfer and so on. Liu S et al studied the droplet transfer mode and forming process in 5kW CO_2 laser-MAG hybrid welding, it is found that arc characteristic, droplet transfer mode and final weld bead geometry are strongly affected by the distance between laser and arc, the droplet transfer mode is changed from globular transfer to projected transfer with the increasing DLA[Liu et al. (2012)]. Lei Z et al studied characteristics of droplet transfer in 3kW CO_2 laser-MIG hybrid welding, it was found that the droplet transfer mode is changed from short circuiting transfer to projected transfer due to interaction between CO_2 laser and MIG arc in CO_2 laser-MIG hybrid welding process, and the frequency of droplet can be improved by adjusting the parameters[Lei et al. (2004)].

The above researches mainly focus on the influence of high-power laser on the arc and droplet transfer. Our team discovered the low power pulsed laser enhancing arc discharge phenomenon. It found that the arc plasma can be stabilized by the laser pulse, and the enhancing effect of laser on arc plasma leads to the characteristic variation of the arc plasma, including the arc composition, the arc behavior, the arc electron temperature and density, which results in a very stable arc discharge in high speed welding conditions [Liu and Chen (2013a;2013b;2011)]

Considering the low power pulsed laser enhancing arc discharge phenomenon, this study mainly focuses on the improvement of the laser pulse to the droplet transfer based on the matching control of laser pulse and arc waveform. Using high-speed camera, the characteristics of droplet transfer after employing this system is studied. By comparing the variation in the characteristics of droplet transfer with laser acting on the peak value and basic value of the MIG arc waveform respectively, the interactions between laser and droplet transfer are analyzed.

Experimental setup

As is shown schematically in Fig. 1, the heat source is composed of a pulsed Nd: YAG laser (LWS-1000) hybrid and a direct current pulsed MIG arc. The laser, with a wave-length of 1.064μm, is focused by a lens with a focal distance of 150 mm into a spot measuring about 0.5 mm on the surface of the workpiece. The MIG arc acts behind the laser along the welding direction with an adjustable DLA, and the angle of the metal electrode axis to workpiece is 45^o. Argon with a purity of 99.99% is used as the shielding gas, and the flow rate through the MIG nozzle is 15L min^{-1}.

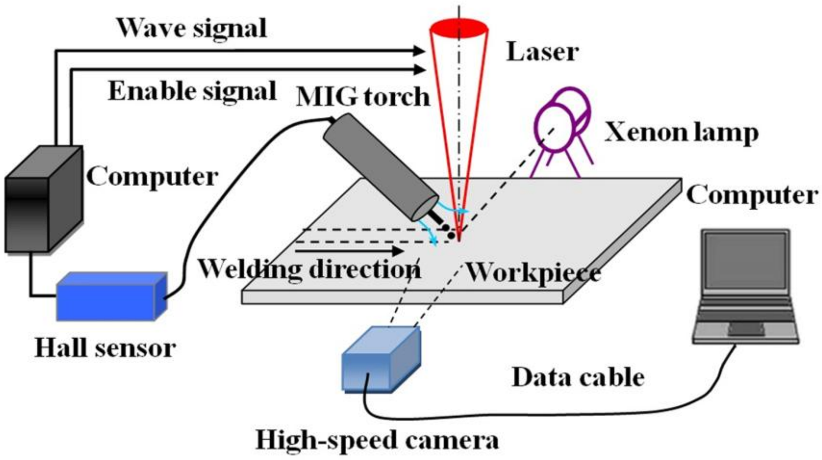

Figure 1. Schematic diagram of experimental devices

A xenon lamp is positioned towards the laser acting point and perpendicularly to the welding direction to avoid the influence of arc to droplet transfer, and on the opposite side a high-speed camera is placed to acquire the droplet transfer. A suitable optical filter should be attached to the camera lens to ensure suitable light intensity. The acquiring frequency of the camera is set to be 1000 frame/s and the interval time between every two successive photos is 1ms. By a cable, the data acquired is transferred to a computer that can translate the data into visible images through corresponding software.

