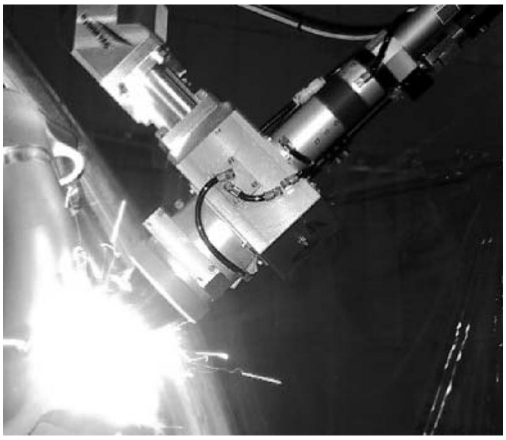

Laser Welding System for Various 3-D Welding - Development of Coaxial Laser Welding Head -

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Mitsubishi Heavy Industries, Ltd. (MHI) has developed a hybrid welding head that combines arc and laser welding functions, with the aim of applying it to the welding of sophisticated objects of complex shape such as car bodies. The hybrid welding head eliminates the directivity problem of laser welding by arranging the electrode and laser beam axes coaxially and reducing the number of controlling axes used for welding. In addition, MHI has extended the coaxial welding procedure to laser brazing. This paper presents examples of the welding results obtained by using the newly developed welding head and shows the effects of increasing groove gap tolerance, eliminating the directivity of welding, and increasing the penetration depth of brazing filler metal.

1. Introduction

Efforts are actively under way to apply laser welding to practical use as a welding procedure with high efficiency and low distortion. In particular, notable advances have been made in YAG laser welding technology for application mainly in the automobile industry, through the easy transmission and stable quality of the laser beam together with the recent appearance of high power oscillators[(1)-(4)]. On the other hand, since the narrow tolerance for groove gaps in laser welding, the accurate machining and fitting of a groove, and precise setting of the welding head on a target object are essential to proper operation, a greater relaxation of work tolerances is necessary in order for laser welding to be of practical use.

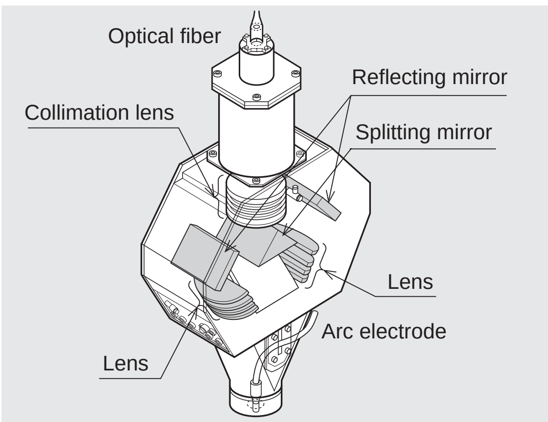


Fig. 1 Concept of coaxial arrangement of arc electrode and laser beam
A laser beam is split into two halves by mirrors. The arc electrode is located in the space given between the split half beams, thereby making it possible to realize the coaxial arrangement of the arc electrode and laser beam.

In order to solve these problems, a hybrid welding procedure that combines both arc and laser welding functions has been developed to make laser welding with large gap tolerance possible. In order to realize laser welding processes performed without many welding axes and directivity, the newly developed welding procedure is characterized by the coaxial arrangement of the laser beam and filler metal wire. In addition, this coaxial technology has been extended to laser brazing so as to be able to feed brazing filler metal wire coaxially with the laser beam.

This report introduces the newly developed welding head and highlights its effectiveness with examples of the results obtained by its practical implementation.

2. Arc-laser hybrid welding

2.1 Concept of coaxial laser-coaxial hybrid welding head

The research and development of hybrid welding systems consisting of both arc and laser welding functions has been carried forward by many research engineers[(5)(6)]. However, since the arc welding torch is located at the side of the laser optical axis in such systems, some axes are needed to control the arc torch and keep it in a given direction. This reliable and precise control is necessary to carry out the 3-dimensional welding of assemble complex components required in the automotive and other industries. Thus, this study has investigated how to make the arc axis coaxially with the laser axis in order to reduce the number of the axes used. The basic concept for making the arc and laser coaxial axes is shown in **Fig.1**.

