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CO_2 laser-micro plasma arc hybrid welding for galvanized steel sheets

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Abstract: A laser lap welding process for zinc-coated steel has a well-known unsolved problem-porosity formation. The boiling temperature of coated zinc is lower than the melting temperature of the base metal, which is steel. In the autogenous laser welding, the zinc vapor generates from the lapped surfaces expels the molten pool and the expulsion causes numerous weld defects, such as spatters and blow holes on the weld surface and porosity inside the welds. The laser-arc hybrid welding was suggested as an alternative method for the laser lap welding because the arc can preheat or post-heat the weldment according to the arrangement of the laser beam and the arc. CO_2 laser-micro plasma hybrid welding was applied to the lap welding of zinc-coated steel with zero-gap. The relationships among the weld quality and process parameters of the laser-arc arrangement, and the laser-arc interspacing distance and arc current were investigated using a full-factorial experimental design. The effect of laser-arc arrangement is dominant because the leading plasma arc partially melts the upper steel sheets and vaporizes or oxidizes the coated zinc on the lapped surfaces. Compared with the result from the laser-TIG hybrid welding, the heat input from arc can be reduced by 40%.

Key words: galvanized steel; CO_2 laser; micro plasma; hybrid welding

1 Introduction

The laser welding is being increasingly applied to the assembly of automobile parts as a faster the welding speed enhances the productivity and a lower heat input minimizes the welding distortion. The laser welding enables one-sided access and does not cause any electrode wear compared with the conventional resistance spot welding.

For body-in-white of automobiles, the galvanized steel sheets are widely used to ensure the corrosion resistance. The galvanized steel sheets entail the problem of porosity generated by the expulsion of zinc layer on the lapped surface. The vaporization temperature of zinc is lower than the melting temperature of steel. Therefore, during laser irradiation, the coated-zinc layer is vaporized before the base material is molten. When the base material is molten and the molten pool is generated, the zinc vapor expulses, which creates a spatter and results in porosity in the weldment[1−3].

A wide variety of methods have been suggested to reduce the defects in the laser lap weld joint of galvanized steel sheet, and the active research is underway on these methods. The prime examples of methods include the formation of gaps or holes between sheets, application of pulse welding, the application of laser-arc hybrid welding and use of new alloy design [4−18]. What is most widely used method in industries is gap formation, but it is not easy to constantly maintain adequate gaps.

The laser-arc hybrid welding is a technology that combines the laser welding and arc welding, generating a single weld pool and fully leveraging the strengths of both welding methods[19−21]. In laser-arc hybrid welding, the weldment can be preheated and post-heated using the arrangement of laser and arc. The zinc layer of the lapped surface can be removed with the leading arc plasma before laser irradiation, so the quality of welding can be guaranteed. Previous studies have primarily used the tungsten inert gas (TIG) arc to perform laser-arc hybrid welding, and thereby ensure the welding quality [8,14]. In these studies, however, the TIG current of 100 A has been adopted in addition of laser heat input, resulting in an increase in heat input at the lateral sides of the weldment. The plasma arc welding, like TIG welding,

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utilizes non-consumable electrodes. As the orifice gas and constricting nozzles are additionally applied, the arc is constricted and has high density. Thus, this method produces a plasma arc of the highest density among all arc welding techniques[22−25].

This study implements laser-arc hybrid welding based on the micro-plasma arc with an aim of achieving low-heat input, high-quality arc welding. The lap weld joint characteristics of the galvanized steel sheet are assessed without any particular control over the gaps.

2 Experimental

For comparing with laser-TIG hybrid welding, the experiment is done under the same conditions as described in Ref.[14]. The materials and fixed welding conditions used in the experiment are suggested in Tables 1, 2 and 3, respectively. Both sides of the steel plate are galvanized with 54 g/m^2 zinc and the thickness of the zinc coating is approximately 50 μm.

