Minimization of Welding Defect in CO_2 Laser Welded Tube

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To minimize the weld defect in manufacturing of the welded tube by using CO_2 laser, the monitoring of the welding quality and the seam tracking along the butt-joint lengthwise to the tube axis are studied. The longitudinal butt-joint is shaped from 60kgf/㎟grade steel sheet by 2 roll bending method, and welded by the CO_2 laser welding system equipped with the seam tracker and plasma sensor. The laser welded tube has the thickness of 1.5㎜, diameter of 105.4㎜ and length of 2000㎜. The precise positioning of the laser beam on the butt-joint to be assembled is obtained within 200㎛ by the laser vision sensor. The artificial defects in the butt-joint are well observed by the signal of plasma intensity measured from the plasma sensor of UV wavelength range within 400nm. The developed CO_2 laser tube welding system has the function of the precision seam tracking and the real-time monitoring of the welding quality. In conclusion, the laser welded tube can be used for manufacturing of automobile chassis and components after hydro-forming.

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1. Introduction

The tubular hydro-forming is the representative method in one-body forming technologies that can produce the final form at one time in the manufacturing of automobile parts of a complicated shape. The tube, the raw material of the tubular hydro-forming, is manufactured by HF-ERW(High Frequency Electric Resistance Welding) and it is widely used in the automobile chassis such as engine cradle and instrumental panel beam.

Nowadays, the application fields of the automobile part by the tubular hydro-forming have been expanded from the automobile chassis to automobile body. It is expected to use the tube of the thin thickness and large diameter. However, the manufacturing method depending on ERW technology is not enough to satisfy the required manufacturing conditions. In addition, the conventional ERW method is also impossible for manufacturing of the conical tube and tailor tube. Therefore, it is very important to use the laser welding method for the manufacturing of tubes.

As an example, the processes to manufacture the tailor tube by forming the laser welded tailored blank and then to manufacture the automobile bumper beam by one body forming are shown in Fig. 1. The forming process, the pre-welding process to make the tube of the plate, has several manufacturing methods such as UO-bending, bending on press brake, continuous roll forming and 3 or 2 roll bending. In the case of forming the steel plate(tension strength: 60kgf/㎟, thickness: 1.4~1.6mm) into the tube (diameter:>100 mm, length: 2m), such as bumper case shown in Fig. 1, the straightness of the lengthwise butt joint to be welded by laser is very important.

In order to obtain a good result in the welding process, the position error between welding line and focal point of laser beam should be maintained within 200㎛ because the beam size at focal point is less than 500 ㎛. As shown in Fig. 2, the lengthwise butt joint is sometimes not straight but distorted because of the precision cutting difficulty of plate in lengthwise due to high strength material, thin thickness and large diameter, and the heat distortion in welding process. Therefore, the high strength structure of welding jig is needed to minimize the error of welding. And also the tracking technology of the welding line is needed to control the position of the laser welding head by detecting the error of the straightness of the welding line in welding process as shown in Fig. 3. The papers[1,2] related to the tracking of welding line in welding process is limited to the plate and the papers connected with the tube of high tensile steel plate are not reported.

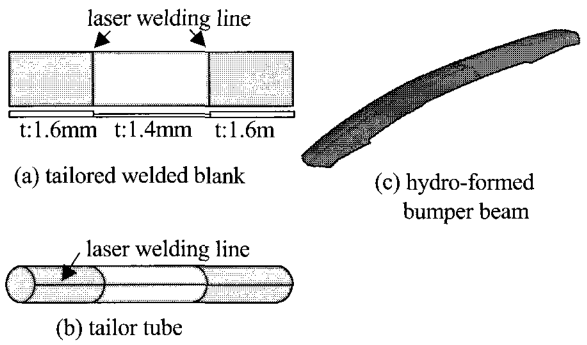


Fig. 1 One body forming process for bumper beam

To monitor the quality of laser welding in field, the research of the measurement of laser induced plasma light[3-7], acoustic emission signal[8,9], reflected light intensity[10] and electric field intensity of plasma[11] is accomplished. Specially, the measurement of plasma light intensity is mainly studied because of the simplicity of measurement equipment and the correlation of the welding condition. But its application field is mainly related to the plate and the research related to the tube is not reported.

