STUDY ON THE PREVENTION OF WELD DEFECTS IN CO_2 LASER WELDING

by

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Laser welding is suitable to produce high-precision weldments, because of low heat input and deep penetrations as compared with bead widths. The partially penetrated weld of steels, in general, is susceptible to porosities. It is suspected that gases such as oxygen and nitrogen in the base metal, the metallic vapor generated from the molten pool or the shielding gas are trapped in the weld metal due to unstable flow of the molten metal. However, the definite causes of porosity formation in laser welding have not yet been clarified.

In the present report, the causes and the prevention of the porosity formation in partially penetrated welds of steels made by CO_2 laser welding were investigated. The results are summarized as follows:

(1) The porosities are caused by the metallic vapor and the gases trapped in the molten metal due to unstable metal flow in the molten pool with a key hole.
(2) The porosities can be prevented by using a mixed gas of O_2 and N_2 as a shielding gas and stabilizing the flow of the molten metal.
(3) The porosities can be prevented if the shape of the molten pool is stabilized by a beam oscillation along the weld center line.

INTRODUCTION

Laser welding is suitable to porduce high - precision weldments, because of low heat input deep penetrations as compared with bead widths. The partially penetrated weld of steels, in general, is susceptible to porosities. It is suspected that gases such as oxygen and nitrogen in the base metal, the metallic vapor generated from the molten pool or the shielding gas are trapped in the weld metal due to unstable flow of the molten metal. However, the definite causes of porosity formation in laser welding have not yet been clarified.

In the present work, the effective factors on porosity formation in CO_2 laser welding of carbon steel (JIS SM400) and stainless steel (JIS SUS304) were investigated using 3KW CO_2 laser facility. The prevention of porosities was also studied from the viewpoint of welding procedure.

Formation of Porosities

Fig. 1 shows an example of porosities in laser welds of carbon steel. There are no porosities in the fully penetrated weld, but small porosities of diameter less than 0.4 mm are observed in the partially penetrated welds.Fig. 2 shows the solidification patterns of bead-on-plate welds in the laminated plate of stainless steel and carbon steel. The solidification line near the root is curved and shows an unstable metal flow. Fig. 3 shows fractographies of the insides of porosities. Their shapes are not uniform and it is suggested that the porosities is caused by rapid solidification. On the insides of the porosities, a solidification substructure which seems to be the solidification boundary face appears and this substructure resembles

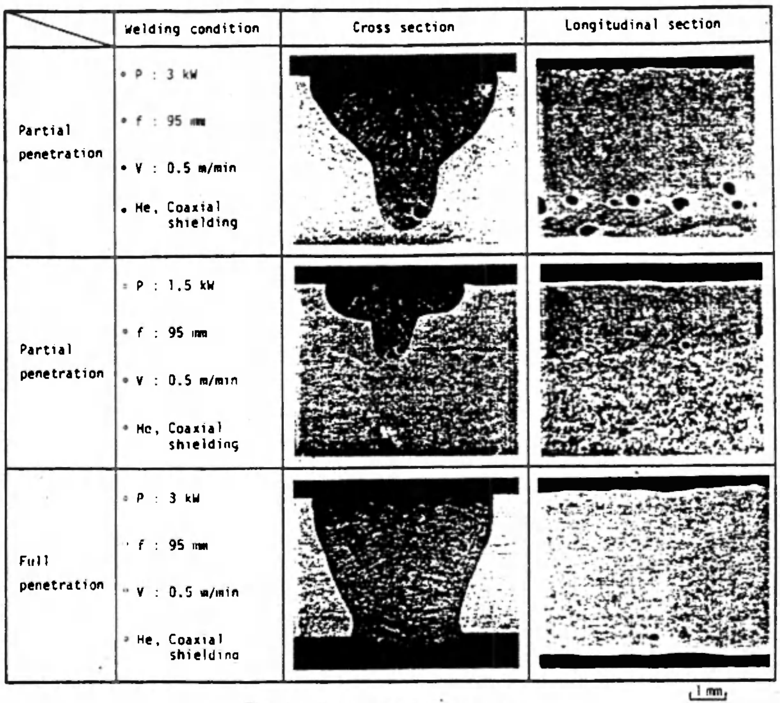

Fig. 1 : Porosities in laser weld

the internal structure of shrinkage cavities.

