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OPTIMAL PROCESSING AND SYSTEM MANUFACTURING OF A LASER WELDED TUBE FOR AN AUTOMOBILE BUMPER BEAM

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ABSTRACT−A study has been conducted for an optimal processing and an apparatus for manufacturing a laser welded tube for one-body formed bumper beam. The tube dimensions used in calculation were the thickness of 1.4 mm, the diameter of 105.4 mm and the length of 2000 mm. The tube was formed of a cold rolled high strength steel plate (tensile strength of 600 MPa). The two-roll bending method was the optimal tube forming process in comparison with the UO-bending method, the bending method on the press brake, the multi-step continuous roll-forming method and the 3-roll bending method. Monitoring of the welding quality was conducted and the seam tracking along the butt-joint lengthwise to the tube axis was also examined. The longitudinal butt-joint was welded by using a CO_2 laser welding machine equipped with a seam tracker and a plasma sensor. The CO_2 laser tube welding machine could be used for precise seam tracking and real-time monitoring of the welding quality. As a result, the developed laser welded tube could be used for a one-body formed automobile bumper beam.

KEY WORDS : Laser welded tube, Bumper beam, Seam tracking, Real-time quality monitoring

1. INTRODUCTION

Among one-body forming technologies, the hydro-forming technology can manufacture a part of complicated shape through one forming process. A tube, to which this technology is applied, is manufactured by using high frequency electric resistance welding (HF-ERW) and applied to automobile chassis such as an engine cradle and an instrumental panel beam.

Meanwhile, it is expected that development of automobile parts using the tubular hydro-forming technology is gradually expanded from automobile chassis to body parts, and a tube having a thin thickness and a large diameter is required. Therefore, the tube manufacturing method dependent on the ERW only is not sufficient to meet the requirements. Moreover, the conventional ERW method is not able to manufacture a conical tube and a tailor tube of which the structure and functions are upgraded. It can be, therefore, thought that in order to manufacture such a tube of complex shape, it is essential to manufacture a laser welded tube.

Compared with the conventional process to fabricate a product by welding the parts made by the press method, the one-body forming technology has the advantage of enabling a product to have a lighter weight and the number of parts to be decreased and further the manufacturing cost to be reduced by forming the part through a single simple process.

Meanwhile, a bumper beam can be an automobile part to which the said advantage is expected to be applicable. Thus, as a basic research to develop the one-body formed automobile bumper beam, this study was to focus on development of the technology and the apparatus for manufacturing the laser welded tube of a steel plate having a tensile strength of 600 MPa and further provide an approach to minimize the defective rate of the welding work.

2. SPECIFICATIONS AND MANUFACTURING PROCESS OF A TUBE FOR ONE-BODY FORMED BUMPER

Typically, an automobile bumper is constructed of a bumper cover, an energy absorber, a bumper beam and a stay as shown in Figure 1 and those parts are respectively manufactured by the press forming method. However, if a tube for one-body forming is used, the structure of the bumper gets to be very simple, as shown in Figure 2 and further it enables the number of parts to be decreased and the weight of the bumper to be lighter. Particularly, the

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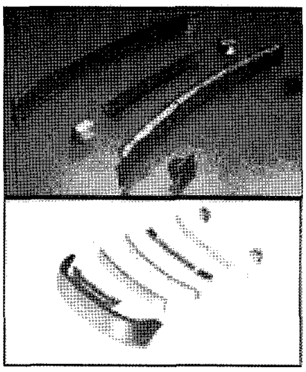


Figure 1. Press-formed bumper.

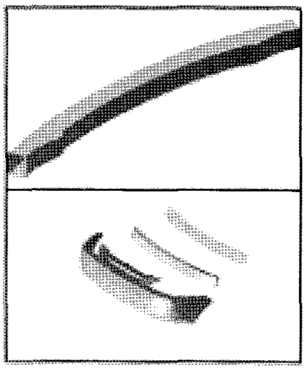


Figure 2. One-body formed bumper.

Table 1. Mechanical properties for 60 kgf grade steel.