Table 1 Mechanical properties of SGCD1 (JIS G 3302) steel used

Yield strength/MPa	Tensile strength/MPa	Elongation/%
147	292	48

Table 2 Chemical composition of SGCD1 (JIS G 3302) steel used (mass fraction, %)

C	Si	Mn	P	S
0.002 8	0.009	0.129	0.007 9	0.009 7

Table 3 Welding conditions for SGCD1 (300 mm×100 mm×1 mm) used in experiments

Parameter	Value
Laser power/kW	4
Diameter of laser spot/mm	0.4
Shielding gas	100% He (25 L/min)
Electrode diameter/mm	1.5
Angle between laser and arc/(°)	30
Arc length/mm	2
Welding speed/(m·min^{-1})	3
Joint	Lap joint

The experimental setup, including a customized hybrid welding head and the definitions of the welding parameters, is shown in Fig.1. The pure helium was used as the shielding gas and was supplied through the plasma torch nozzle at 25 L/min. The workpiece was pressed

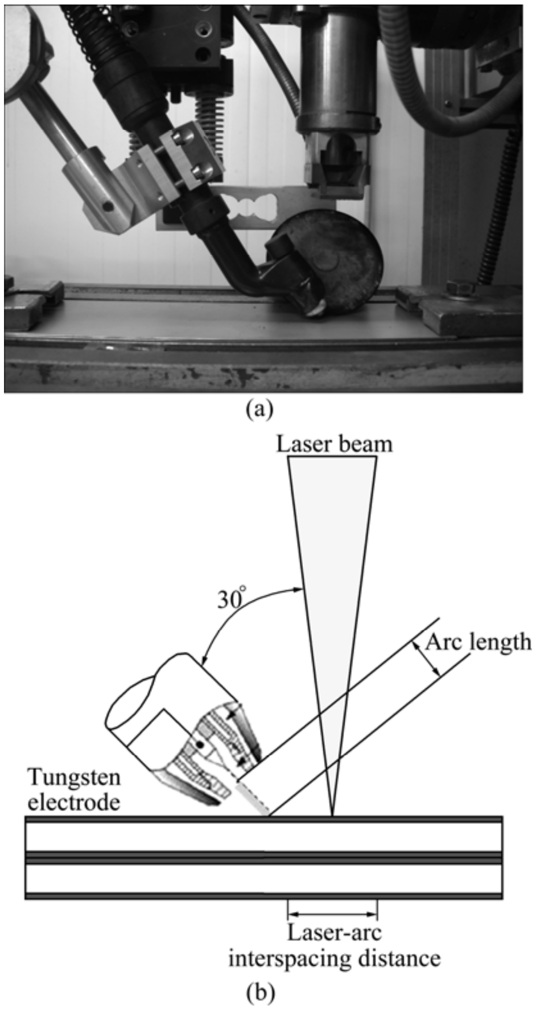

Fig.1 Experimental setup for hybrid welding: (a) Photo of laser-plasma hybrid welding head; (b) Schematic diagram of hybrid welding configuration

and fixed without a gap using a guide-roller.

In order to assess the characteristics of weld beads by welding process, the laser, plasma and laser-plasma hybrid welding processes were applied to galvanized steel sheets. In laser-plasma hybrid welding, the influence of process parameters on the weld quality was assessed.

3 Results and discussion

3.1 Weld shape by welding process

Fig.2 shows the top surface, a longitudinal cross-section and a transverse cross-section of the welds that resulted from lap joint welding without a gap on galvanized steel sheets. There are weld defects inhibiting bead continuity throughout the welds. The representative weld defects are blowholes and porosities.

