

Application of Laser Welding Technologies to Automotive Bodies[†]

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Abstract:

The application of remote laser welding to the high tensile steel sheet lap joint and the rigidity improvement of the frame parts by application of continuous welding were introduced. In the lap welding of 980 MPa grade steel sheet, the remote laser welded joints showed higher cross tensile strength than the resistance spot welded joints. The remote laser welding, which allowed easier control of the weld size, had an advantage for the improvement of peel strength. As a result of torsional rigidity test of the hat shape test pieces whose fringes were welded by resistance spot welding, laser welding and laser-arc hybrid welding, laser and laser-arc hybrid welding as continuous welding provided the higher rigidity. Further changing welding position from the fringe center to the corner end and the inside corner led to improve the rigidity.

1. Introduction

Laser welding is one of the welding methods which are applied in the production of automotive bodies. Although laser welding has a short history in comparison with resistance spot welding and arc welding, accompanying the spread of high power CO₂ lasers in the 1990s, laser welding became widely applied to welding of tailored blanks^{1,2)}. Subsequently, makers began marketing high power Nd: YAG lasers, which enable laser beam transmission via optical fiber, and robotic three-dimensional welding technologies were developed and applied to automotive body-in-white assembly in place of resistance spot welding³⁻⁵⁾. However, for various reasons, which included the high cost of the laser

equipment, strict joint accuracy requirements, etc., this technology was used in a limited range of applications.

In recent years, fiber lasers and disc lasers have been widely adopted. Because these devices enable beam transmission by optical fiber in the same manner as the Nd: YAG laser, have high power, and also have excellent focusing properties, they have attracted renewed attention to application of laser welding to body-in-white assembly. Application of remote laser welding^{6,7)}, which is realized by a laser with a high focusing property, is continuing to expand as a welding method that can substantially shorten welding time and has cost merits in spite of the high cost of the laser equipment. Moreover, high strength steel sheets have been progressively adopted in auto body parts in recent years with the aim of reducing auto body weight, heightening the need for a changeover from spot welding by resistance spot welding to continuous welding by laser welding or laser/arc hybrid welding in order to satisfy both auto body weight reduction and strength and rigidity requirements.

JFE Steel develops and supplies steel sheets with excellent properties, responding to the need for weight reduction in automotive bodies, and has also developed laser welding and laser/arc hybrid welding technologies as welding methods for improving the performance of parts when using those sheets. As examples of recent research and development at JFE Steel, this paper describes the results of studies of application of remote laser welding to lap welding of high strength steel sheets, and rigidity improvement by laser welding and laser/arc hybrid welding as continuous welding methods for the fringes of frame parts.

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2. Remote Laser Welding of High Strength Steel Sheet Lap Joints

2.1 Features of Remote Laser Welding

A schematic illustration of the configuration of the optical system of the remote laser welding process is shown in **Fig. 1**. High speed control of the angles of a pair of mirrors, which are called galvanometer scanners, makes it possible to move the laser beam irradiation point instantaneously within a designated range on the workpiece and perform welding of distant points within the laser irradiation point with no loss of beam movement time. Since use of a focusing lens with a long focal length is effective for increasing the laser irradiation area, systems that combine this technology with a fiber

