Technical Report

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Development of 2D Brazing Method to Realize Optimum Thickness Distribution of Components for Light Steel Body Frames

Tasuku ZENIYA* Hitomi NISHIBATA
Shinji KODAMA Masanori YASUYAMA

Abstract

Recently, in order to improve crash safeness and achieve light weight automotive bodies, it is important to design optimum sheet thickness distribution to suppress the bending deformation. In many cases, components are reinforced partly through attaching reinforcement by spot welding. However, a large joining area is needed to enhance reinforcing. Here, the full brazing method developed utilizing the hot stamping process is introduced.

1. Introduction

In the automotive industry field in recent years, reduction in the thickness of parts has been sought in the pursuit of lightweightness of bodies to reduce the emission of carbon dioxide. However, since reduction in the thickness of parts deteriorates their performance, it is necessary to increase the strength of steel sheets to secure crashworthiness. Therefore, the application of high tensile strength steel to automotive bodies is increasing.[1, 2] For example, the application of hot-stamping (hereinafter referred to as HS) technology to center pillars is increasing.[3] A center pillar is a structural channel that secures the space of the driver and fellow passengers at the time of collision. The HS technology enables the production of high strength steel channels with high accuracy by applying quenching and press-forming simultaneously.

To secure the cabin space of the driver and fellow passengers at the time of collision, it is necessary to suppress the deformation of structural channels, and high bending performance is required for a center pillar. A center pillar is made of high tensile strength steel, and its bending performance is further enhanced by reinforcing parts partially attached by spot (hereinafter referred to as SP) welding. However, as shown on the left side in **Fig. 1**, in the conventional method, as the reinforcing parts are built into the center pillar parts after they have been independently formed, a gap of several millimeters as shown with allowances inevitably takes place between the center pillar parts and the reinforcing parts. When such a gap exists, both parts are deformed independently and a deformation difference is developed. Therefore, they do not behave as a single thick sheet, and the effect of improving bending performance by increasing thickness is not achieved. To reduce the gap to the extent possible, the patchwork-tailored welded blanks (hereinafter referred to as PW-TWB) method is practically employed.[4]

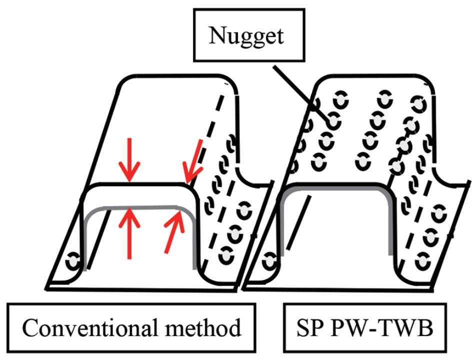

Fig. 1 Reinforce method of hat channel

In this method, steel sheets of the main parts and of the reinforcing parts are SP-welded before press-forming, and then press-formed to an object channel. Joining of steel sheets at the ridge line area that was impossible with the conventional method becomes possible by SP-welding, and the gap between the center pillar parts and the reinforcing parts can be reduced. However, even if press-forming of the object channel is attempted by using the SP PW-TWB method, as steel sheets are not joined in areas other than welded areas, a deformation difference is developed at the unwelded area of the center pillar parts and the reinforcing parts during bending deformation, and the effect of improving bending performance expected with the summed thickness of two sheets is not achieved.

* Researcher, Application Technology Research Lab., Steel Research Laboratories
1-8 Fuso-cho, Amagasaki City, Hyogo Pref. 660-0891