Specimen / Plate Dir.		YS (MPa)	TS (MPa)	EL (%)	r15%	N10-20%
Steel Plate having a tensile strength of 600 MPa	RD	463	628	23.1	0.65	0.168
	45°	448	605	25.7	1.13	0.168
	90°	468	632	21.1	0.95	0.163
	mean	457	621	23.9	0.97	0.167

shape of the bumper beam would be as shown in the upper one of Figure 2.

By analying collision of a center pendulum on the basis of the basic design of the bumber, an optimal sectional shape of the bumper beam was found out and and it was evaluated whether its performance was satisfactory. In this analysis, the automobile weight of 1,350 kg was applied to the bumper system and the pendulum, and the initial speed of 5.2 km/h, a little higher than the actual test speed, was applied to all joints of the impact pendulum. The bumper beam material was the cold rolled high tensile strength steel plate having a tensile strength of 600 MPa, and its mechanical properties are shown in Table 1. Calculated results are shown in Figures 3 and 4. In this study, a laser welded tube for a one-body formed bumper beam was determined to have a diameter(ø) of 105.4 mm, a

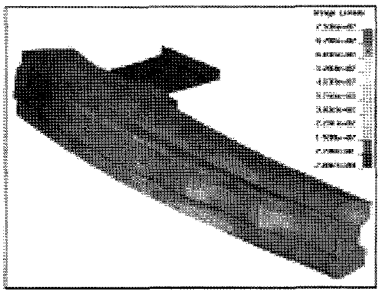


Figure 3. Calculated results (ø) 105.4 mm (t) 1.2 mm.

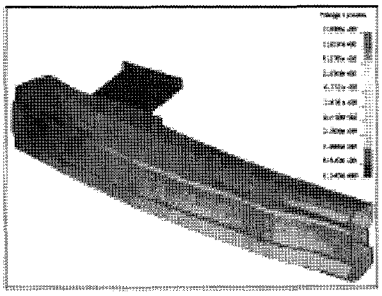


Figure 4. Calculated results (ø) 105.4 mm and (t) 1.4 mm.

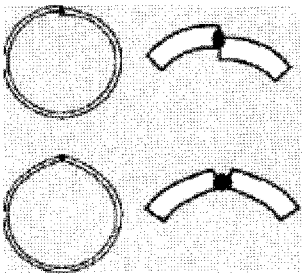


Figure 5. Welding joints.

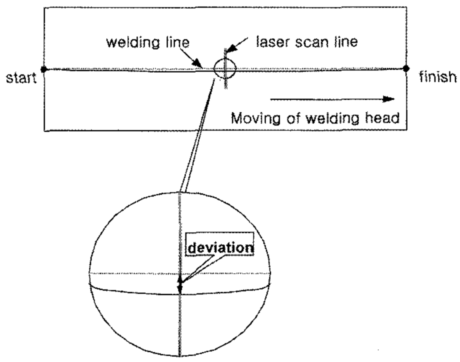


Figure 6. Error and deviation in a longitudinal weld line of a tube.

thickness(t) of 1.4 mm and a length(l) of 2000 mm.

Processes for forming a tube out of a steel plate include UO-bending, bending on the press brake, continuous roll forming and two or three roll bending. At the time of laser welding, a formed tube shape is very important, which is one of significant parameters to determining the laser welding quality. Typical problems of the butt joint to be laserwelded could be summarized as shown in Figure 5 and 6. Standardization of a section of the tube and the longitudinal straightness of the butt joint are very important. This is because in the case of using the CO_2 laser, the beam focal size is within 100 μm and therefore, the good welding result can be only obtained if an error between the focal position of the laser beam and the weld line is kept to be within 200 μm.

There is even a case that as shown in Figure 6, the butt joint is not straight but slightly distorted due to some difficulty resulting from the required precision of cutting a steel plate longitudinally, high strength, thin thickness and large diameter, etc. and further a case that any thermal deformation takes place during the welding work. Therefore, it is necessary to develop a tube forming apparatus and a welding apparatus to solve such problems.