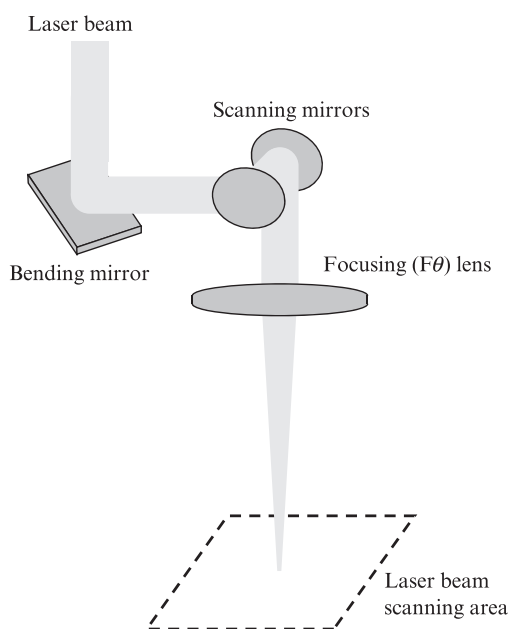


Fig. 1 Schematic illustration of remote laser welding process

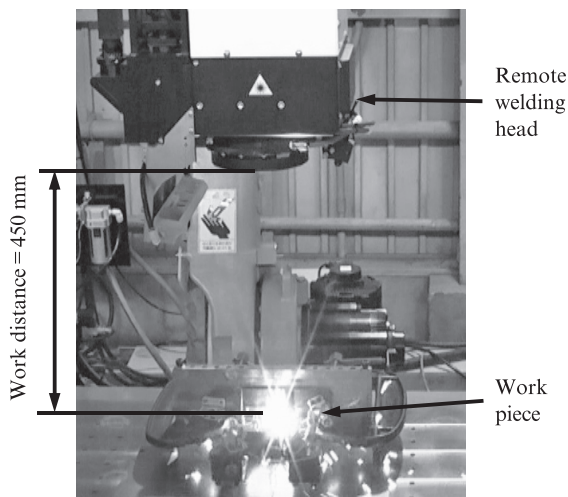


Photo 1 Example of robotic remote laser welding system

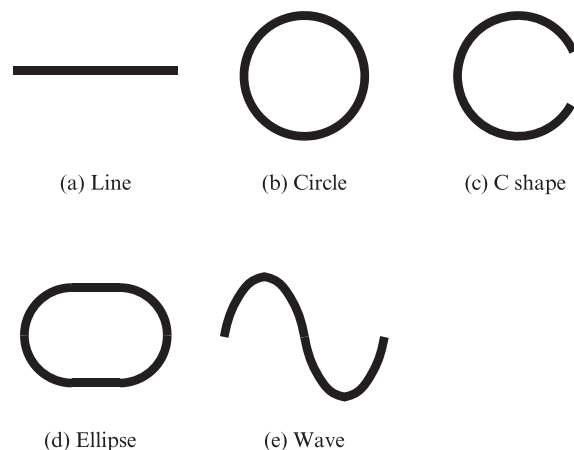


Fig. 2 Variation of weld line shapes in remote laser welding

laser or disc laser, which have excellent focusing properties, have been widely adopted. **Photo 1** shows an example of a robotic remote laser welding system. This system combines a fiber laser oscillator, a 6-axis articulated robot, and a galvanometer scanner optical system, realizing a beam irradiation area with a diameter of 200 mm ϕ on the workpiece at a work distance of 450 mm. This system enables high efficiency “on-the-fly” welding, in which the operation of the robot and control of the galvanometer scanners are synchronized.

Unlike welding by robots or processing machines, in remote laser welding, there are basically no restrictions on the shape of the weld line because the laser beam is scanned by the galvanometer scanners. This means that welding can easily be performed in various shapes other than a straight line; as shown in **Fig. 2**, welding is also possible in a circle, C shape, elliptical curved line, wave line, and other shapes. This means it is possible to select the weld line shape which is best suited to the part shape and required properties.

2.2 Properties of Lap Joints of 980 MPa Class High Strength Steel Sheets by Remote Laser Welding

Although remote laser welding has the advantage of greatly shortening welding time in comparison with resistance spot welding, the properties of remote laser welded joints still have not received adequate study. Therefore, a remote laser welding test was performed to confirm the peel strength of the sheets, as peel strength is frequently considered a problem in resistance spot welding.