In order to acquire the accurate matching control of laser pulse and arc waveform, the matching control system is developed. Hall sensor is used to detect the arc wave in welding process. As shown in Fig. 1, the data signal of MIG arc is transmitted to computer and acquired by NI PCI-6221, the DAQ system process the signal and capture the feature points of arc by the computer, thus accurately analyze the waveform field of MIG arc, and realize a continuous trigger control of laser pulse on peak value and basic value of MIG arc respectively by outputting the wave signal and enable signal to YAG laser directly. The function of this system is as shown in Fig 2. The laser pulse distribute in the pulsed MIG arc waveform uniformly.

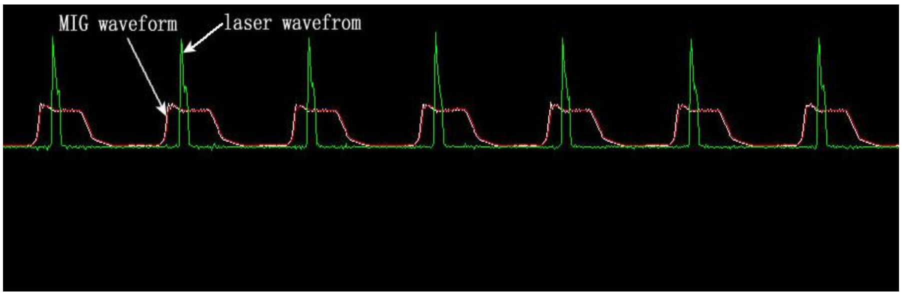

Figure 2. Schematic diagram of function of the matching control system

Experiments are performed at atmospheric pressure and room temperature. A 6061 aluminum alloy plate with a thickness of 2 mm is applied as the workpiece. Oxide film and grease on the plates are cleaned before welding. In this welding system, workpiece travels in a direction, while the MIG torch, the high-speed camera and the laser beam maintain fixed. Therefore, the information of droplet transfer can be acquired continuously and steadily.

Experiment results

In the single DC pulsed MIG welding, there are different modes of droplet transfer (such as one droplet per pulse and one droplet every two pulses). It's the mode of drop transfer that determines the pattern of pulse scatter distribution, so we should confirm the mode of drop transfer in this experimental condition. In MIG welding process, the metal electrode is the anode during the DC MIG arc, in which the electrons are accelerated to impact and heat the welding wire. Thereinto, the peak value is used to melt the welding wire, and the basic value is used to maintain the burning of the arc. As is shown in fig.3, the cycle of arc plasma is about 14ms (the peak value is about 3ms and the basic value is about 11ms), and the cycle of drop transfer is the same, so the mode of drop transfer is one drop per pulse in this experimental condition.

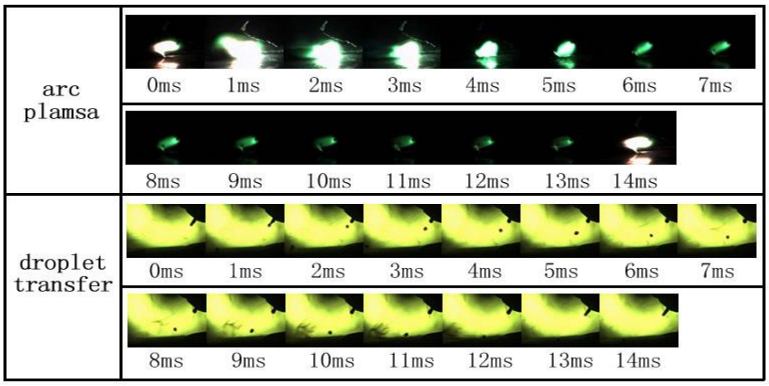

Figure 3. The relationship of the MIG arc and drop transfer

Therefore, the pattern of laser pulse distribution is determined to be the format as shown in the fig.4. The laser pulse acts on the peak value and basic value respectively. That is to say, the pulse scatter act on the period when the droplet forming and entering into molten pool respectively.