In order to minimize any welding defects, a welding jig is required to have a high rigidity structure, and it is also required to secure the technology for enabling the laser beam to track an actual weld line by detecting a straightness error of the weld line during the welding work and further controlling a position of the laser welding head on the basis of such deteted result. Papers (Aubry *et al.*, 2000; Beersiek *et al.*, 1996) on tracking a weld line during the laser welding work are limed to the case of a flat plate and any paper on tracking a welding ling during the laser welding work for a tube made of a high tension steel plate has not been published yet.

Meanwhile, studies have been mainly conducted on measurement of the laser-induced plasma light (Beyer and Abels, 1992; Coste *et al.*, 1998; Gatzweiler *et al.*, 1998; Gu and Duley, 1996; Li and Steen, 1992), measurement of acoustic signals (Matsunawa *et al.*, 1995; Nam *et al.*, 2002), measurement of the reflective light intensity of laser (Ono *et al.*, 1992) and measurement of the plasma electric field intensity (Ishide, 1994) for real-time monitoring the laser welding quality in the welding field. Particularly, many studies has been conducted on measurement of the plasma light intensity because the correlativity between the simplicity of the measuring apparatus and the welding conditions is notable. However, in those studies, flat plates have been mainly used, and any report on the results of a study using a tube has not been available.

3. FORMING APPARATUS AND EXPERIMENT

In order to compare the tube formed of the cold-rolled high strength steel plate having a tensile strength of 60 kgf/mm^2 for this study, a steel plate having a tensile strength of 350 MPa was additionally used for forming a tube.

Figure 7 shows a tube sample formed of a steel plate having a tensile strength of 350 MPa, which was primarily formed by using a UO-bending mold and then additionally formed through the multi-step pressing process. The post-forming gap was approximatley 15 mm, which was of a suitable level for laser-welding. However, since the multi-step pressing process was additionally performed after the primary forming, it is disadvantageous to use this method for mass production. For forming a tube having a length of 2m or so, a press of 600–800 ton was required. Particularly, as for a tube to be formed of a steel plate having of 600 MPa, it could not be formed because it was very difficult to manufacture a mold for the UO-bending process.

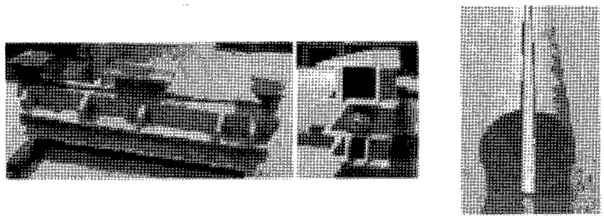
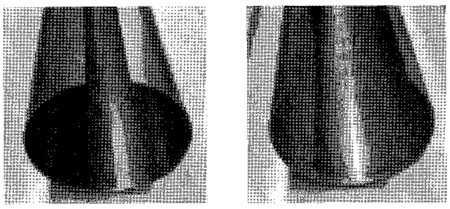
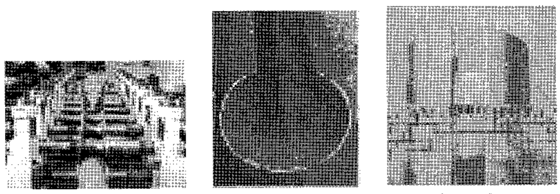


Figure 7. UO-bending jig and a bended tube.



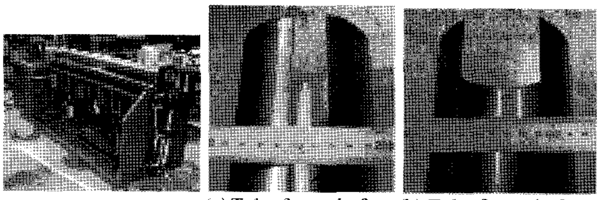
(a) Tube formed of a steel plate having a tensile strength of 350 MPa
(b) Tube formed of a steel plate having a tensile strength of 600 MPa

Figure 8. Press-bended tubes.



(a) Formed tube (b) Tube of WEIL co.

Figure 9. Multi-step roll forming apparatus and tubes.



(a) Tube formed of a steel plate having a tensile strength of 350 MPa (b) Tube formed of a steel plate having a tensile strength of 600 MPa

Figure 10. Three-roll bending machine and tubes.