Using 980 MPa class high strength steel sheets (JFS A 2001, JSC980Y (JFS: The Japan Iron and Steel Federation Standard)) with a sheet thickness of 1.6 mm, full penetration welding was performed at the center of the lapped part of a cross tensile strength specimen (in accordance with JIS Z 3137 (JIS: Japanese Industrial

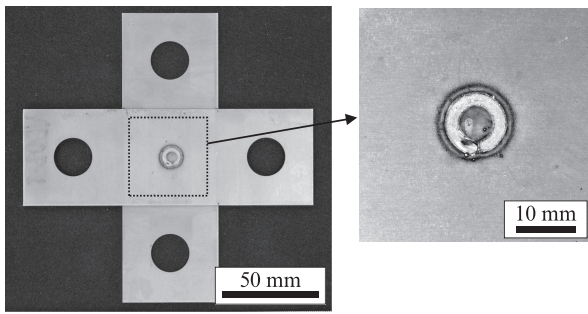


Photo 2 Appearance of cross tension test specimen (Weld line diameter = 8 mm)

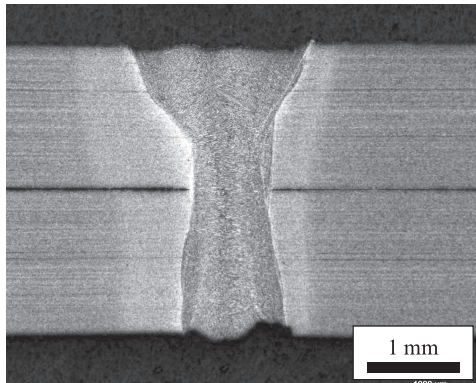


Photo 3 Macrostructure of cross section of remote laser weld

Standards)) as shown in **Photo 2**, so that the weld line formed a circle with a diameter of 3–12 mm. (Photo 2 shows the appearance of a specimen with the weld line diameter of 8 mm.) The laser welding conditions were laser power: 4.0 kW and welding speed: 2.5 m/min. The macrostructure of the cross section is shown in **Photo 3**. The width of the weld metal at the sheet interface was approximately 0.8 mm.

Figure 3 shows the cross tension test results of the remote laser welded joint. For comparison, the figure also shows the cross tensile strength of a resistance spot welded joint with a fusion nugget diameter of 5.4 mm (generally required nugget diameter: $4\sqrt{t}=5.1$ mm, t : sheet thickness (mm)). In all the specimens, the fracture positions in the cross tension test of the remote laser welded joints were in the base metal near the weld metal. An example of cross-sectional observation of the fracture position is shown in **Photo 4**.

The cross tensile strength of remote laser welded joints increases with increasing weld line diameter. The cross tensile strength of remote laser welded joints can be expected to achieve about 1.5 times that of resistance spot welded joints with the same weld sizes (nugget diameters). Based on this result, it is considered possible to obtain peel strength equal to or greater than that of resistance spot welds in joints of 980 MPa class high strength steel sheets by laser welding with a narrower fringe width or weld size than in resistance spot weld-

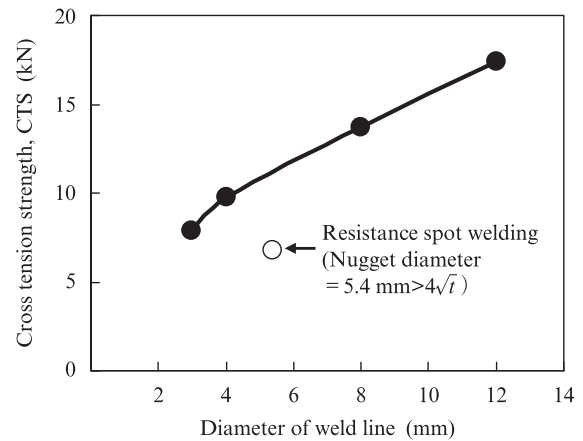


Fig. 3 Cross tension test result of remote laser welded joints of 980 MPa grade steel sheet