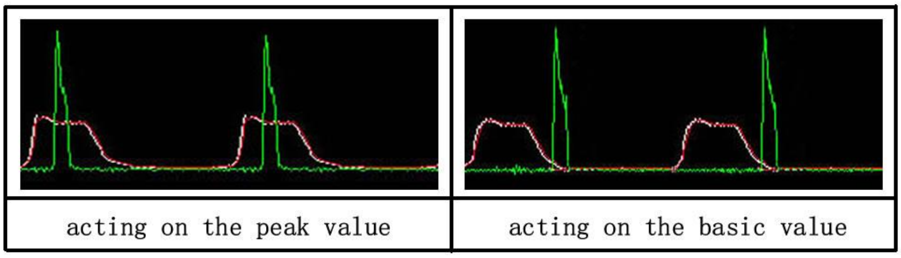

Figure 4. Schematic diagram of the MIG arc waveform position of laser pulse acts on

Fig.5 shows the necking mode with different laser pulse distribution modes between pulsed laser and DC pulse MIG arc. It is found that the necking mode under different laser pulse distribution modes has different variation rules: when the laser pulse act on the peak value, the necking of droplet deviates from the axis more easily with the increase of laser power, that is to say the necking form is changed from symmetrical necking to asymmetrical necking; to the contrary, there was no significant deviation in the necking of droplet during the laser pulse act on the basic value.

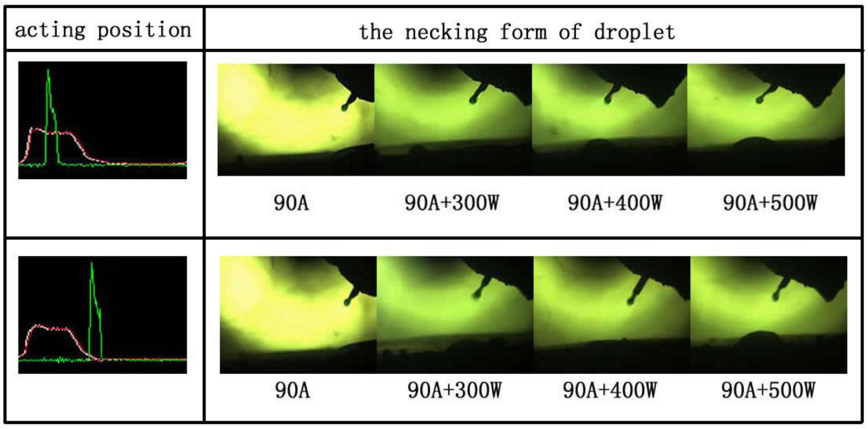

Figure 5. The diagram of the necking form of droplet

Due to the difference of laser pulse acting on the peak value and basic value, the path of droplet shares certain regularity during the droplet entering into molten pool: There is no deviation between the path of droplet transfer and the metal electrode axis without laser pulse, and the angle between the path and axis increases with the increasing of the laser power when the laser pulse acting on the peak value. During the laser pulse acting on the basic value, there is no significant deviation between the path of droplet and the metal electrode axis, just as is shown in Fig 6. It indicates that there are some differences of the interactions between laser pulse and arc plasma under different laser pulse distribution modes.

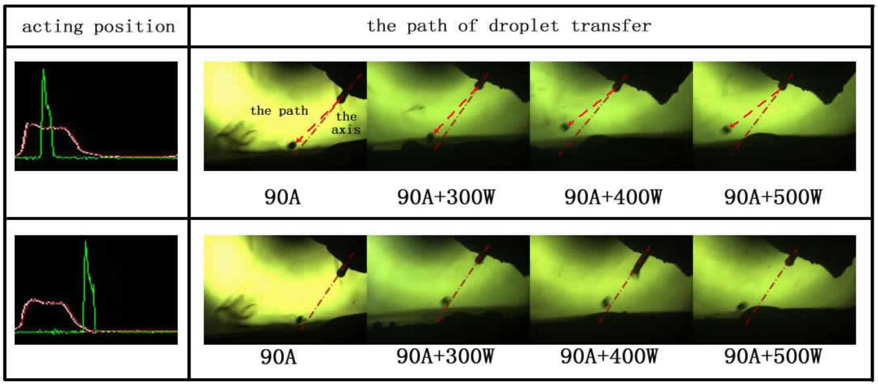

Figure 6. The diagram of the path of droplet transfer

In the droplet transfer cycle shown in Fig.7, the time for the droplet entering into melt pool is about 11ms in the single MIG welding, and it almost occupies the whole time of the basic value (the basic value is about 11ms).