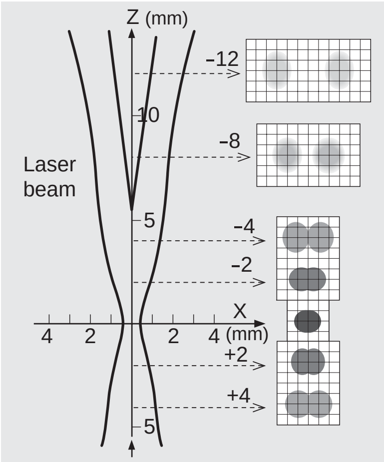


Fig. 2 Beam-focusing state
The figure shows the beam focused close to the focal point.

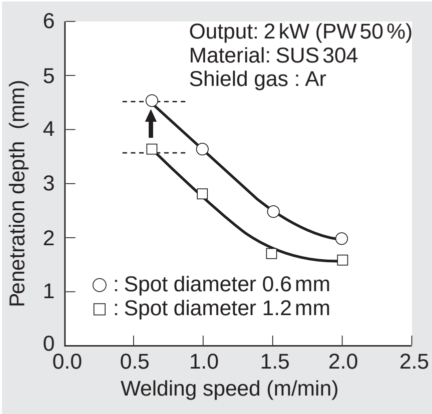


Fig. 3 Effect of focused diameter on depth of penetration
The depth of penetration is increased about 1.3 times by reducing the diameter of the focused laser beam from 1.2 mm to 0.6 mm.

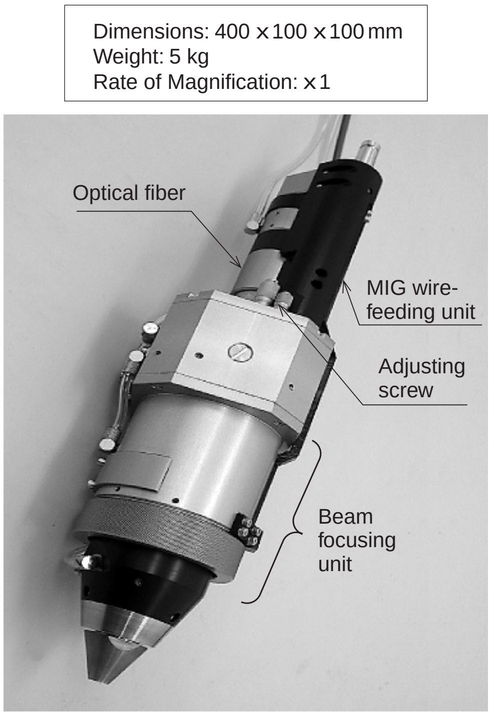


Fig. 4 View of MIG-YAG hybrid welding head
External view of a compactly designed welding head expected to be operated by a robot.

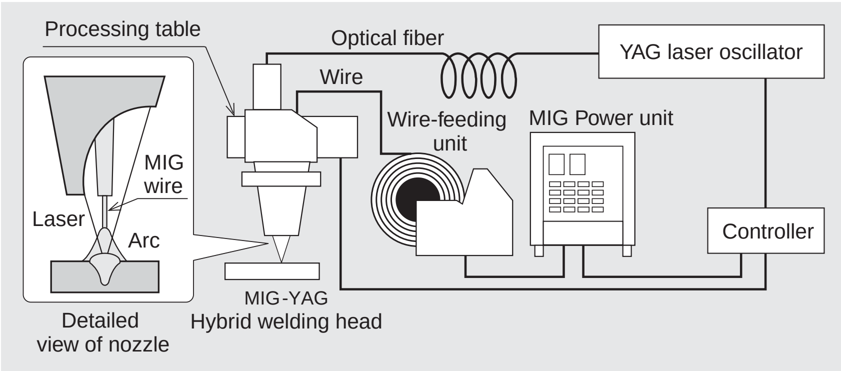


Fig. 5 Standard configuration of equipment
General diagram of hybrid welding including auxiliary units.