Table 1 Gas content of base metal and weld metal

Sampling Position	P(KW)	f(mn)	V (m/min)	Shielding	Number of Porosities per 10 mm bead	N(ppm)	O(ppm)
Base metal	-	-	-	-	-	538	36
Partial penetrated weld metal	3.0	95	0.5	He,coaxial	20	510	70
''	1.0	''	''	''	0	562	82

Table 1 also shows the results of gas analysis of weld metals with and without porosities and base metal. There is no significant difference in nitrogen content between the weld metal and base metal, but the oxygen content in the weld metal is higher than that in the base metal. There are no significant differences in nitrogen and oxygen contents between the weld metals with and without porosities. It is suggested from this data that the N2 and O2 contents do not have a direct relationship with the formation of porosities.

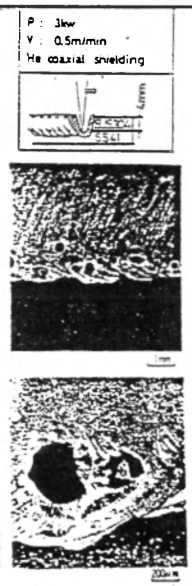

Fig. 2 : Solidification pattern in partial penetration welds

From the above results, the behaviours of molten metal during laser welding are schematically illustrated in Fig. 4. The beam key hole in the molten pool during the laser welding becomes unstable due to multi-reflection of beam, high pressure of the metal vapor and flow convection of the molten metal and gas formation. The opening diameter locally becomes smaller.

The key holes filled with metal vapor and gases do not allow the metal flow in molten pool to make an irregular shape of key holes. This irregular rear shape causes the porosities during the rapid solidification.

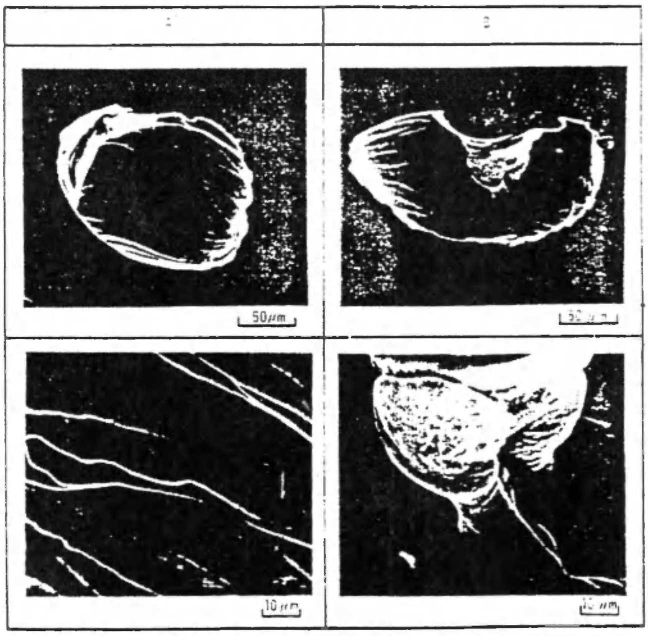

Fig. 3 : Fractography of porosities in laser welds

Prevention of Porosities

As mentioned above, the porosities are formed by the irregular metal flow due to the metal vapor and gases in the key hole. To prevent them, the following effective methods were proposed. The effectiveness of these methods on the prevention of porosity formation was investigated in the present work.

1) To reduce the generation of metal vapor by reducing the laser output power and increasing the welding velocity.

2) To decrease the surface tension of molten metal by adding an active nitrogen or oxygen gas into the shielding gas in order to stabilize the flow of the molten pool as shown in Fig. 5.

3) To oscillate laser beam in the welding direction to increase the opening diameter of key hole so that the metal vapor, main cause of porosities, would be evolved easily.

Experimental Procedure

Using a 3 KW CO_2 laser apparatus whose specifications are shown in Table 2, bead-on-plate welding of steel was carried out by the set-up shown in Fig.6. Materials used were stainless steel plates (JIS SUS304) of 4 mm and 6 mm in thickness and carbon steel plate (JIS SM400) of 6 mm in thickness. The welding conditions are shown in Table 4.