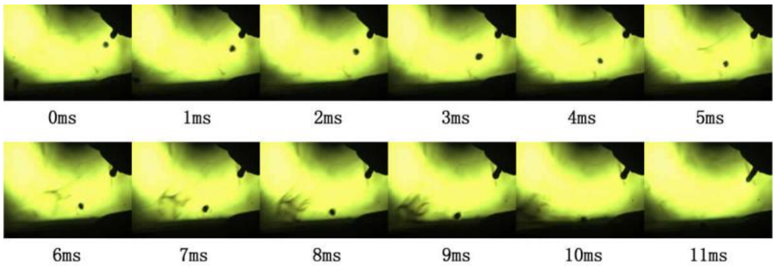

Figure 7. The time of MIG droplet entering into melt pool

Figure 8 is a typical metal transfer cycle from the comparative experiment between different pulse scatter distribution modes under different laser power. As can be seen, during the laser pulse acting on the peak value, the time for the droplet entering into melt pool is reduced with the increase of the laser power. For example, the time with 400W power is about 6ms, and it decreases about 4ms than that in the single MIG welding, and decreases about 1ms than that with 300W power.

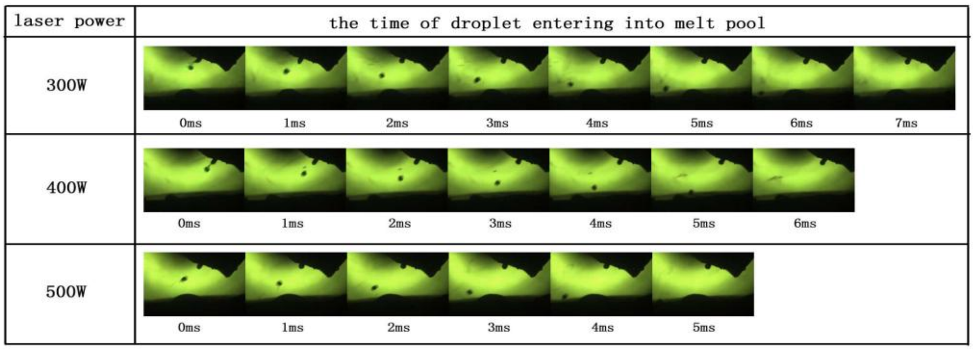

Figure 8. The time of droplet entering into melt pool during laser pulse acting on peak value

As is shown in Fig 9, during the laser pulse acting on the basic value, there are the same phenomena compared with the laser acting on the peak value: the time of droplet entering into melt pool is reduced with the increase of the laser power. The only difference is that the time of droplet entering into melt pool is shorter when laser pulse acting on the basic value. For example, the time with 400W power is about 4ms, and it decreases about 1ms than that with 300W power.

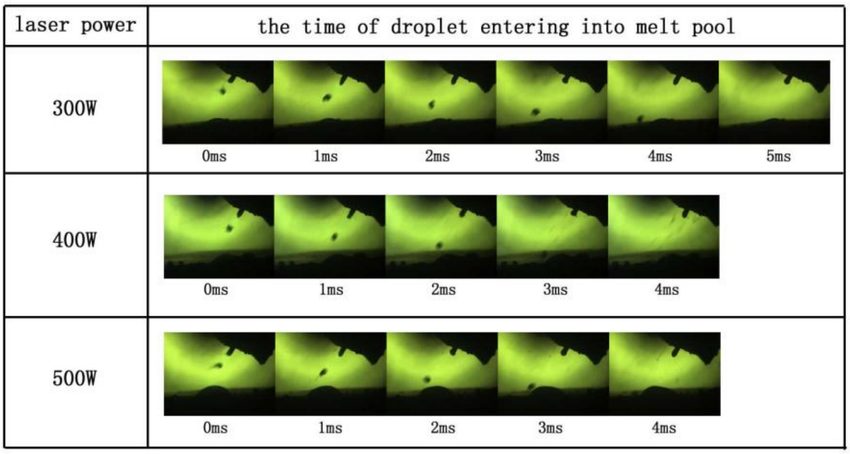

Figure 9. The time of droplet entering into melt pool during laser pulse acting on basic value

Therefore, the time of droplet entering into melt pool with laser pulse is shorter than that without laser pulse, and the time with laser acting on the basic value is shorter than that with laser acting on the peak value.