Fig.3 shows the shapes of the top surface,

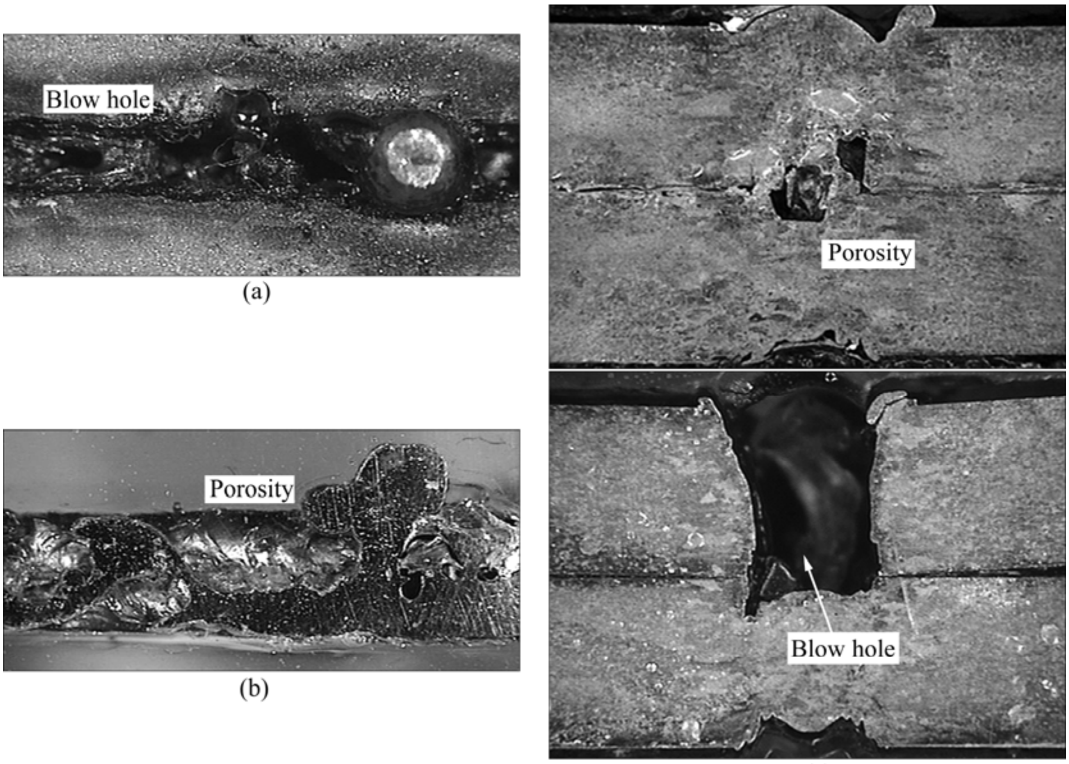

Fig.2 Weld defects of autogenous laser lap welding of zinc-coated steel[14]: (a) Top surface; (b) Longitudinal cross-section; (c) Transverse cross-section

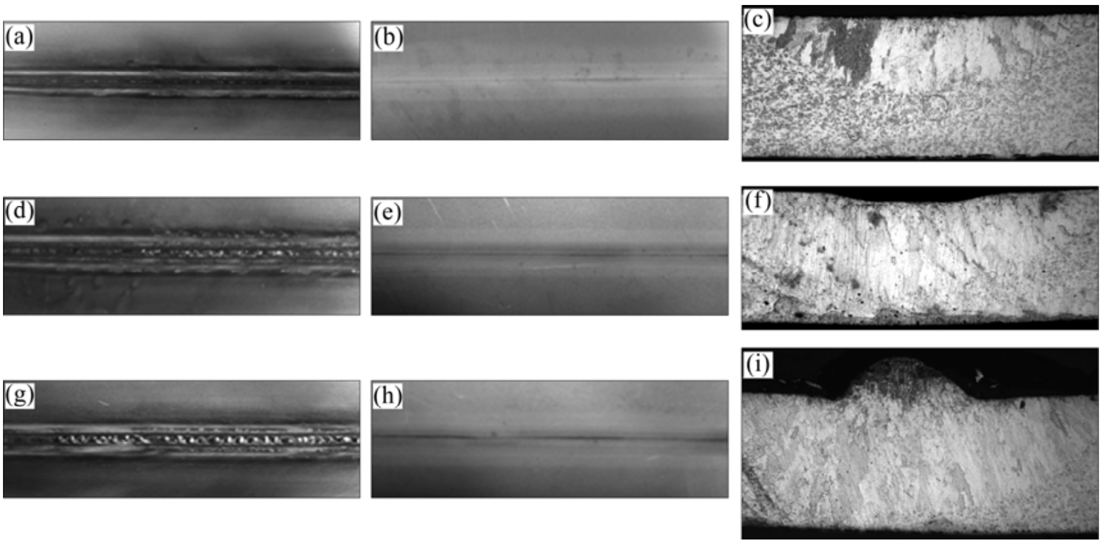

Fig.3 Bead shapes for plasma arc welding of galvanized steel sheets: (a) 60 A, top surface; (b) 60 A, bottom surface; (c) 60 A, cross-section; (d) 70 A, top surface; (e) 70 A, bottom surface; (f) 70 A, cross-section; (g) 80 A, top surface; (h) 80 A, bottom surface; (i) 80 A, cross-section

longitudinal cross-section and transverse cross-section when the plasma arc alone is applied. When the arc current is altered from 60 A through 70 A to 80 A, only the upper plate is molten though lap welding is done. The figure shows that the plasma arc heat input of 60 A current is sufficient to remove the coated-zinc layer on the bottom surface of the top plate. Meanwhile, at the arc current of 80 A, even the bottom surface of the top plate is molten, and the zinc coating of the lapped surface expulses, causing defects.