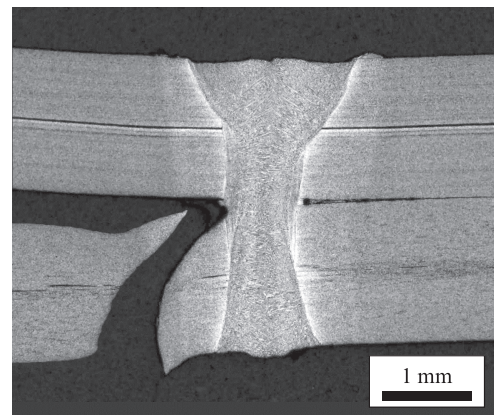


Photo 4 Example of macrostructure of fracture part after cross tension test

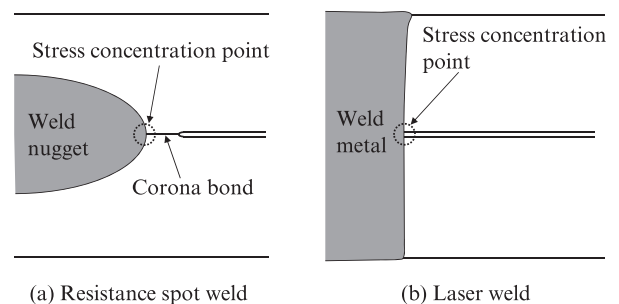


Fig. 4 Comparison of fracture parts in cross tension test between resistance spot weld and laser weld

ing.

Figure 4 shows a schematic comparison of the weld cross sections of resistance spot welds and laser welds. Although the fracture initiation position in the cross tension test is in or near the weld metal at the sheet interface, the shape of that position is different in resistance spot welding. In resistance spot welding, the weld nugget is formed by passing the welding current while applying electrode force, and as a result, a solid-phase bond region called a corona bond exists at the sheet

interface near the weld nugget. As a result, the weld nugget boundary at the sheet interface forms an extremely sharp notch, as shown in Fig. 4 (a), and a large stress concentration is thought to occur at that point. In particular, because hardening in the heat affected zone in the vicinity of the weld nugget is remarkable in welding of high strength steel sheets such as 980 MPa class steel, peeling fracture occurs easily under low loads due to this stress concentration. On the other hand, as shown in Fig. 4 (b), since a solid-phase bond region like the corona bond does not exist in laser welds, the notch in the weld metal at the sheet interface is not as sharp as in resistance spot welding, and the degree of stress concentration is low. It is thought that this results in a condition which is resistant to peeling fracture under low load. Accordingly, it can be said that laser welding not only makes it possible to expand the weld size easily in comparison with resistance spot welding, but is also an advantageous welding method for improving peel strength because the weld shape is not conducive to stress concentration.

The results described above suggest that remote laser welding is not simply an efficient welding method, but is also a superior method for improving joint properties such as the peel strength of high strength steel sheet joints, which is a problem in resistance spot welding.

3. Rigidity Improvement by Application of Continuous Welding to Frame Parts

3.1 Merits of Application of Laser Welding and Laser/Arc Hybrid Welding to Frame Parts

It is possible to reduce the thickness of sheet used in auto bodies by adopting high strength steel sheets. Although this is an effective method of reducing auto body weight, reduced rigidity due to the thinner sheet thickness is a concern. In addition to the properties of the steel sheets, the rigidity of parts is also strongly influenced by the welding state. In comparison with spot-shaped welds, like that in resistance spot welding, continuous welding, which is possible with laser welding and laser/arc hybrid welding, is considered to be advantageous for improving rigidity. Moreover, laser welding is also a high speed, low heat input welding method, and makes it possible to weld narrow fringe widths in comparison with the resistance spot welding. Thus, in addition to the effect of continuous welding, a weight reduction effect can be expected by reduction of the fringe width. With laser/arc hybrid welding, deposited metal can be added to the weld by superimposing arc welding; this enables welding with a larger gap than in laser welding, and thus makes it possible to relax joint

accuracy requirements.

In order to satisfy both weight reduction of frame parts and rigidity improvement, H-One Co., Ltd. studied application of continuous welding to frame fringe parts, and carried out rigidity tests with hat shape specimens in joint research with JFE Steel to clarify the rigidity improvement effects of applying laser welding and laser/arc hybrid welding and adjusting the fringe welding location.