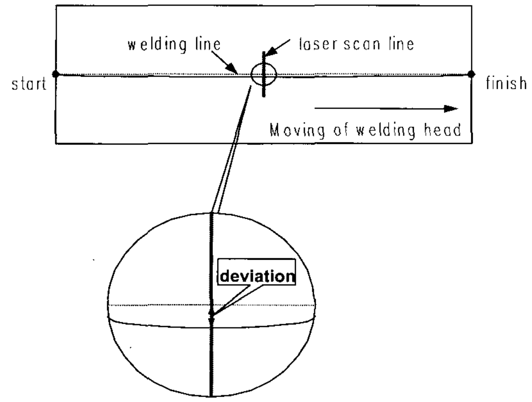


Fig. 2 Error and deviation in longitudinal welding line of tube

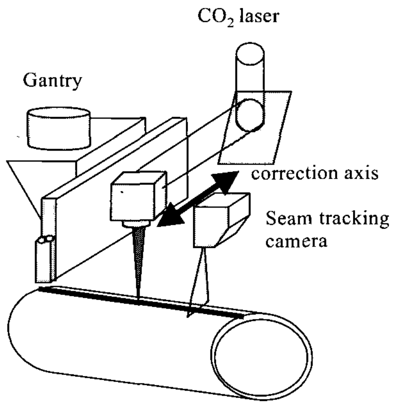


Fig. 3 Schematic diagram of seam tracking of tube

Therefore, the purpose of this study is to implement the CO_2 laser welding equipment with the tracker of welding line and plasma sensor, and to obtain the technology to minimize the welding error when the tube is manufactured by using the high strength steel plate of 60kgf/㎟ grade for an automobile.

2. Experimental method and system

2.1 Tube samples

To manufacture the tube sample for welding, the 2 roll bending equipment as shown in Fig. 4 is used. Tube samples(diameter: 105.5mm, length: 2000mm) are formed by using the steel plate(tension strength: 60kgf/㎟, thickness: 1.5 mm), which is a cold rolled high strength steel plate (SPFC90) for an automobile.

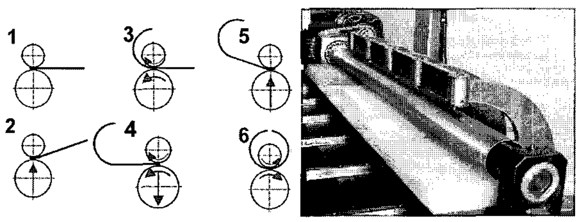
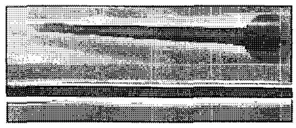
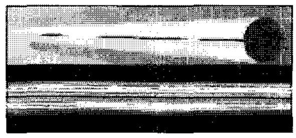


Fig. 4 2 roll bending process

In Table 1, the tube of 60kgf/㎟ shows that the forming is very difficult due to the effect of the spring back and the gap of the welding joint parts is about 45 mm. As compared with it, the tube of 35kgf/㎟ shows that the forming is done well and the gap of it is about 4mm. Thus, in case of using the tube of 60kgf/㎟, the welding jig to strongly join the butt joint by the rotating roller is manufactured to maintain the gap within 200㎛.

Table 1 Gap size of longitudinal joint by 2 roll bending

material	gap size	tube shape before welding
60kgf/㎟	45mm	
35kgf/㎟	4mm	

2.2 Development of experimental system

Fig. 5 shows the schematic diagram of CO_2 laser welding head and jig to weld the butt joint of the tube. The welding job is done with moving the material of the tube type through the welding jig. To compensate the deviation between laser beam and welding line, the tracking sensor of the welding line is attached on the welding head. And also, the plasma detector as the welding inspection equipment is attached to monitor the welding quality in welding process. The welding head with the tracking sensor and the inspection equipment and jig are shown in Fig. 6.