Table 3 Chemical composition of materials used

(Wt%)

material	thickness (mm)	c	Si	Mn	P	S	Ni	Cr
stainless steel	4	0.60	0.60	1.20	0.0035	0.010	8.81	18.07
(JIS, SUS304)	6	0.03	0.29	0.95	0.0030	0.005	8.81	18.46
carbon steel (JIS, SM400)	6	0.11	0.10	0.34	0.015	0.015	-	-

Table 4 Welding condition

	Laser Power	(KW)	0.5 3.0
	Focus length	(mm)	95,127,191
	Welding speed	(m/min)	0.5 3.0
		Shielding gas	He + N (0 100%) He + O (0 10%)
	Shielding	Shielding Method	Coaxial flow
	Direction		X (Welding direction)
Oscillation	Frequency	(Hz)	0 80
	Amplitude	(mm)	0 7

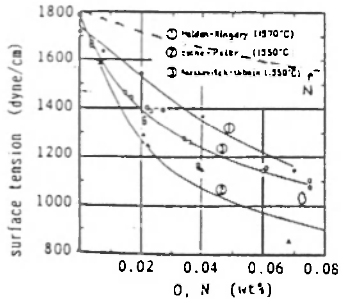

Fig. 5 : Effect of oxygen, nitrogen on surface tension of molten iron

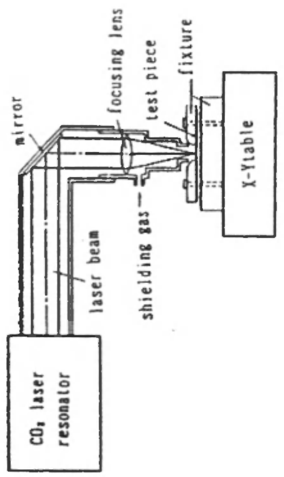

Fig. 6 : Configuration of laser welding

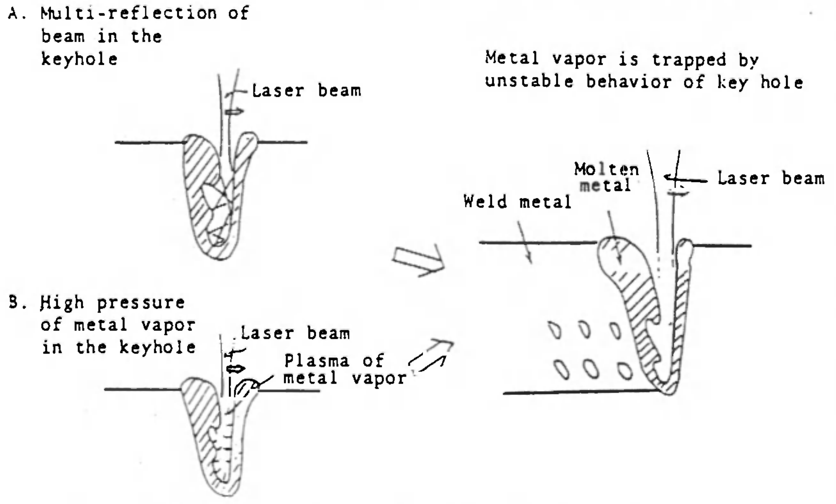

Fig 4 : Assumed mechanism of formation of porosities

Table 2 Specification of CO2 laser apparatus

Item	specification
laser power range	500 3000 W
resonation type	3 axis cross type
power stability	5%(8Hr)
wave length	10.6
kaser gas	CO_2 - N_2 - He - CO

The shielding gas was helium gas mixed with oxygen or nitrogen at a flow rate of 40/ /min.

The laser beam was ocillated using a mirrow in the welding direction, and the amplitude and frequency were varied in the ranges of 0 - 7 mm and 0 - 80 Hz respectively.

After welding, the welds were examined by radiographic test and their cross sections were observed under an optical microscope for porosities.