3.2 Rigidity Test Applying Continuous Welding with Hat Shape Specimen

In order to verify the rigidity improvement effect in welding of the fringes of frame parts by applying laser welding and laser/arc hybrid welding as continuous welding methods in comparison with resistance spot welding, a torsional rigidity test was carried out by using a hat shape specimen with the geometry shown in Fig. 5. The lapped fringe parts on the two sides of this hat shape specimen were welded by three welding methods, that were, resistance spot welding (welding pitch: 35 mm), laser welding, and laser/arc hybrid welding. (With the latter two welding methods, continuous welding was performed over the full length of 800 mm.) Three welding positions were arranged, as shown in Fig. 6, these being the center of fringe position, the cor-

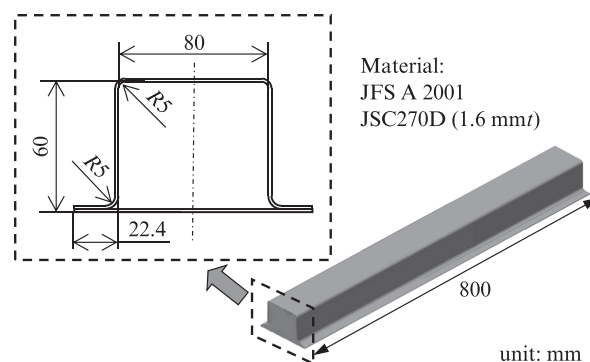


Fig. 5 Hat shape test piece for torsional rigidity test

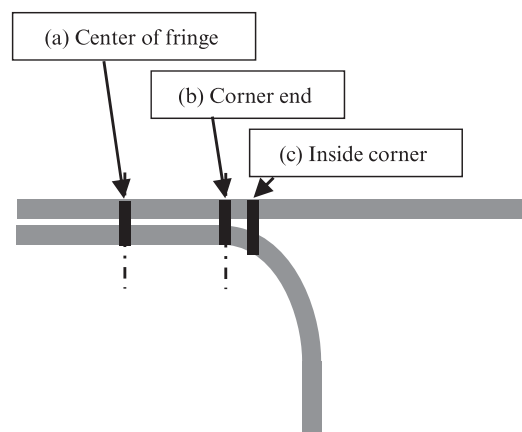


Fig. 6 Welding positions at fringe of hat shape test piece

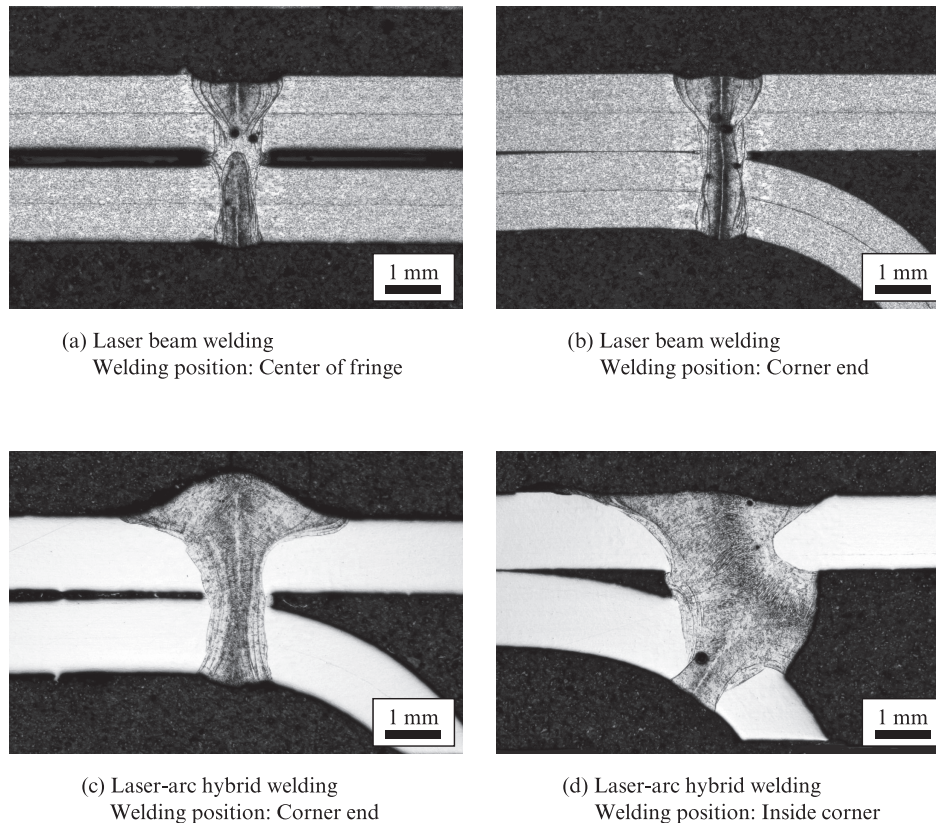


Photo 5 Macrostructures of laser and laser-arc hybrid welds

Table 1 Welding conditions of laser and laser-arc hybrid welding

	Laser beam welding	Laser-arc hybrid welding
Laser power (kW)	3.0	3.0
Arc current (A)	—	160
Welding speed (m/min)	2.0	2.0
Shielding gas	Ar	Ar-20% CO ₂
Welding wire	—	JIS Z 3312 YGW12 (dia. = 0.9 mm)

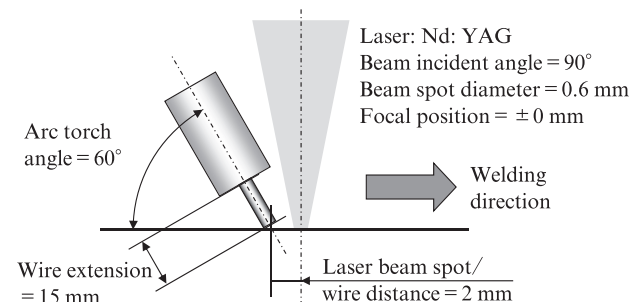


Fig. 7 Schematic illustration of laser-arc hybrid welding