The laser beam radiated from the optical fiber is split in half by a splitting mirror and two reflecting mirrors, after which the split beams are then focused on the target object through focusing lenses. The arc electrode is located in the space produced between the split laser beams, thereby realizing the coaxial arrangement of the axes of the laser beam and arc electrode.

Fig. 2 shows the result analyzed by ray-tracing of the process in which the split beams are collected together at one place near the focal point. The figure shows the analysis results obtained when a laser beam radiated from an optical fiber with a core diameter of 0.6 mm is focused in a diameter of 1.2 mm at the position of just focus.

In this case, since the laser beam is completely split at the location 8 mm above the focal point, a space is created between the two split-half beams where the electrode can be placed. The focusing properties of the laser are determined by considering various factors such as the quality of the beam generated by the laser, dimensions of the head, properties of the target materials (type, thickness, and shape of grooves, etc.), and the arc welding equipment being used in conjunction with the system.

When considering a joint shape, for instance, a smaller focused beam diameter is effective for butt joints of a thick plate, while in fillet welding, a relatively larger focused beam diameter is better, since a wider bead is required instead of deeper penetration, in this case. Therefore, it is desired to choose the conditions that best correspond to the target object being welded.

Fig. 3 shows the results of an examination of the effect of a focused diameter on the depth of penetration. In stainless steel plates welded with an laser output of 2 kW, for example, it can be seen that reducing the focus diameter from 1.2 mm to 0.6 mm improves penetration by about 1.3 times.

2.2 Specifications of commercial laser-arc hybrid welding head

A compact-designed welding head has been developed based on the prototype unit shown in Fig. 1 as a step in commercializing this equipment.

Fig. 4 shows the appearance and specifications of a compact head, while **Fig. 5** shows the standard configuration of the device. Not only is new equipment available that is provided with all new components, but units are also available that can be easily combined with an existing laser oscillators and arc welding power units.

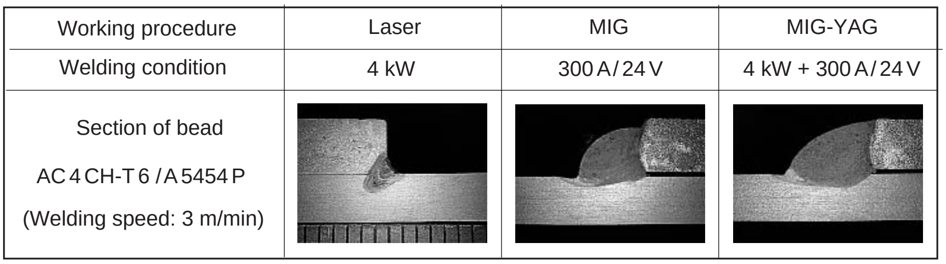


Fig. 6 Comparison of working procedures for lap fillet welding of aluminum alloy
The hybrid welding achieves both the required leg length and depth of penetration, which are impossible to achieve by laser or MIG welding alone.