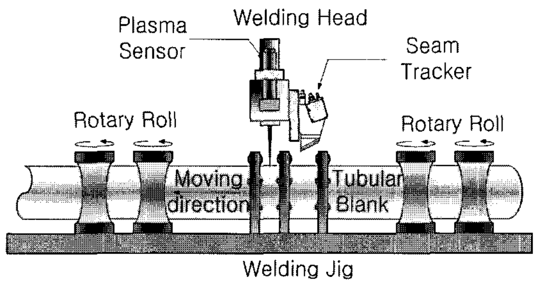


Fig. 5 Schematic diagram for laser welding head

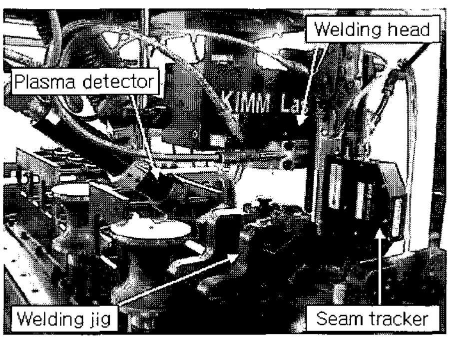


Fig. 6 Laser welding head and fixture

Fig. 7 shows the total system configuration to control the laser welding equipments. CNC is used to control the position compensation of the welding head with the signal of the tracking sensor of the welding line and axis control of the equipments. The speed controller attached on the welding jig part controls the welding speed by the rotation speed of the rotating roller.

The analog signal to be output from the tracking equipment of the welding line to compensate the welding position is converted into the input signal type of CNC by V/F converter. The laser vision sensor to track the welding line is model MVS-5 of MVS Inc.(combination of laser emitter and CCD camera). The measuring range of the laser vision sensor is 5㎜ × 7㎜. The horizontal resolution is 0.01㎜ and the vertical resolution is 0.013㎜.

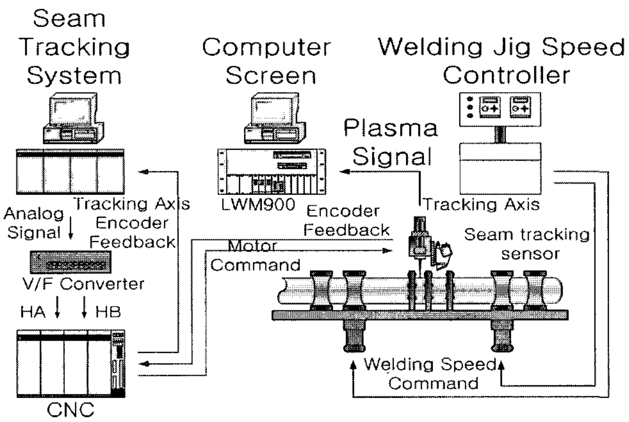


Fig. 7 Interfacing and control system for laser welding of tube

The plasma measurement equipment used in this study is LWM900 of JURCA Inc.(Germany). The equipment is the self-learning and real-time monitoring system to be needed in the teaching mode of welding process to establish the position-true and process -reference. It is known that the plasma is partially in thermal equilibrium state. And in this case it is similar with the spectrum emission of the black body and it obey Plank's law of emission. At this time, the maximum point of radiation curve obey Wien's law of displacement and the wave length of light emitted from plasma is about 190~400nm[12]. Therefore, in this study, the plasma intensity is measured by using UV sensor to be proper in this wave length range. The condition of the tube laser welding and monitoring is given in Table 2 and the installed position of plasma sensor is shown in Fig. 8.

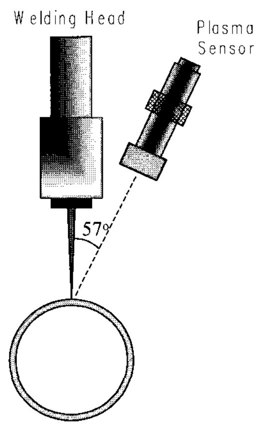


Fig. 8 Position of plasma sensor

Table 2 Experimental condition

weld length		1600㎜
welding speed		2000㎜/min
CO_2 laser power		2.8㎾
focal length		200mm
focused beam diameter		500μ m
beam mode		muti-mode
shielding gas		Ar(30 l/min)
distance from laser beam and laser vision sensor		110㎜
sampling frequency		60㎐
plasma sensor (see Fig. 8)	distance	180㎜
	angle	57°

3. Experimental results and discussion

3.1 Laser weld seam tracking

The segment profile of the welding joint of the tube detected by the tracking sensor of the welding line is shown in Fig. 9. The segment profile is obtained to connect the features extracted from the rounding profile with one another. The center position(→) of the welding line of the tube is exactly shown in Fig. 9.

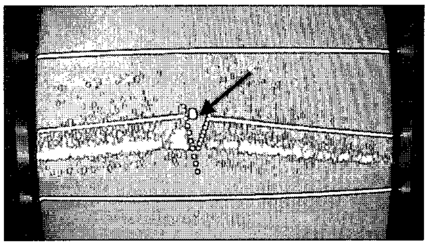


Fig. 9 Segments profile of tube joint

The welding line with respect to the moving direction of the material is slightly rotated when the tube material is supplied and transferred in welding jig. In this case, the welding is bad because the beam laser and the welding line are not aligned as shown in Fig. 10. After the compensation function of the welding line position is operated, the position of the laser beam and welding line is well aligned as shown in Fig. 11. The small error is related with the response time of motion control loop and it can be neglected as compared with the diameter size of laser beam.