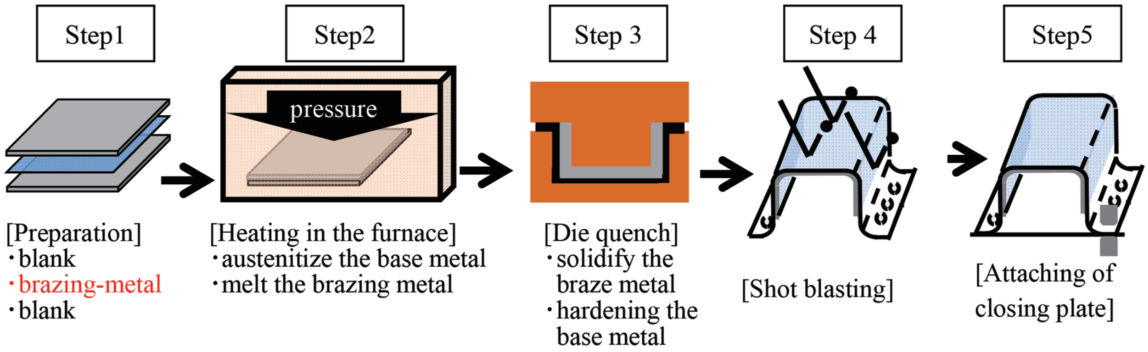

Fig. 2 Schematic diagram of 2D brazing utilizing hot stampimg process

To maximize the effect of increasing sheet thickness with reinforcing parts, it is necessary to join the center pillar parts and the reinforcing parts entirely on the whole face, and to suppress the deformation difference between the parts. Then, instead of spot joining by SP-welding, a method of brazing the entire interfacing area of the center pillar parts and the reinforcing parts by using the heating process in the HS process was developed.

This article reports the outline of the 2D brazing method that utilizes the HS process and the result of evaluation of the jointing strength obtained by the method. Furthermore, this article also reports the effect of improving bending performance by applying the 2D brazing method that was confirmed by the three-point bending test of a hat channel produced in the method. The result of the three-point bending test is reported. Additionally, the result of study on the detectability of an unfilled area by nondestructive inspection of the welded area is also reported.

2. 2D Brazing Method Utilizing HS Process

In **Fig. 2**, a schematic diagram of the 2D brazing method utilizing the HS process based on the example of a hat channel is shown. Firstly in step 1, a set of steel sheet blanks for main parts and for reinforcing parts with a brazing metal filled in between is prepared. In step 2, the set of the steel sheet blanks is heated in a furnace, being pressurized, wherein the base metals are austenitized and the brazing metal is molten. Then, the steel sheet blanks are transferred to the die-quenching station, where they are quenched by dies and press-formed simultaneously as step 3. In step 4, after press-forming, they are descaled by shot blasting, and in step 5, a closing plate is attached by SP-welding. Thus, a closed section channel is completed.

3. Method of Experiment

3.1 Test steel sheet and test brazing metal

For the experiment, a non-coated HS steel sheet and a Zn-coated HS steel sheet that yield 1.5 GPa tensile strength after quenching were used, the chemical compositions of which are shown in **Table 1**. The thickness of the steel sheets used for the experiment is as follows: 1.4 mm, 1.6 mm and 1.8 mm for the jointing strength evaluation test, 1.2 mm, 1.4 mm and 2.6 mm for the hat channel strength test, and 0.8 mm and 2.3 mm for the nondestructive inspection test. As described previously, in the HS process, steel sheets need to be transformed to single phase austenite microstructure to apply quenching to the steel sheets.

In the brazing method, as heating in the HS process is used as the heating source of brazing metal, a brazing metal that enables brazing in the furnace at a temperature above the austenite transformation temperature (831°C in the case of the test steel in this article) is used for joining. Furthermore, when the liquid metal embrittlement described below is taken into consideration, selection of a brazing metal having a solidus temperature close to the furnace temperature is appropriate. **Figure 3** shows the liquidus temperature range of general brazing materials arranged referring to the JIS. In this experiment, brass foil and bronze foil that enable brazing at the furnace temperature of 900°C–1 000°C in the HS process, are relatively low in cost, and allow brazing in open air atmosphere were used. The chemical compositions and physical properties are shown in **Table 2**.

Table 1 Chemical compositions of hot stamped sheet (mass%)