Figure 8 shows tube samples formed by pressing them five times according to the method for bending on the press brake. It can be known that while the tube formed of a steel plate having a tensicle strength of 350 MPa has a gap of 25–30 mm, the tube formed of a steel plate having a tensile strength of 600 MPa, which was hit by the spring-back, has a gap of 55–60 mm which is greater about 2 times than the former gap.

Figure 9 shows the multi-step continuous roll-forming process, which enables tubes to be continuously manufactured of a coiled steel plate. It can be known that the tube, which was formed of a steel plate having a tensile strength of 600 MPa according to the multi-step roll forming method suitable for continuous production (for linear tubes having the same thickness), has a gap of 50mm similar to that of the tube formed of the same steel plate according to the method for bending on the press brake as shown in Figure 8, but greater than a gap of 20 mm had by the product of WEIL, a foreign company.

Figure 10 shows the three-roll bending machine and the formed tubes. It can be known that while the tube, which was formed of a steel plate having a tensile strength of 300 MPa, has a gap of 25 mm, the tube formed of a steel plate having a tensile strength of 600 MPa, which was hit by the spring-back, has a gap of 57 mm greater than the former gap. In the case of using the UO-bending method, the method for bending on the press brake, the multi-step continuous roll-forming method and the three-roll bending method respectively, the tube formed of a steel plate having a tensile strength of 350 MPa could have a gap of 15 mm at minimum, while the tube formed of a steel plate having a tensile strength of 600 MPa could have a gap of 50 mm at minimum. In order to reduce the formed tube gap, the two-roll bending method was developed by modifying the three-roll bending apparatus as shown in Figure 11.

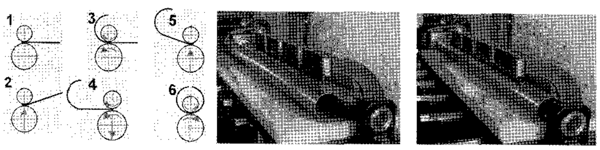
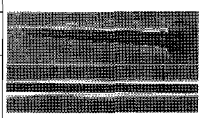
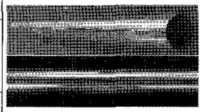


Figure 11. Two-roll bending process.

Table 2. Gap sizes by various processes.

Material	Process	Gap size (mm)	Tube shape formed by 2 roll bending
Steel plate having a tensile strength of 600 MPa	Continuous roll forming	50–65	
	Press brake	55–60	
	3 roll bending	57	
	2 roll bending	45	
Steel plate having a tensile strength of 350 MPa	UO bending	15	
	Press brake	25–30	
	3 roll bending	25	
	2 roll bending	4	

Gap sizes of the tube samples formed by various forming methods including the two-roll bending are listed in Table 2. As a result of forming the tube with a diameter of 105.4 mm and a length of 2000 mm by using a steel plate having a tensile strength of 600 MPa and a thickness of 1.4 mm, it, which was hit by the spring-back, has a join gap of 45 mm. Meanwhile, it can be known that in constrast to such tube, the tube formed of a steel plate having a tensile strength of 350 MPa was well formed with its gap being 4 mm. Wherein, the butt joint was perfectly made without using a welding jig. In order for the butt joint of the tube formed of a steel plate having a tensile strength of 600 MPa in this study to be suitable for laser-welding, its gap should be maintained within 200 μm and therefore, a welding jig, which enables the

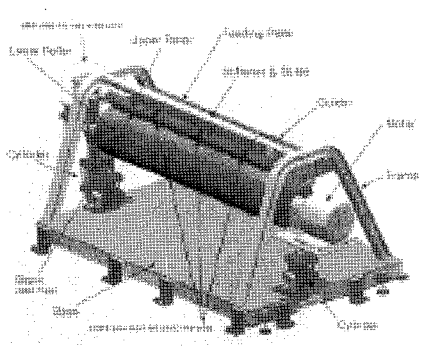


Figure 12. Design concept of a two-roll bending machine.