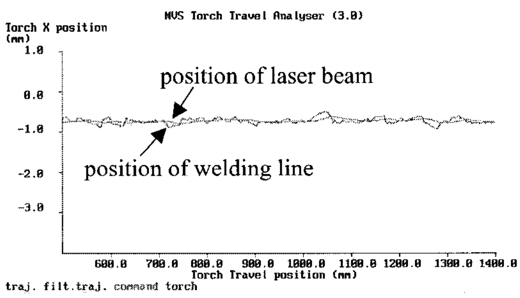


Fig. 10 Deviation of laser beam and welding line

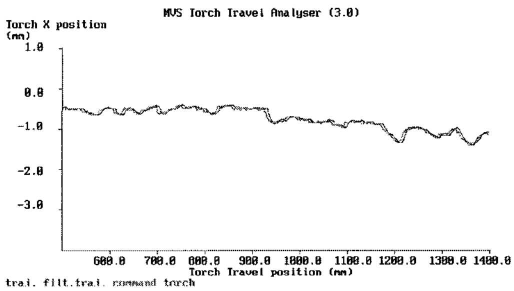


Fig. 11 Seam tracked welding line

3.2 Plasma Measurement

To maintain the high productivity in laser welding, the quantitative evaluation method to predict the quality of the laser welding is very important. In this study, the measuring method of the plasma emitted in welding process is used. To inspect the quality of the laser welding, the reference value of the plasma intensity should be established. To establish the reference value, the welding test is performed 5 times. The detecting graphs of the plasma signal to establish the reference value are given in Fig. 12.

After the welding test is performed to establish the reference value of the plasma intensity, 5 samples of Fig. 12 are established as the reference value. The low bound and upper bound of the reference value are established as -30% and +30% and the results are given in Fig. 13. If the plasma intensity exists between minimum and maximum region as shown Fig. 13, the welding result is good quality. After the welding tetst is performed to 5 defect holes in 250 mm interval to be made intentionally on the butt joint of the tube, the detected plasma signals of the welding line are shown in Fig. 14. The plasma signal is suddenly changed 5 times at the hole position. And this means the welding defect because the discontinuity of plasma occurred when the welding is not properly performed. The welding shape of the hole defect to be welded improperly is shown in Fig. 15.

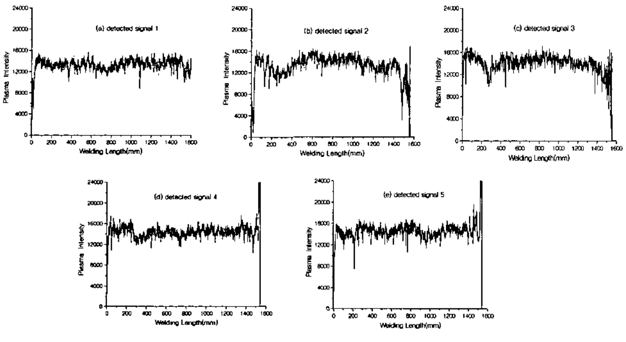


Fig. 12 Experimental data for reference value of plasma intensity

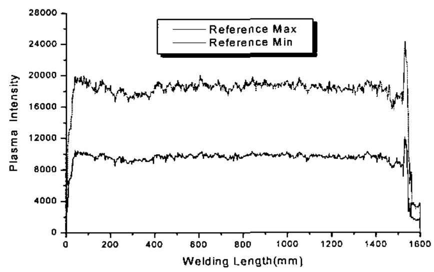


Fig. 13 Reference Max. and Min. values of plasma intensity

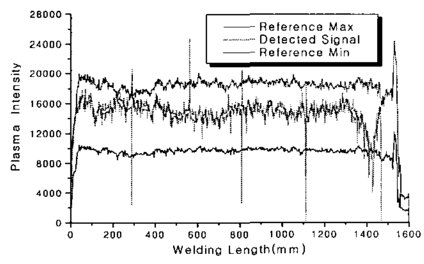
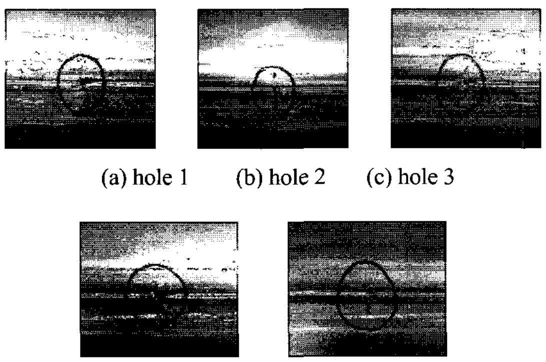