C	Mn	B	Cr
0.21	1.26	0.001	0.2

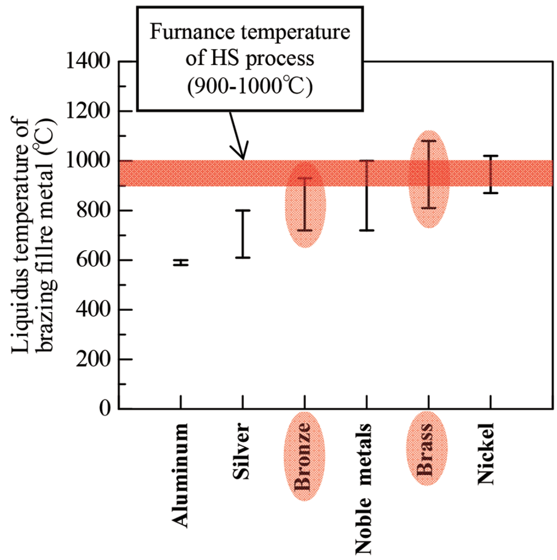

Fig. 3 Liquidus temperature range of the various brazing filler metal

3.2 Evaluation method of liquid metal embrittlement crack

When actual channels are manufactured, quenching and forming-bending work are applied at a high temperature, and in certain types of brazing metal (e.g., copper brazing metal), the occurrence of liquid metal embrittlement (hereinafter referred to as LME) crack is anticipated. Then, the high temperature bending test was applied to the brazed test specimens, and the relationship between the pres-

Table 2 Chemical compositions and material properties of brazing filler metal

Materials	Chemical compositions (mass%)	Liquidus temperature (°C)	Solidus temperature (°C)	Use of application
Brass	Cu: 64%–68% Zn: Bal.	930	903	Strength evaluation of joints and hat channels
Bronze	Cu: 80% Sn: 20%	925	770	Evaluation of LME crack

ence of the LME crack and solidus temperature was examined. Test specimens 60 mm in length and 30 mm in width, filled in between with a brazing metal for the entire area were heated at 1 000°C for 5 min. The test specimens were bent at the center by a punch of R=5 mm until reaching an angle of 90° at the two experiment temperature levels of 800°C and 750°C. Subsequently, the presence of the LME crack was checked through the observations of the appearances of the test specimens and the cross section of the jointed area. As the LME crack is anticipated in the bending applied in the liquidus state, this test was conducted only using bronze that has low solidus temperature.

3.3 Pressurization in furnace

The blank sheets to be joined are warped in the furnace as temperature rises, and spoil the wetting performance of the brazing metal. Then, the effect of pressurization in the furnace on the state of joining was evaluated by using the test specimens of the cross tensile strength (CTS) test referred to in 3.4, and by observing the fracture surface of the test specimen. The test was conducted for the two levels of without pressurization and with pressurization of 7×10^{-4} MPa under the condition of heating at 1 000°C for 5 min.

3.4 Evaluation method of jointing strength

The load acting on the brazing metal at the interface in actual channels is considered to be the result of the load acting in the sharing direction and the one acting in the separating direction. Therefore, jointing strength was evaluated by the tensile shear strength (hereinafter referred to as TSS) test and CTS test. In **Fig. 4**, the shapes of test specimens are shown. The TSS test specimen was made of two steel sheets 90 mm in length and 25 mm in width (20 mm for some tests) overlaid on each other by a length of 25 mm (15 mm for some tests) at the edge area. The whole overlaying area was grazed. The CTS test specimen was made of two steel sheets 150 mm in length and 50 mm in width overlaid on each other by a length of 50 mm at the center area. The whole overlaying area (50 mm × 50 mm) was grazed. Furthermore, to compare jointing strengths, the TSS test and CSS test were also conducted for the SP-welded joint referring to JIS Z 3136.

For the tensile share strength test of the SP-welded joint, a test specimen was prepared in the following way: the 30 mm edge areas of two steel sheets 100 mm in length and 30 mm in width were overlaid on each other at the edge area of 30 mm, and the steel sheets were SP-welded so as to form a nugget with a diameter of 5.36 mm ($4\sqrt{t}$ (t: sheet thickness)) at the center of the overlaid area. For the cross tensile strength test, the two 50 mm center areas of two steel sheets 150 mm in length and 50 mm in width were overlaid on each other at the center area of 50 mm, and the steel sheets were SP-welded at the center of the overlaid area under the same condition as that for the TSS test specimen. The tension tests were conducted at a tension rate of 10 mm/min at room temperature.