Experimental Results and Discussion

Effects of Output Power and Travel Speed on Porosities

Fig. 7 shows the relationship between the number of porosities and the beam output power using the different focus lens. As the output power increased, the nimber of porosities increased. It is considered that with an increase in the output power, the molten metal was heated up to an elevated temperature to generate metal vapour and the flow of the molten metal in the molten pool became unstable and excited.

The number of porosities increased when the focal length of lens was short. This may be because with the short focal length of lens, the spot diameter becomes smaller and more metal vapour is generated and trapped in the molten metal.

Fig. 8 shows the relationship between porosities and welding speed. As the welding speed increased, the number of porosities decreased. When the welding velocity was 3 m/min, no porosities occured.

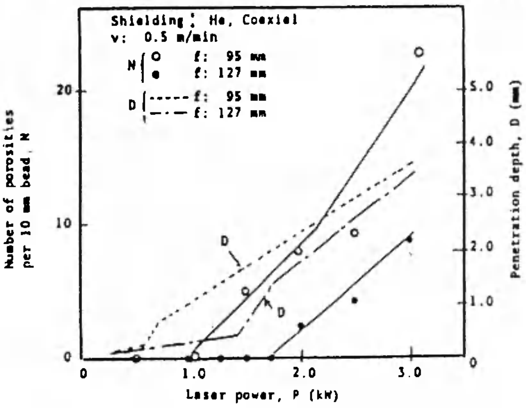

Fig. 7 : Effect of laser power and focusing conditio on number of porosities

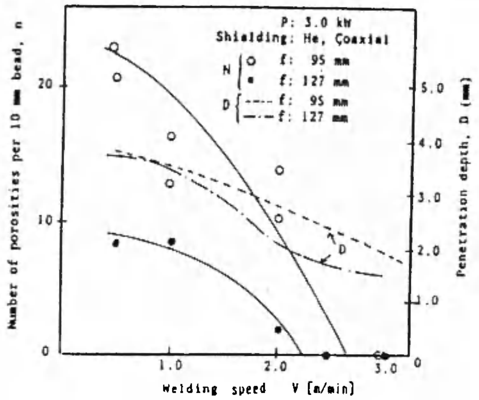

Fig. 8 : Effect of welding speed on number of porosities

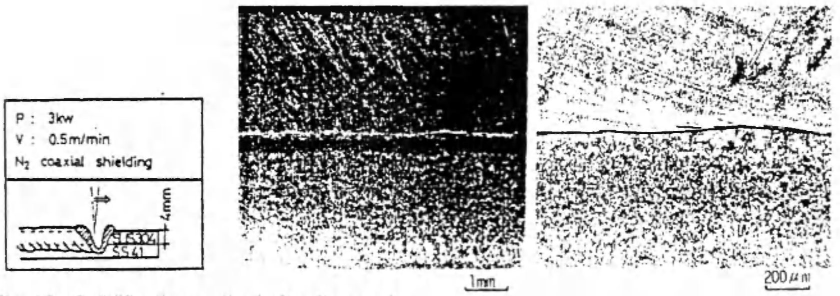

Fig. 10 : Solidification method of molten pool

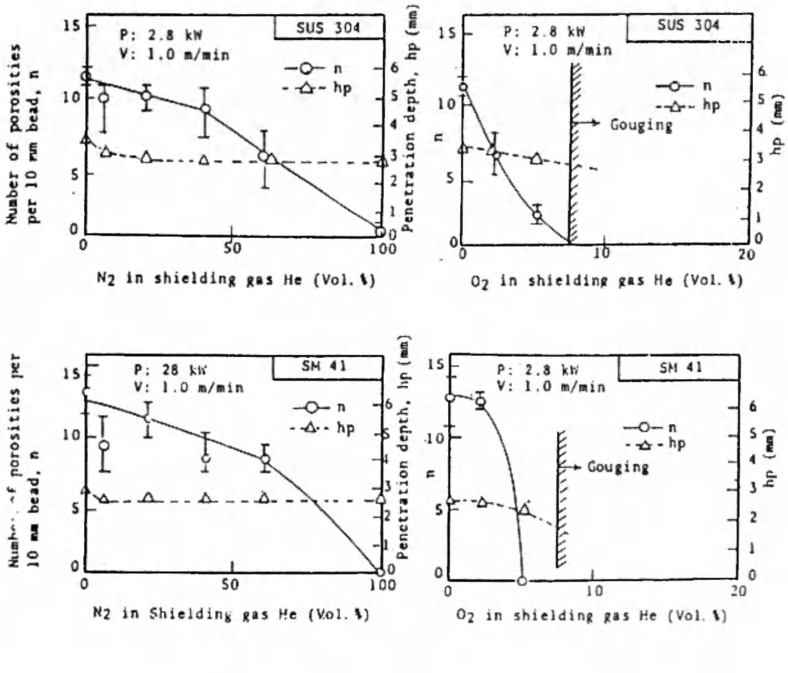

Fig. 9 : Effect of active gas on penetration and number of porosities

It is obvious that in high-speed welding, the key hole was extended long in the welding direction and the opening diameter of key hole became large so that the metal vapour was ejected more easily.