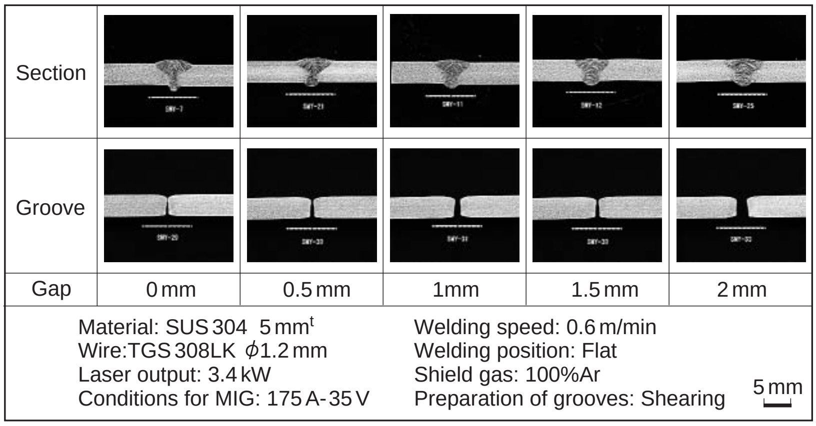


Fig. 7 Enlargement of gap tolerance by hybrid welding
Welding can be performed under constant conditions for groove gaps between 0 to 2 mm in size.

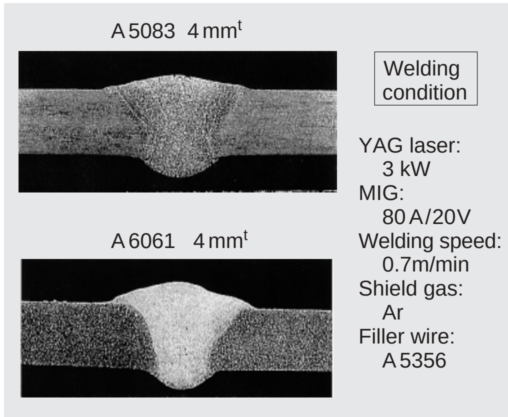


Fig. 8 Example of welding of thick aluminum plate
Example of high-speed one-pass welding of aluminum thick plate (4 mm).

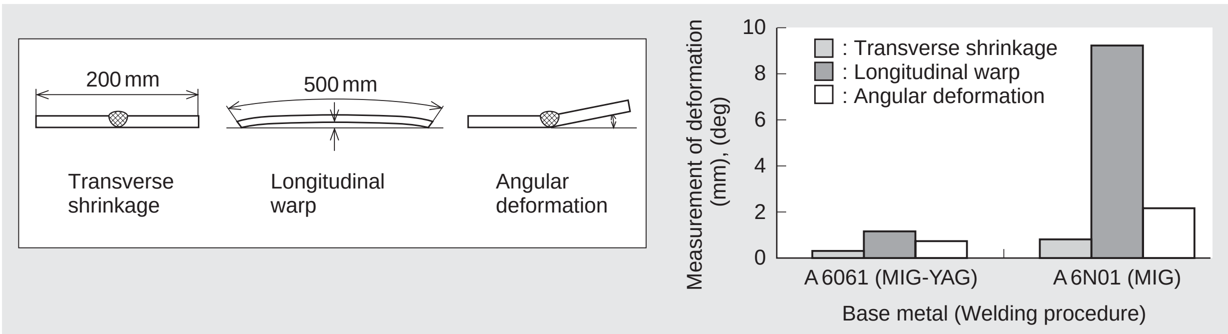


Fig. 9 Comparison of welding distortion
A longitudinal warp in MIG welding can be reduced to 1/9 by hybrid welding.

2.3 Examples of welded results

Fig. 6 shows examples of lap fillet welding joints of aluminum alloy. It is difficult to ensure a sufficient leg length in the case of laser welding alone. The bead shape is apt to become unstable easily and penetration becomes poor within a high-speed zone, in the case of MIG welding work alone. On the other hand, in hybrid welding, stable beads can be obtained and maintained within the high-speed zone, while ensuring adequate penetration.

Fig. 7 shows some examples of stainless steel plates that have been butt-welded with different groove gaps. In this case, the grooves were prepared by shearing, with gaps of up to a maximum of 2 mm at a pitch of 0.5 mm. The figure shows that the hybrid welding head can perform welding of a plate with a thickness of 5 mm, under a constant condition, with gaps of up to a maximum of 2 mm. In other words, welding with a wide gap tolerance can be performed using the hybrid welding head.