In order to ensure the impact on the formation of the laser pulse distribution pattern, the welding experiment is performed on aluminum plate with the laser of 500W and speed of 1500mm/min. Under the same welding conditions, the laser pulse is controlled to act on different positions of MIG arc wave form. Fig. 10 shows the hybrid weld bead appearances under the welding parameters with different laser pulse distribution modes. It can be seen that the weld appearance with laser pulse acting on the basic value is better than that with laser pulse acting on the peak value. When the laser pulse acts on the basic value, the laser-induced plasma can stabilize the small basic value easily, and the droplet is more advantageous to enter the melt pool because of the shorter time.

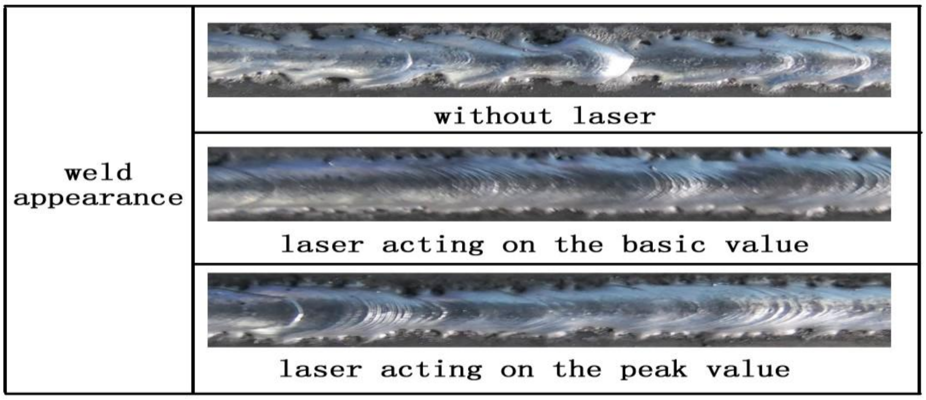

Figure 10. The appearances with different laser pulse distribution modes

Discussion

From above results, it can be seen that, in the process of laser-MIG hybrid welding, the laser pulse cause the above-mentioned change, and the force on droplet is the primary cause of this change, so we should analyze the force on the droplet caused by the laser pulse. F_g is the gravity force, F_p is the plasma flow force, F_{CZ} is the electromagnetic pinch force. The plasma flow force is caused by the electromagnetic pressure difference, which is one part of the electromagnetic pinch force. Because the size of droplet has not changed, so compared with the single welding, the F_g also has no change in the laser-MIG hybrid welding.

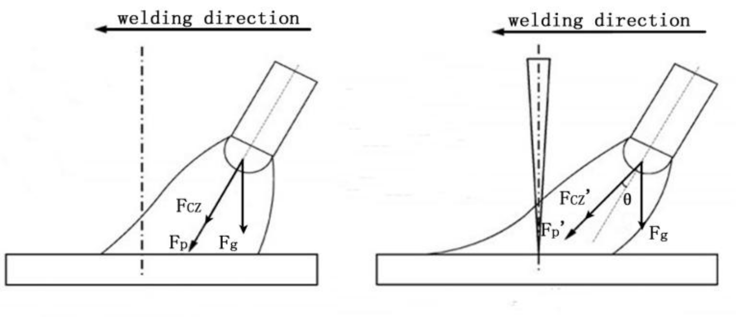

Figure 11. Schematic diagram of force of droplet of MIG welding and laser-MIG hybrid welding