Using the arc current of 60 A which can remove the zinc layer on the lapped surface, so the laser-plasma arc hybrid welding was carried out. The top surface, the longitudinal cross-section and the transverse cross-section of the welds are shown in Fig.4, which shows good welds without any porosity or the blow hole. The laser-arc hybrid welding of galvanized steel sheets can be done, without producing a gap, even at the arc heat input of 40%, lower than that at the current of 100 A used in conventional laser-TIG hybrid welding.

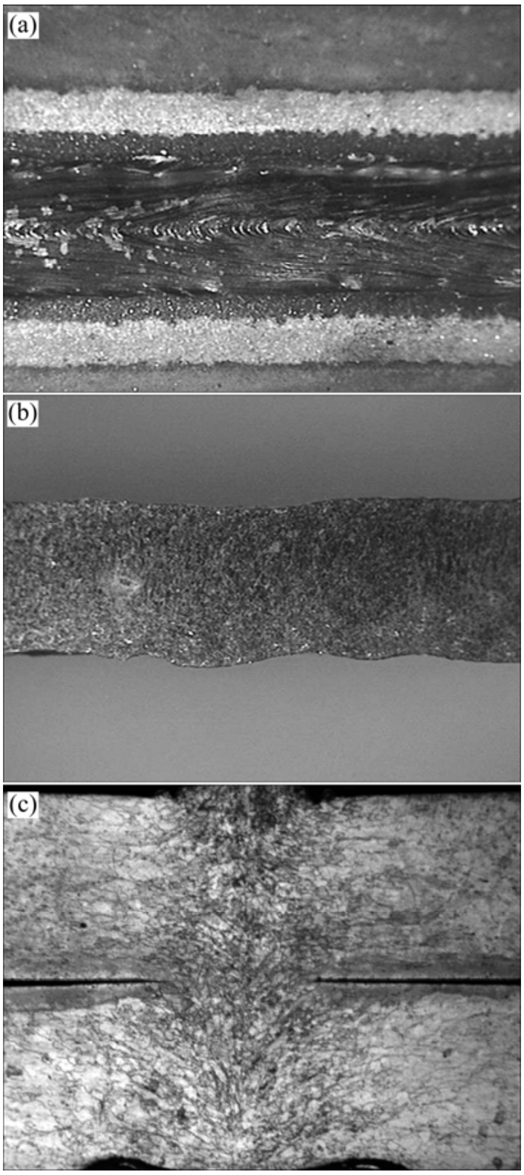

Fig.4 Bead shapes for laser-micro plasma hybrid welding of galvanized steel sheets (Arc current: 60 A; Laser-arc inter-spacing distance: 4 mm): (a) Top surface; (b) Longitudinal cross-section; (c) Transverse cross-section

3.2 Evaluation of welding parameters

Full factorial experiments were performed, and the factors and levels shown in Table 4 are applied to evaluating effects of the laser-arc arrangement, the laser-arc interspacing distance and arc current. For each of the 18 combined conditions, the welding was done three times and the amounts of spatter before and after the welding were measured to be used as the index of determining the quality of welding. The analysis of variance (ANOVA) results for the main effects (A, B, C) and the error term (ERROR) are shown in Table 5. F_0 is the F value calculated from the F distribution which is determined by the number and degrees of freedom of the factors[21]. When the P value is less than 0.05, the effect of the factor is statistically significant at a significance level of α=0.05.

A comparison of F values for individual factors demonstrates that the effect of laser-arc arrangement is dominant. As shown in Fig.5, the occurrence of spatter declines considerably when the arc rather than the laser is leading. When the laser leads the arc, it is subject to the influence of zinc vapor on the lapped surface layer in laser autogenous welding.

In the arc leading, as shown in Table 6, only the main effect of laser-arc interspacing distance is significant at a significance level of α=0.05 as the P value