Fig. 8 shows examples of the welding results of butt-welded aluminum alloy plates with a thickness of 4 mm using the hybrid welding head. The figure shows that the hybrid welding head can weld plates with a thickness of 4 mm at a high speed of 0.7 m/min. In addition, the effectiveness of hybrid welding in minimizing deformation is remarkable compared with conventional MIG welding, as shown in **Fig. 9**. Another advantage of the hybrid welding head is that welding can be done without the need to depend on the direction of the head, since it is provided with an arc electrode arranged coaxially with the laser beam.

As shown in the example of circular welding in **Fig. 10**, it is not necessary to adjust the direction of wire feeding, so that the newly developed welding head also reduces the workload of the operator by eliminating the need to set precise position settings for welding two- or three-dimensional objects.

3. Laser brazing

3.1 Specifications of commercial laser brazing head

As with the hybrid welding head, MHI has also developed a coaxial laser brazing head capable of feeding filler metal wire coaxially with a laser beam. This brazing head will be used for laser brazing that is widely applied to car bodies in automobile production plants in Europe. This brazing head makes it possible to satisfy a user's need to treat sharp changes in brazing lines, which are often seen in trunk-lids and other complex components. **Fig. 11** shows the appearance and specifications of the brazing head.

3.2 Example of brazed results

Fig. 12 shows examples of brazing work. The figure shows that the head can stably perform one-stroke brazing in a plane, as the need for careful setting of the direction of the head is eliminated by coaxial wire feeding. In addition, the bead can be formed so that it corresponds exactly with sudden changes in the brazing line.

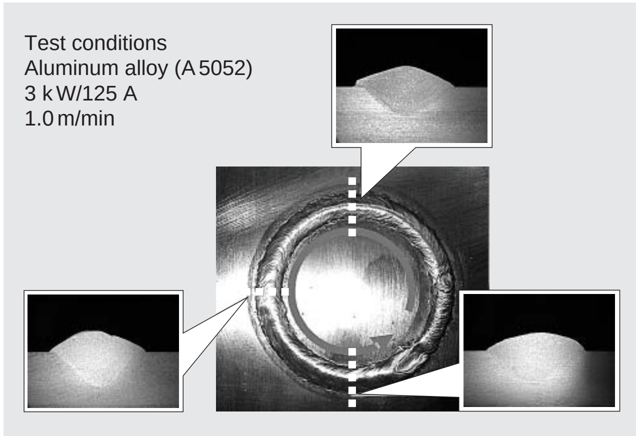


Fig. 10 Example of circular welding
The driving axis of the arc torch is not required even in circular movement, by using the coaxially arranged arc and laser torches.

Fig. 13 shows a cross section of a flare groove joint. It is difficult for the filler metal to penetrate into the interior of the groove when the filler metal wire is fed from the side of the joint. However, as can be seen in this figure, the filler metal can penetrate sufficiently into the depths of the groove when the hybrid brazing head is used. From this fact, it is thought that the melting efficiency of the wire is increased because the wire is preheated by feeding the wire coaxially with laser beam.

Dimensions: 410 × 120 × 110mm
Weight: 5.2 kg
Rate of magnification: ×1.3

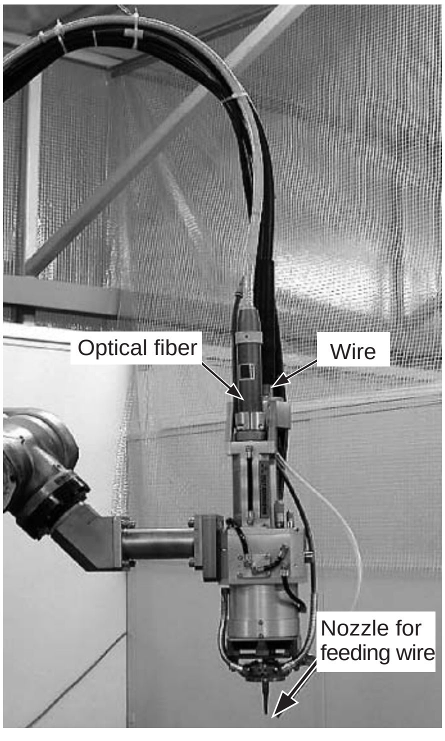


Fig. 11 View of coaxial laser brazing head
Operability by a robot was improved by arranging the laser and wire coaxially into a compact unit.