3.5 Method of three-point bending test of hat channel

Relationships between bending load and stroke, and between bending load and absorption energy were investigated for a hat channel with the three-point bending test. In the bending test, as shown in **Fig. 5**, a hat channel test specimen was placed on the supporting points (R=30 mm) arranged 500 mm apart, and was bending-deformed by a punch of R=150 mm, ramming at a collapsing rate of 15 mm/min with a total maximum stroke of 50 mm. **Figure 6** shows the overview of the hat channel samples used for the test. An area of 170 mm × 595 mm of the main part of the hat channel (A) produced by the brazing method was brazed. Additionally, in consideration of the convenience in handling of the sheets during the brazing process, one point SP-welding was applied at the center of the sheets.

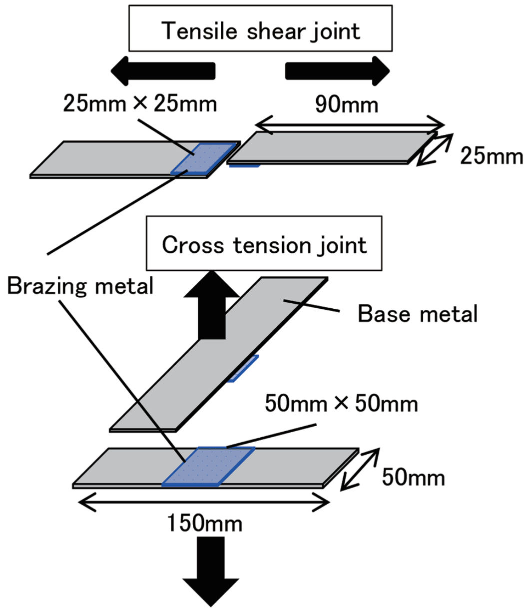

Fig. 4 Shape of TSS and CTS specimens

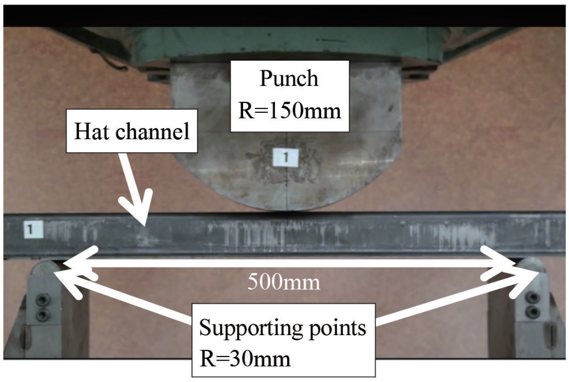

Fig. 5 Schematic of three-point bending test

The brazing condition was determined as follows based on the result of study on jointing strength as described in 4.1: joining temperature of 1 000°C, joining time of 10 min and brazing metal thickness of 100 μm. In addition, the quenching-start temperature was set at 800°C. For comparison purposes, the following hat channels were prepared.
hat channel (B): prepared in a method simulating the conventional method, in which main hat parts and reinforcing parts are prepared separately and joined subsequently by spot welding,
hat channel (C): prepared in the SP PW-TWB method, in which the main hat blank sheet and the reinforcing part blank are SP-welded at the sheet blanking stage.
hat channel (D): single sheet hat channel, in which the hat is made of a HS steel sheet 2.6 mm in thickness that is the sum of the thickness of the main parts and that of the reinforcing parts. Only hat channel (D) has 2.6 mm thickness in the full range, not only in the reinforced area but also in the flange area.

3.6 Method of nondestructive inspection

In the channels thus produced, as the joining area exists between sheets, it is difficult to detect the unfilled area by observation from outside. Then, the feasibility of detecting the unfilled area (internal defect) by nondestructive inspection was studied. There are various nondestructive inspection methods, and in this study, inspection of the unfilled area was conducted by X-ray radiograph examination that is generally used for inspecting welded parts, under the condition of a tube current of 3.0 mA, tube voltage of 50–150 kV, and radiation time of 2 min. The CTS test specimen was used, and the X-ray radiographic examination was applied after brazing. The fractured section was obtained by forced fracturing in the tension test. By comparing the X-ray radiograph examination image with the fracture surface, the detection accuracy of the unfilled area by nondestructive inspection was verified. The thickness of the used brazing metal was 100 μm, and the base metal sheet thickness was 0.8 mm and 2.3 mm as previously described. The test was conducted for two levels. In this test, to clarify the difference in test results distinctively, pressurization in the furnace was not applied when preparing the CTS test specimens. The area of the filled-in brazing metal was 40 mm × 40 mm.