Effect of Active Gases on Porosity Formation

Fig.9 shows the effects of the shielding gas on the depth of penetration and porosities. Comparing with the helium shielding, the shielding with helium gas mixed with an active oxygen or nitrogen gas brought about a remarkable reduction in the number of porosities although the penetration depth decreased slightly. The number of porosities became zero when the mixing ratio of nitrogen gas was 100% and that of oxygen gas was about 5%. The same tendency was observed in laser welding of both stainless steel and carbon steel.

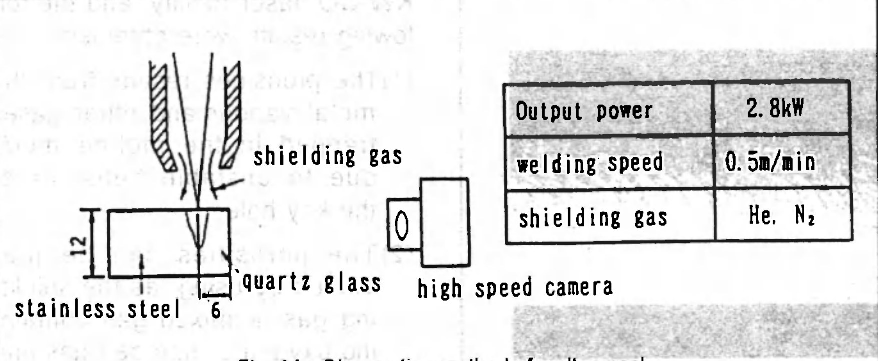

Fig. 11 : Observation method of molten pool

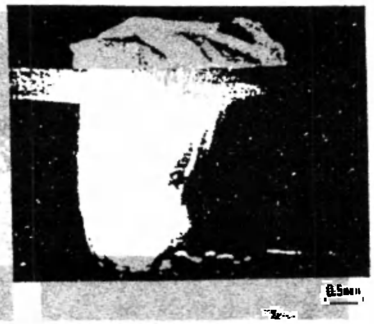

Fig. 12 : Behaviour of molten pool (Shielding gass : He)

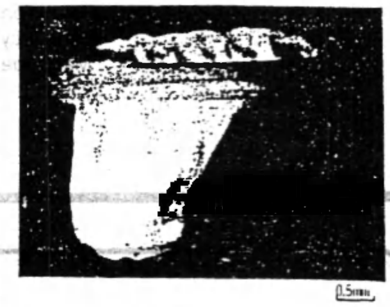

Fig. 13 : Behaviour of molten pool (Shielding gass : N_2)

Fig. 10 shows the solidification pattern of the cross section when only nitrogen gas was used for shielding. The solidification line was less disturbed, smoother and straighter than that shown in Fig. 2 in which pure helium was used for shielding. It is presumed that when the shielding gas contained oxygen or nitrogen gas, the surface tension would have decreased as shown in Fig. 5 and the flow of molten metal would have been stabilized, ensuring smooth filling of the key hole with molten metal and thereby preventing prorsities.