When the laser pulse acts on the MIG arc, there is the laser-induced plasma generating on the surface of the materials. The cation and free electron in the laser-induced plasma attract the arc to discharge in this area, and the boot of arc will be compressed [13, 15]. Therefore, the hybrid arc is changed because of the influence of laser pulse. The higher the laser power is, the stronger the electromagnetic attraction gets. That change also makes the direction of the electromagnetic pinch force and plasma flow force originally along with the axis of the wire offset at an angle θ°, just as is shown in Fig 11. Therefore, the extent and direction of the electromagnetic pinch force both change under the function of laser pulse. Therefore, the necking mode of droplet transfer changes regularly from symmetrical necking to asymmetrical necking by the influence of changed electromagnetic pinch force and plasma flow force when the laser pulse acts on the peak value of the MIG arc waveform, just as is shown in Fig 12. The droplet deviates from the wire axis, and with the laser power increasing, the larger the attraction it has, the bigger the angle of deviation is. When the laser pulse acts on the basic value of the MIG waveform, that is the droplet enter into the melt pool, the effect of laser pulse on the necking of droplet is not obvious for the reason that the droplet has already fallen off, then it also has little effect on the path of droplet entering into melt pool.

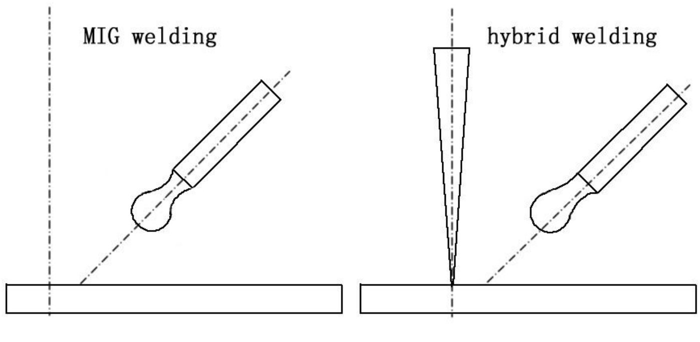

Figure 12. Schematic diagram of necking form of droplet for MIG welding and laser-MIG hybrid welding

When the laser pulse acts on the MIG arc, the boot of MIG arc can be compressed at the place being acted by laser due to the effect of laser pulse[15,16], which results in the increasing of the electromagnetic pressure difference between the electrode and the surface of workpiece. The electromagnetic pressure difference causes the change of the plasma flow force. Therefore, the extent of plasma flow force is also increased.

The time of droplet entering into melt pool is mainly influenced by the speed of the droplet. The speed of the droplet is mainly influenced by the plasma flow force after the droplet falls off. The plasma flow force increases due to the action of the laser pulse, therefore, it is the increasing of plasma flow force that gives rise to the shorter time of the droplet entering into the melt pool. The laser power is increasing, the faster speed it has, and the faster the speed of droplet has, then the shorter of the time that the droplet entering into the melt pool is. The time with laser acting on the basic value is shorter than that with laser acting on the peak value, this is because that the influence of the plasma flow force to the speed of droplet transfer with laser pulse acting on the basic value is stronger than that with laser pulse acting on the peak value.

Conclusions

The influence of the laser pulse to the droplet in laser-MIG hybrid welding on 6061 aluminum alloys is studied in this paper, and the following conclusions can be drawn:Laser pulse can changes the necking form of droplet and the speed for droplet transfer by changing the electromagnetic force. The necking form of droplet deviates from the axis more easily with the increase of laser power during the laser pulse acting on the peak value, and because of the influence of the necking of droplet, the angle between the path for the droplet entering into melt pool and wire axis increases with the increasing of the laser power, but there is no significant change for the path during the laser pulse acting on the basic value. The time of droplet entering into melt pool has a few characteristics under the action of laser pulse. The time of droplet entering into melt pool is shorter than that without laser. The time with laser power of 300W, 400W and 500W is 7ms, 6ms and 5ms during the laser pulse acting on the peak value. And the time with laser power of 300W, 400W and 500W is 5ms, 4ms and 4ms during the laser pulse acting on the basic value. The weld appearance with laser pulse acting on the basic value is better than that with laser pulse acting on the peak value.

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