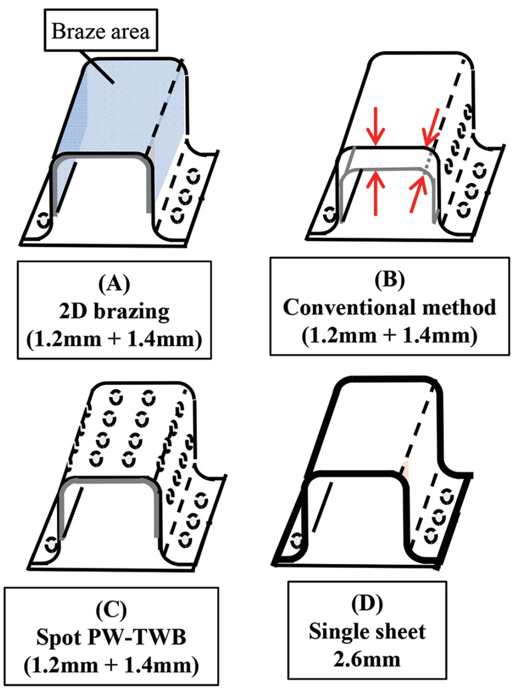

Fig. 6 Simple overview of hat channels for three-point bending test

4. Result of Experiment and Study

4.1 Effect of bending temperature on liquid metal embrittlement crack

Figure 7 shows the results of bending tests conducted at 800°C above the solidus temperature of bronze and at 750°C below the solidus temperature of bronze. In the bending work in this test, a tension stress is produced on the inner face of the sheet contacting the brazing metal, and LME can be developed. In the bending work at 800°C above the solidus temperature, LME was observed occasionally. On the other hand, in the bending work below the solidus temperature, LME did not take place. This confirmed that the LME crack can be suppressed by controlling the temperature of the joined blank sheets so as to be bent below the solidus temperature of the brazing metal. In the brass high temperature bending test at 800°C below the solidus temperature, it was confirmed that no LME crack was developed on the inner side of bending.

4.2 Effect of pressurization in furnace on braze area

In **Fig. 8**, fracture surfaces of the CTS test in the case of without pressurization and in the case of with pressurization are shown. In the case of without pressurization (0 MPa), the unfilled area was observed occasionally outside the dark area enclosed by a dashed line. With low pressurization of 7×10^{-4} MPa in the furnace, the unfilled area becomes much smaller compared with the case of without pressurization and good fracture surface is obtained. It is considered that when the furnace temperature rises, by pressurization and by sup-

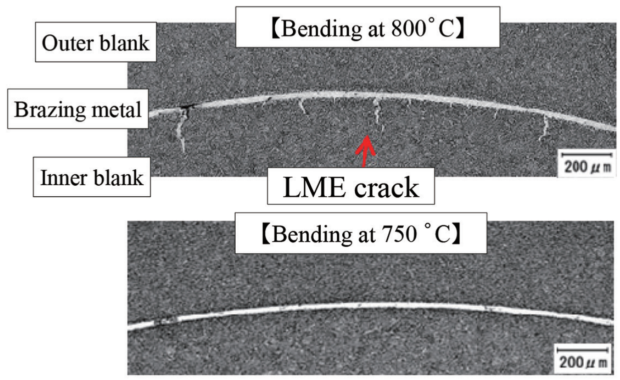

Fig. 7 Interface of 2D brazed specimens bending at 800°C and 750°C

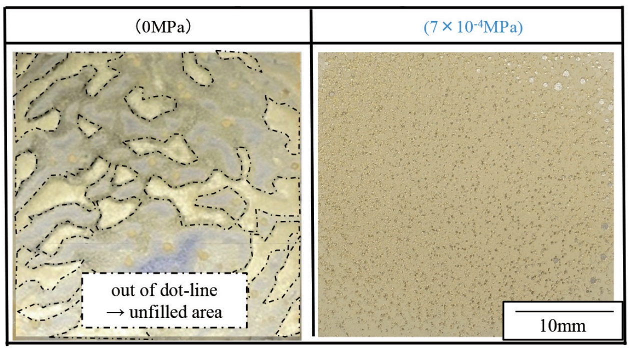

Fig. 8 Fracture surface of CTS test at the case of 0 MPa and 7×10^{-4} MPa

pressing the warping of blank sheets to be joined thereby, the occurrence of a gap between the blank sheets to be joined and braze metal unfulfilled area is prevented, and an excellent joining interface is considered to be formed.