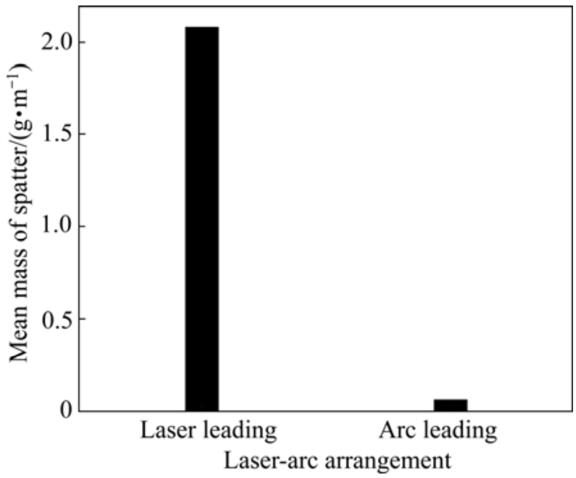

Fig.5 Effect of laser-arc arrangement on mean mass of spatter

Table 4 Control factors and their levels for full factorial design

Factor	Parameter	Level		
		1	2	3
A	Arrangement of laser and arc	Laser leading	Arc leading	
B	Arc current/A	60	70	80
C	Laser-arc distance/m	4	6	8

Table 5 ANOVA results of full factorial experiments

Source	Degree of freedom	Sum of square	Mean square	F_0	P
A	1	36.804 4	36.804 4	1 790.49	0
B	2	0.143 9	0.071 9	3.50	0.043
C	2	0.227 2	0.113 6	5.53	0.009
Error	30	0.616 7	0.020 6		
Total	35	37.792 2			

Table 6 ANOVA results for arc leading cases

Source	Degree of freedom	Sum of square	Mean square	F_0	P
B	2	0.001 111	0.000 556	0.20	0.822
C	2	0.034 444	0.017 222	6.20	0.020
B×C	4	0.002 222	0.000 556	0.20	0.932
Error	9	0.025 000	0.002 778		
Total	17	0.062 778			

is under 0.05. In the case of arc current, it is believe that the zinc layers on lapped surface are fully removed at or above 60 A, as shown in Fig.3. The amounts of spatter generated by the level of arc current and the laser-arc interspacing distance are shown in Fig.6. The amounts of spatter increase as the laser-arc interspacing distance becomes longer. In order to confirm this, the high-speed photography is performed, with 3 000 frames per second, and the results are shown in Fig.7. The reason for such results is considered to be as follows: with increasing the laser-arc distance, the less interaction is made between the laser and the arc. When the distance is 8 mm, as shown in Fig.7(c), the molten pool generated by the leading arc is separated from the molten pool created by laser irradiation.

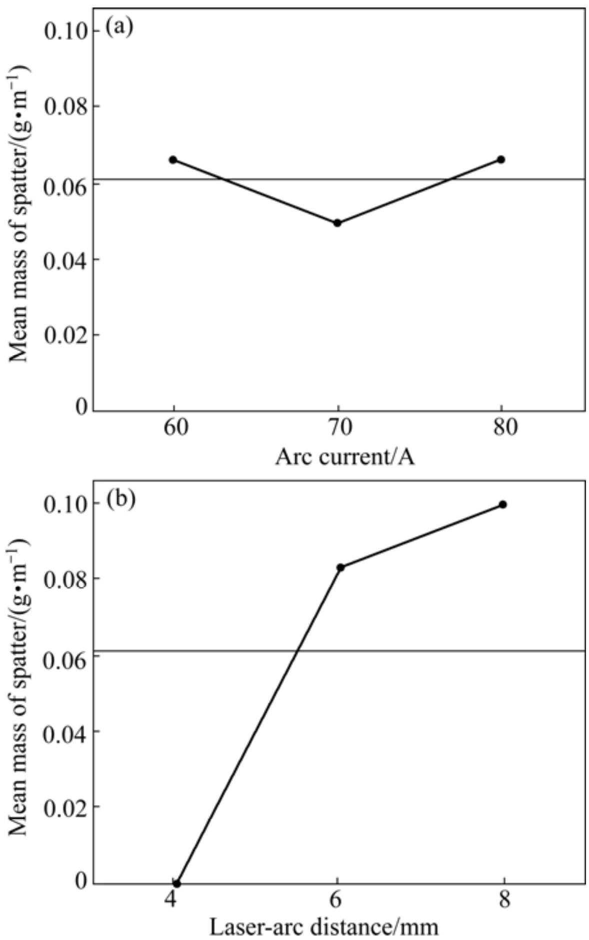

Fig.6 Influence of arc current (a) and laser-arc distance (b) on mean mass of spatter

4 Conclusions

1) The gap-less lap weld joints are formed on galvanized steel sheets and performed laser-plasma hybrid welding.

2) The plasma welding enabled formation of high-density arc plasma, so a good weld bead shape has been obtained with a 40% smaller arc heat input than that found in laser-TIG hybrid welding.