ner end position, and the inside corner position (4 mm inner from corner end position). Three types of test specimens were prepared by welding only the center of fringe position (resistance spot welding), the center of fringe and the corner end (laser welding), and the corner end and the inside corner (laser/arc hybrid welding). **Table 1** shows the welding conditions used in laser welding and laser/arc hybrid welding. In laser/arc hybrid welding, a method in which the laser beam preceded the arc torch was used, as shown in **Fig. 7**. **Photo 5** shows the cross-sectional macrostructures of the fringe welds by laser welding and laser/arc hybrid welding. With laser/arc hybrid welding, the fusion width at the corner end position was wider than that in laser welding, and a defect-free weld was obtained because the deposited

metal filled the gap between the lapped sheets at the inside corner position.

A torsional rigidity test, as shown in **Photo 6**, was performed with the hat shape specimens prepared as described above. The values of rigidity were calculated from the angle-torque curve under torsional loading. **Figure 8** shows the torsional rigidity ratio, which is defined as the ratio of the rigidity of each test specimen when the value of the resistance spot welding specimen (welding pitch: 35 mm, welding position: center of fringe) is assumed to be 1. These results clarified the fact that a rigidity improvement of approximately 8% (comparison of RSW (CTR) and LBW (CTR)) is obtained by the change from resistance spot welding to continuous laser welding, and a further increase in this