4.3 Effect of joining condition on jointing strength

First, the effects of joining temperature and joining time on jointing strength were examined. In **Fig. 9**, jointing strength at joining times of 5 min and 10 min at the joining temperature of 950°C is shown, and in **Fig. 10**, jointing strength at the joining temperatures of 950°C and 1 000°C for the joining time of 10 min is shown. Except the case of base metal fracture in the TSS test of the test specimen with the joining temperature of 1 000°C and joining time of 10 min, all test specimens exhibited cohesive fracture. In the case of a joining temperature of 950°C, 34.8 kN of TSS and 4.2 kN of CTS, both with 5 min, rose to 45.6 kN and 5.1 kN with 10 min, respectively. In the case of a joining time of 10 min, 45.6 kN of TSS and 5.1 kN of CTS at 950°C rose to 48.5 kN and 8.9 kN respectively at 1 000°C. This indicates that the jointing strength of TSS and CTS is improved by the higher joining temperature and longer joining time.

Next, the result of the study on the effect of brazing metal thickness on jointing strength is described. The brazing metal thickness is denoted by the thickness of the brazing metal filled-in before joining. The joining area was 20 mm in width and 15 mm in length. The result is shown in **Fig. 11**. All fractures exhibited cohesive fracture mode. Although the difference in TSS between the case of a brazing metal thickness of 50 μm and that of 100 μm was small, regarding both TSS and CSS, the joining strength tends to increase as the brazing metal thickness increases. Generally, in brazing, TSS increases as the brazing metal thickness decreases; however, the trend of joining strength obtained in this method was different from the general trend.[5)]

Figure 12 shows the result of comparison of the strength of a brazed joint and that of the SP-welded joint. The brazed joint was provided under the condition of a heating time of 1 000°C, joining time of 10 min and the brazing metal thickness of 100 μm, which is considered to be the best within the scope of this study. When compared with the jointing strength of the SP-welded joint, the brazed TSS joint strength is 2.2 times higher, the brazed CTS joint strength is 2.7 times higher, and the jointing strength of a 2D brazed joint was higher than that of the SP-welded joint. From this finding, the 2D brazed joint was judged to have sufficient strength to form structural channels.

4.4 Factors influencing jointing strength

To examine the relationship between the brazing condition and jointing strength, composition analysis of the brazing metal after brazing was conducted for the brazing metal thickness of 10 μm and