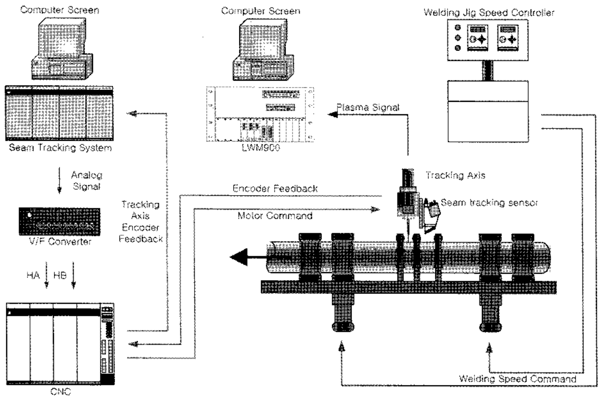


Figure 13. Schematic diagram for structure and control of a weling machine.

butt joint to be strongly made by rigid rollers, should be manufactured. Meanwhile, on the basis of the results of using a simplified two-roll bending apparatus, a precise 2 roll bending machine was designed. Figure 12 shows a 3 dimensional conceptual view of the 2 roll bending machine.

4. STRUCTURE OF WELDING MACHINE

Figure 13 is a schematic diagram showing the structure and the control of a machine for laser-welding the butt joint of the tube. The welding work is performed while the tube material is transferred by rolling-rollers of a welding jig.

Since there occurs a case that a welding position of the tube material fed into the welding jig does not meet with the laser beam exactly, a sensor for tracking a weld line was installed in a welding head in order to compensate for it. Also, a plasma detector was installed therein in order to monitor the welding quality during the welding work (See Figure 14).

A CNC was used to compensate for a position of the welding head on the basis of the control of each axis of the laser welding machine and the input signals received from the weld line tracker. The analog signals outputted from the weld line tracker for compensation for a welding

Figure 14. Laser welding head and fixtures.

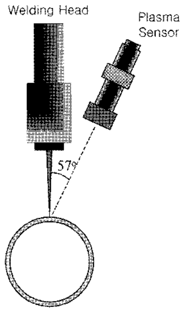


Figure 15. Position of a plasma sensor.

Table 3. Experimetal conditions.

Welding distance		1600 mm
Welding speed		2000 mm/min
CO_2 laser power		2.8 kW
Shielding gas		Ar (30 *l*/min)
Distance from laser beam and laser vision sensor		110 mm
Sampling frequency		60 Hz
Plasma sensor (see Figure 15)	Distance	180 mm
	Angle	57°

position are converted by V/F converter so that it may be in conformity with the input signal format of CNC. As a laser vision sensor for tracking the weld line, MVS-5 of MVS (a combination type of combining a laser emitter with a CCD camera) was used.

The observing range of this laser vision sensor is 5 mm in the horizontal direction and 7 mm in the vertical direction and its resolution is 0.01 mm in the horizontal direction and 0.013 mm in the vertical direction. As a plasma measuring instrument, LWM900 of JURCA, a German company, was used. At the time of laser-welding, plasma is similar to emission of a spectrum of the black body, getting to follow Plank's radiation law. Wherein, a peak point of the radiation curve follows Wien's displacement law and the wavelength range of the light emitted from the plasma is about 190–400 nm (Watanabe *et al.*, 1992). Therefore, in this study, the plasma intensity was measured by using a UV sensor appropriate for this wavelength range. The conditions for the said laser-welding and monitoring of the tube are as shown in Table 3, and the installed position of the plasma sensor is as shown in Figure 15.

5. EXPERIMENTAL RESULTS AND DISCUSSION

Figure 16 shows the segments profile of the butt joint

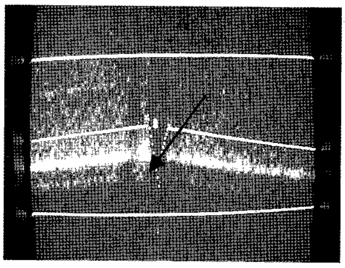


Figure 16. Segments profile of a tube joint.

tracked and detected by the weld line tracking sensor. The segment profile is obtained by extracting feature points from the rounding profile and further connecting them one another. It shows a central position (→) of the weld line of the tube exactly.