To clarify these points, the behavior of molten metal when helium and nitrogen gases were used for shielding was directly observed through quartz glass. Fig. 11 shows the observation method of molten pool. The laser beam was applied to melt the butt joint of stainless steel plate. The molten pool during laser welding was directly observed through the quartz glass from the side. Examples of observation results are shown in Figs. 12 and 13. Fig. 12 shows the behaviours of molten pool under the helium shielding. At the lower part of the key hole, an expanded rear flow is found. The molten metal did not flow into this part smoothly. As a result, the gases and metal vapours remained at this portion to form porosities during rapid solidification.

Meanwhile, Fig. 13 shows the behaviour of molten steel under nitrogen gas shielding. The flow of the molten metal was stable at the rear portion and the key hole had a large opening diameter. Therefore, internal gas and metal vapour were easily ejected upward and the key hole was smoothly filled with molten metal, thereby preventing the formation of porosities.

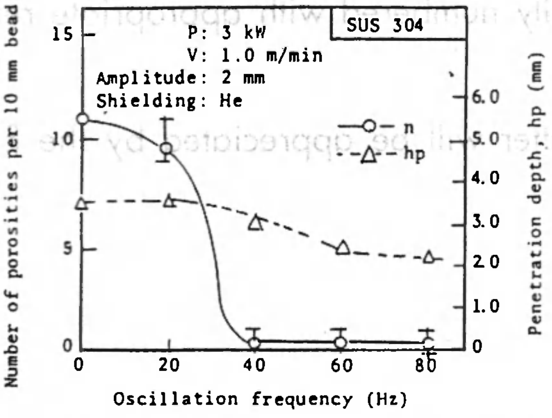

Fig. 14 : Effect of Beam Oscillation on penetration and porosities

Effect of Beam Oscillation on Porosity Formation

Fig. 14 shows the effect of beam oscillation on porosities and penetration depth.

Fig. 15 shows the cross section of laser weld of carbon steel made with beam oscillation.

At the frequency of oscillation of higher than 40 Hz, no porosity was formed.

The reason seems to lie in that as the key hole opening was elongated in the oscillating direction, the metal vapour filling the key hole was ejected smoothly and the rear shape of the molten pool was improved, thereby stabilizing the solidification pattern.

CONCLUSION

The formation of prorsities in partially penetrated laser welds of steels was investigated using 3

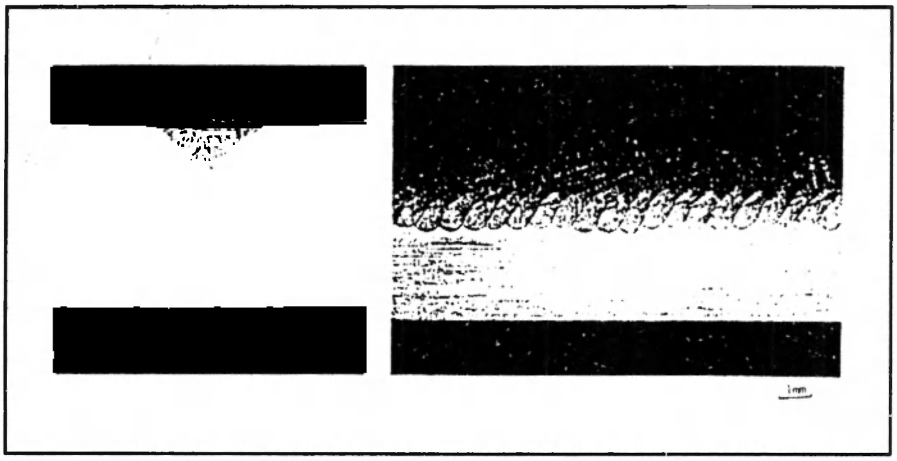

Fig. 15 : Effect of Beam Oscillation on porosities
Oscillation : Welding Direction
Frequency : 40 Hz
Maplitude : 2mm

KW CO_2 laser facility, and the following results were obtained.

(1)The proosities results from the metal vapour and other gases trapped in the molten metal due to unstable behavior of the key hole.

(2)The porosities can be prevented by using, as the shielding gas, a mixed gas containing oxygen or nitrogen gas and improving the flow of the molten metal.

(3)The porosities can be prevented through agitation of the molten metal by beam oscillation in the welding direction.

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