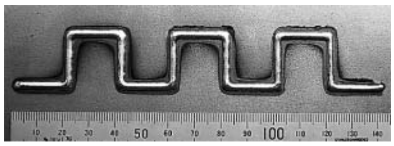
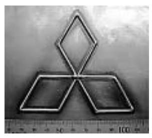
Brazing conditions		Appearance of bead
Type:	Bead on plate	 
Material:	Steel plate	
Plate thickness:	3.0 mm	
Laser output:	2.0 kW	
Welding speed:	0.8 m/min	
Wire feeding rate:	2.8 m/min	

Fig. 12 Example of laser brazing results (1)
Coaxial wire feeding can cope with sudden changes in direction, such as in one-stroke brazing, including shape changes such as right angle inflections and complex forms.

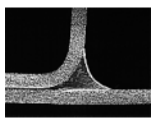
Brazing conditions		Appearance of bead
Type:	Flare joint	
Material:	Zinc coated steel plate	
Plate thickness:	0.75 mm	
Laser output:	3.0 kW	
Welding speed:	3.5 m/min	
Wire feeding rate:	7.0 m/min	Cross section

Fig. 13 Example of laser brazing results (2)
Filler metal penetration into a groove is improved by the preheating effect of the laser beam.

4. Example of application

One major potential application anticipated of this newly developed technology is in the welding assembly of automobile bodies, because of the advantages realized by the coaxial arrangement of the arc or wire and laser. **Fig. 14** shows some example applications of MIG-YAG hybrid welding in the assembly of car bodies. The effectiveness of the coaxial wire-feeding method is being demonstrated through use in various applications.

5. Conclusion

MHI has developed a hybrid welding head suitable for welding sophisticated three-dimensional objects such as car bodies. It has been confirmed that the hybrid welding head, which consists of an arc electrode and a laser beam arranged coaxially, displays effects that are superior to arc welding, in terms of increased welding speed, minimal distortion, and greater penetration depth. The hybrid welding head is also superior to laser welding in ensuring the leg length of fillet welding and increasing the gap tolerance of grooves.

Furthermore, it has been demonstrated that the coaxial arrangement of the arc and laser can reduce the number of controlling axes. In addition, it has been shown that the effect of preheating the wire improves the penetration of brazing filler metal into grooves in laser brazing and also that the coaxial brazing head makes brazing without the need to depend on head direction possible.

This newly developed technology is not just restricted to being used in combination with YAG laser welding, but can also be also applied in combination with diode lasers or fiber laser welding, which have been the focus of growing attention in recent years due to their greater welding power output. MHI not only intends to develop a line up of welding heads that just conform to immediate user needs, but also to combine this technology with groove sensing, quality monitoring, and driving systems to provide these technologies as comprehensively integrated welding systems.

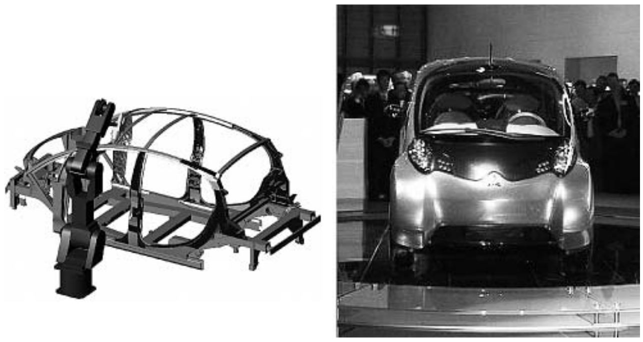


Fig. 14 Application to assembling car bodies
(Concept Car "i" presented by Mitsubishi Motors Corporation)
Example of car bodies assembled by hybrid welding
(exhibited at the Motor Shows in Tokyo and Frankfurt in 2003).

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