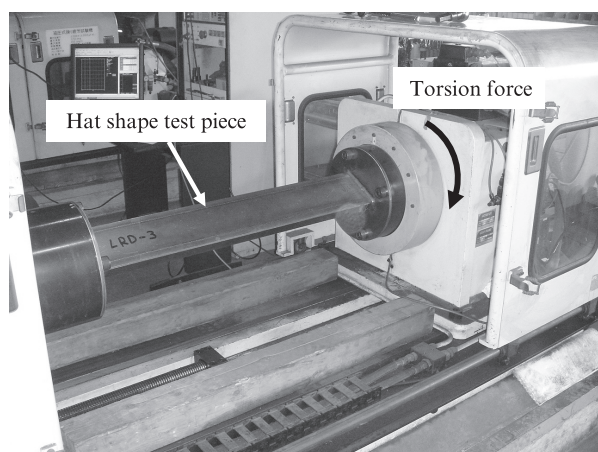


Photo 6 Appearance of torsional rigidity test

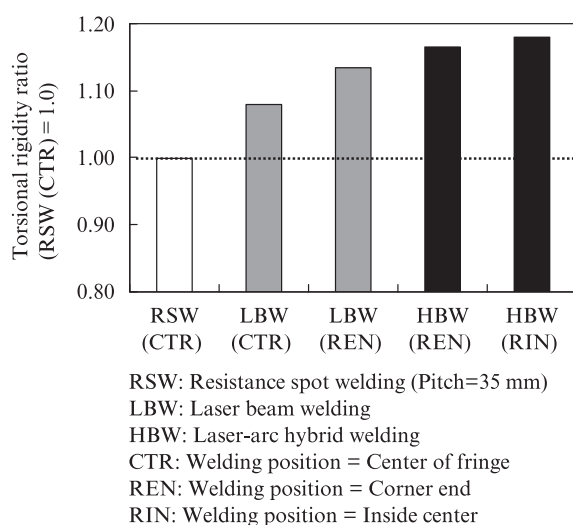


Fig. 8 Torsional rigidity test results

improvement to approximately 13% (LBW (REN)) is realized by performing welding at the corner end position as the welding position. These results also revealed that a rigidity improvement of about 16–18% in comparison with resistance spot welding is achieved by applying laser/arc hybrid welding and performing welding at the corner end position and inside corner.

Figure 9 shows the results obtained by a CAE (Computer Aided Engineering) analysis of the major strain distribution in the fringe in the specimen which was welded by laser welding of the center of fringe (LBW (CTR)) and the specimen which was laser welded at the corner end position (LBW (REN)). In comparison with welding of the center of fringe position (a), welding of the corner end position (b) suppressed welding distortion in the range from the center of fringe position to the corner end. As a result, it can be understood that the strain generated in the vertical wall part decreased, and the torsional rigidity of the specimen increased.

From the foregoing results, in welding of the fringe of frame parts, it is possible to improve rigidity by appli-

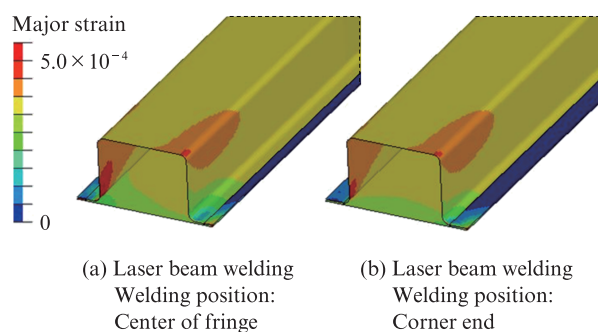


Fig. 9 Computer Aided Engineering (CAE) analysis of major strain distribution at fringe area of hat shape test piece

cation of continuous welding, together with selection of the optimum welding position. This suggested the possibility of satisfying both weight reduction and rigidity improvement by using a combination of high strength and thin thickness steel sheets and the optimum welding method.

4. Conclusion

The need for auto body weight reduction will tend to become increasingly strict in the future. In order to satisfy both weight reduction and auto body strength and rigidity, it will be important to utilize various types of high strength steel sheets effectively, and at the same time, develop new welding technologies. This paper introduced remote laser welding as a welding method that will replace resistance spot welding, and laser welding and laser/arc hybrid welding as continuous welding methods. Until now, the high cost of laser welding systems had been a barrier to practical application. However, against the background of increased needs for high efficiency by development of devices such as remote laser welding and continuous welding of parts when using high strength steel sheets, progress in the diffusion of laser welding technologies to welding of automotive bodies is expected in the future. JFE Steel will devote its efforts to developing new technologies related to laser welding and promoting their practical application, and contributing to auto body weight reduction and improved crashworthiness by expansion of the applications of high strength steel sheets by automotive customers.

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