3) When the arc is leading, the coated-zinc layer is removed using the leading arc before performing laser welding, producing a better weld bead than that in the case of laser.

4) When the arc-laser interspacing distance gets longer, no synergy effects are created between the two thermal sources, and the molten pool has been found to be separated.

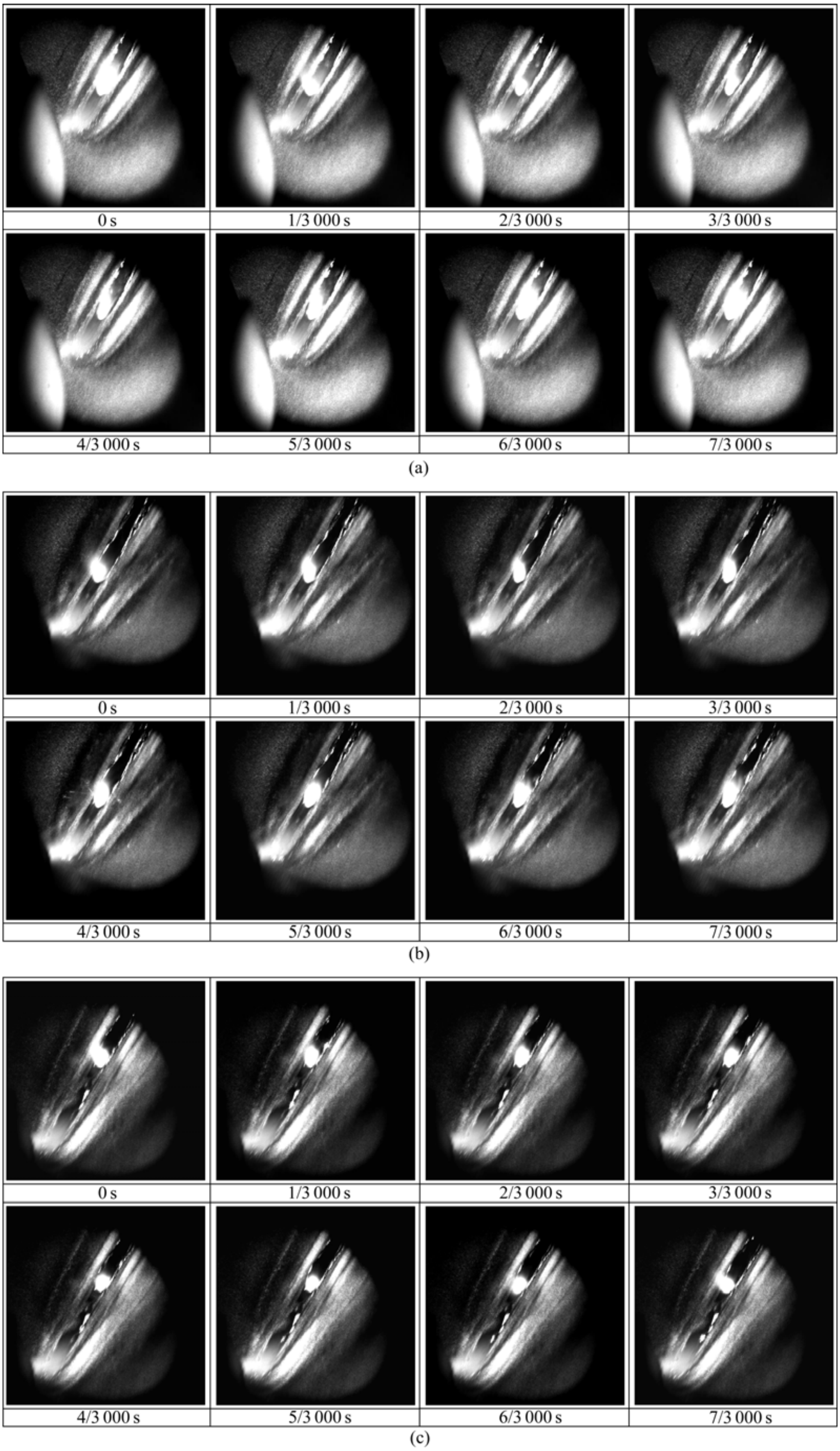

Fig.7 High speed images for laser-plasma arc hybrid welding according to various laser-arc interspacing distance (Arc current: 70 A): (a) 4 mm; (b) 6 mm; (c) 8 mm

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