When the tube material was fed into the welding jig and was transferred, there occurred a case that the weld line was slightly rotated with respect to the direction in which the material went ahead. In this case, the laser beam did not meet with the weld line as shown in Figure 17, and as a result, any welding failed to be done. It can be known that after operating the function to compensate for the weld line position, the position of the laser beam met well with the weld line, as shown in Figure 18. Existence of some error was related to the responsivity of the motion loop and considering the diameter of the laser beam, it was a negligible error.

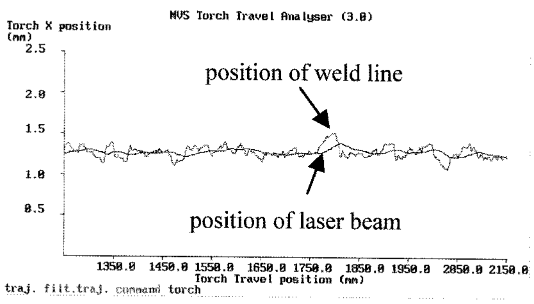


Figure 17. Deviation between the laser beam and the weld line.

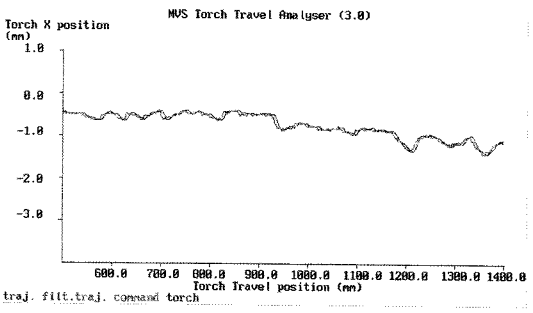


Figure 18. Tracked weld line.

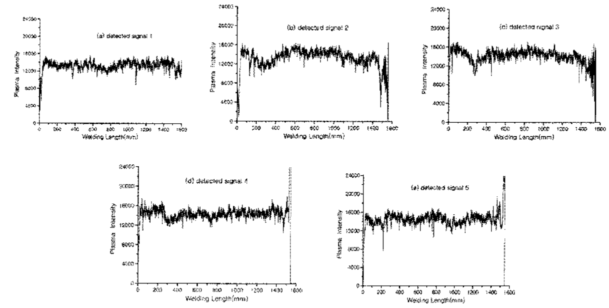


Figure 19. Experimental data for setting a reference value of the plasma intensity.

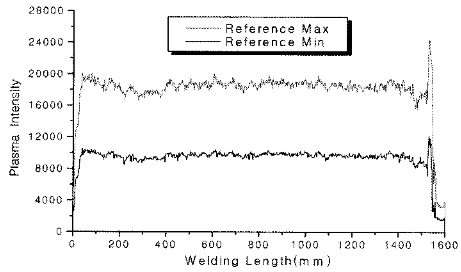


Figure 20. Max. and Min. values of the reference value of the plasma intensity.

In order to monitor the welding quality by using the plasma in the laser welding process, in the first place, a reference value of the plasma intensity should be set for determination of the welding quality. For setting the reference value, the welding work was conducted 5 times. The graphs of Figure 19 show the results of detecting the plasma signals for setting the reference value. After the welding work for setting the reference vale of the plasma intensity was conducted, the reference value was set by using the 5 samples of Figure 19. It was experimentally verified to set an uppler limit and a lower limit of the reference value at a value of +30% and a value of −30%, respectively. The experimental results are as shown in Figure 20. That is to say, if the intensity of

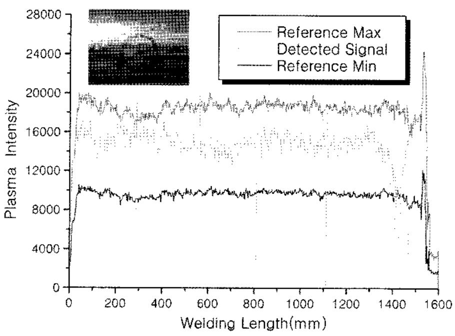


Figure 21. Variation of the plasma intensity when 5 hole defects exist.