Fig. 14 Plasma intensity variation at 5 hole defects



(a) hole 1 (b) hole 2 (c) hole 3

(d) hole 4 (e) hole5

Fig. 15 Poor welding quality at hole defects

The laser welding process with the plasma detecting and seam tracking is shown in Fig. 16 and the weld defect can not be detected in the welded tube as Fig. 17. The comparison of the hardness value between the laser welded tube manufactured in this study(in Korea) and foreign company(in Germany) is shown in Fig. 18. The maximum hardness value has the difference but the welding distribution has the similar shape. The welding quality is good because the fracture is occurred at the base material but not at the welding line in all products of the welded tube(in Korea) and foreign tube(in Germany) as Fig. 19. The fracture of the foreign product occurred at higher internal pressure and its cause is referred as the difference of the material property and the residue stress of the welding.

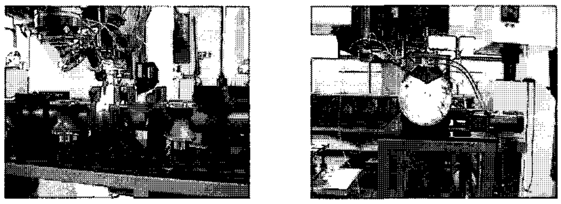


Fig. 16 Laser welding of tube

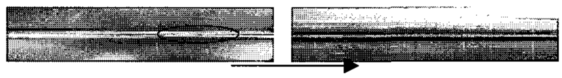


Fig. 17 Laser welded tube with good welding quality

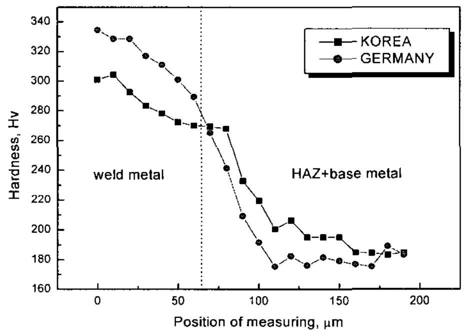
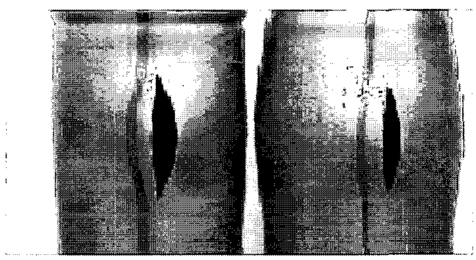


Fig. 18 Comparison of hardness distribution



108.9bar(K) 139.2bar(G)

Fig. 19 Fractured tubes by hydroforming

4. Conclusion

In this paper, the seam tracking and the quality monitoring along the butt joint lengthwise to the tube axis are studied to minimize the weld defect in manufacturing of the welded tube by using CO_2 laser. The results are concluded as follows;

(1) To weld the butt joint of the tube, the CO_2 laser welding equipment is implemented and the seam tracking and the plasma sensors are attached on the welding equipment. Especially, the position signal from the seam tracking sensor is sent to CNC to control the driving axis of the laser welding head.

(2) The welding line and the laser beam could be aligned within 200 ㎛, allowance of precision position, by using the laser vision sensor. And the artificial defects(<ø1 ㎜) are detected by the signal measured from the plasma sensor of UV wavelength range less than 400nm.

(3) The characteristics of the laser welded tube (length 2000㎜, diameter 105.4㎜, thickness 1.5㎜) formed by 2 roll bending method using the high strength steel plate of 60kgf/㎟ grade is equivalent to the foreign products. Therefore, the laser welded tube could be used as the raw materials of one body forming components for automobile and the laser welding equipment could minimize the welding defects of tubes.

(4) The gap of the butt joint is 45mm that it caused by the effect of the spring back of the high strength steel plate. It decreases the formability of tube at the tubular hydro-forming process because it affects the residual stress after welding. Therefore, the technology to further decrease the gap of the welded butt joint is needed.

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