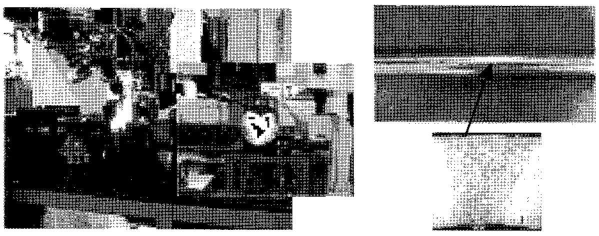


Figure 22. Laser welded tube having the good welding quality.

the plasma emitted in the welding process is in the range of the minimum value to the maximum value, it represents that the welding result is good.

In order to measure any change in the plasma intensity in the case of the poor welding quality, the welding work was conducted with five artificial hole defects (diameter < 1 mm) being formed at intervals of 250 mm on the butt joint of the tube, and as a result, the plasma signals were detected as shown in Figure 21. It can be seen that the plasma signal was sharply changed 5 times at the positions where the holes existed. This change takes place as the plasma not welded appropriately gets to be short-circuited, meaning a welding defect.

Figure 22 shows a scene that the welding machine was performing the laser welding work, operating the weld line tracking fuction and the plasma sensor. It can be known from this Figure that as a result of examining the section of the weld zone in the tube through a light microscopy, the welding quality is very good. In this study, the manufactured laser-welded tube was formed by a hydro forming apparatus, and an one-body formed bumper was manufactured by using a mold for manufacturing a bumper. Figure 23 shows a prototype of the one-body formed bumper beam. Compared with the conventional bumber beam, as a basic model, under mass production, the one-body formed bumper beam had the structural performance equivalent to it or better, and it was possible to make its weight lighter. That is to say, the number of its internal reinforcing parts was reduced from five to one, and its total beam weight was also lighter by 13% or so than the conventional product's total weight. Further, it is expected that it will have an effect to reduce the cost by about 6%. It is also expected that it will give a synergic effect considerably in the aspect of improving the assembly quality and the productivity in addition to the said external factors.

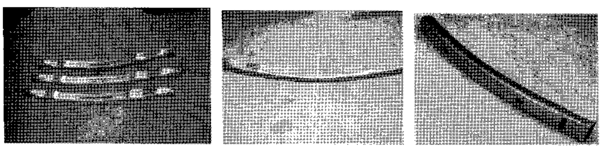


Figure 23. One-body formed bumper beam.

6. CONCLUSIONS

In order to develop a one-body formed bumper beam, this study was to focus on development of the technology and the apparatus for manufacturing the laser welded tube of a steel plate having a tensile strength of 600 MPa and further secure the data for minimizing a difective rate of the welding work. The results could be summarized as follows:

(1) The UO-bending method, the method for bending on the press brake, the multi-step continuous roll-forming method, the three roll-bending method and two roll-bending method were respectively used to form a tube having a diameter of 105.4 mm and a length of 2000 mm out of the steel plate having a tensile strength of 600 MPa and a thickness of 1.4 mm^2. As a result of using the two roll-bending method, a minimal gap of 45 mm could be obtained in the butt-joint and the welding quality was also good. Further, the 3 dimensional design data for the precise two roll bending machine could be secured on the basis of the said results.

(2) In order to weld the butt joint in the longitudinal direction of the tube, a CO_2 laser welding machine was fabricated and a weld line tracker and a plasma sensor were installed in the welding machine. Particularly, it was made to have a structure to send position signals outputted from the weld line tracker to the CNC for controlling the driving axis of the laser welding head so that the laser beam might meet with the weld line positionally.

(3) By using a laser vison sensor, the laser beam could be made to meet with the weld line within 200 μm, a precise position tolerance, and the artificial defects (< ø1 mm) could be detected by the signals having measured the plasma intensity in the range of the UV wavelength smaller than 400 nm.

(4) This study suggests that the laser welded tube can be used as the raw material for the one-body formed automobile part, and it can be known that the fabricated laser welding machine is suitable for minimizing welding defects in the laser welded tube. In the case of the high strength steel, the gap size of the butt joint has an effect on the residual stress due to the effect of its spring-back, and as a result, it gets to decrease the hydro-forming capability. Therefore, the technology for enabling the joint gap to be more decreased is required.

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