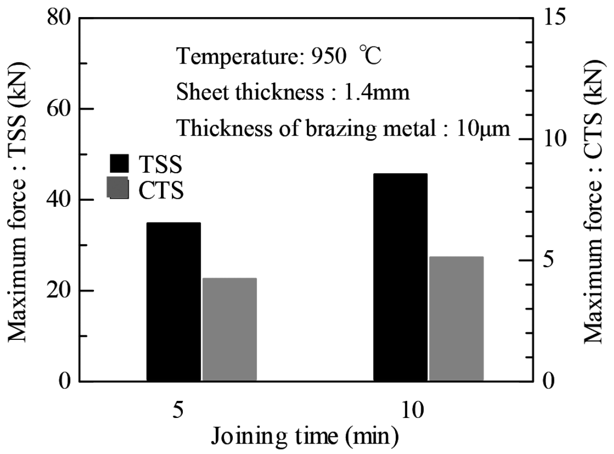

Fig. 9 Effect of joining time of brazing filler metal to joint strength

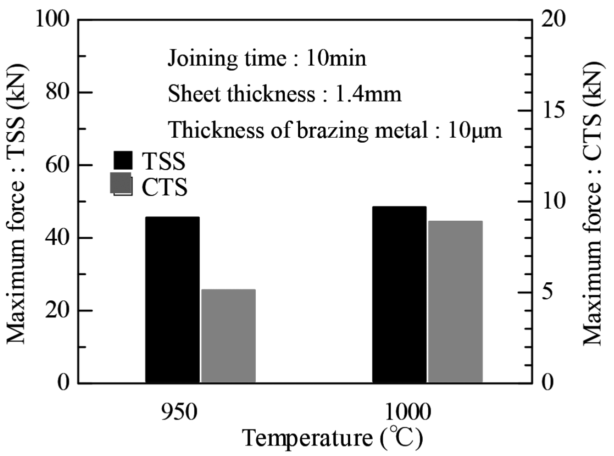

Fig. 10 Effect of joining temperature of brazing filler metal to joint strength

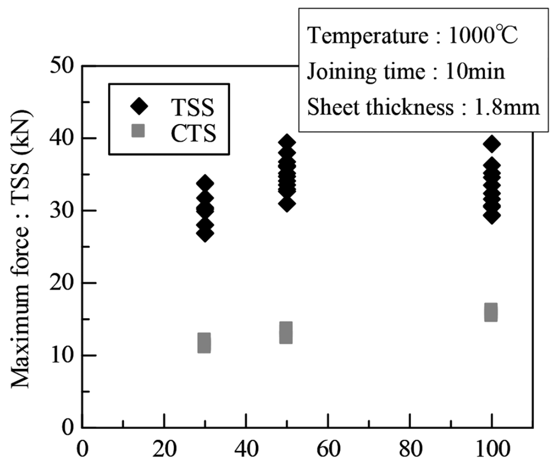

Fig. 11 Effect of thickness of brazing filler metal to joint strength

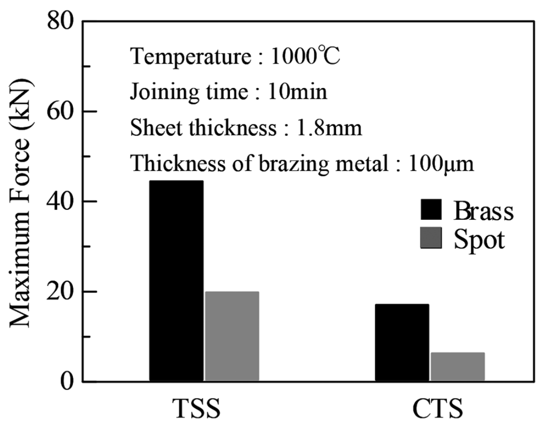

Fig. 12 Comparison of joint strengths made by brass brazing, made by spot welding

50 μm wherein a relatively large difference in joining strength was observed. **Table 3** shows the result of analysis by energy dispersive X-ray analysis of the brazing metal of the test specimen brazed under the condition of 1 000°C, 5 min with a brazing metal thickness of 10 μm and 50 μm. Although the Fe content is higher in the sample with thinner brazing metal thickness of 10 μm, in either case, the brazing metal was composed of a monophase of Cu with solid-soluted Zn. The joint fractured in cohesive fracture mode, and since the difference in chemical compositions due to the difference in brazing condition is small, the relationship between joining strength and brazing metal compositions is considered small. As the pressurization force in the furnace in this brazing method is small, the unfilled area at the microscopic level and unfilled area on the periphery of the brazed region were observed. Therefore, within the scope of the study, under the condition of long joining time, high joining temperature and high brazing metal thickness that realized high jointing strength, the unfilled area was reduced and the joining area increased substantially, and the joining strength increased accordingly.

Then, using the test specimens shown in Fig. 11, the actual joining area that excludes the unfilled area was investigated and arranged with respect to joining strength, the results of which are shown in **Fig. 13** and **Fig. 14**. In both cases of TSS and CTS, the unfilled area was reduced and the actual joining area increased as the brazing metal thickness increased. In addition, both TSS and CTS tended to increase along with the increase in the actual joining area. It was confirmed that, between the cases of thickness of 50 μm and 100 μm, the difference in TSS was small, and the difference in the actual joining area was also small. These results indicate that, as joining strength is influenced by the actual joining area, under the condition of longer joining time, higher joining temperature and higher brazing metal thickness, all of which improve wetting performance of the brazing metal and promote filling-in of the brazing metal, jointing strength increased accordingly.

Table 3 Chemical compositions of brazing filler metal after brazing

Joining temperature (°C)	Joining time (min)	Thickness of brazing filler metal (μm)	Fe	Cu	Zn
1 000	5	10	4.65	63.71	31.65
		50	1.65	67.29	31.07

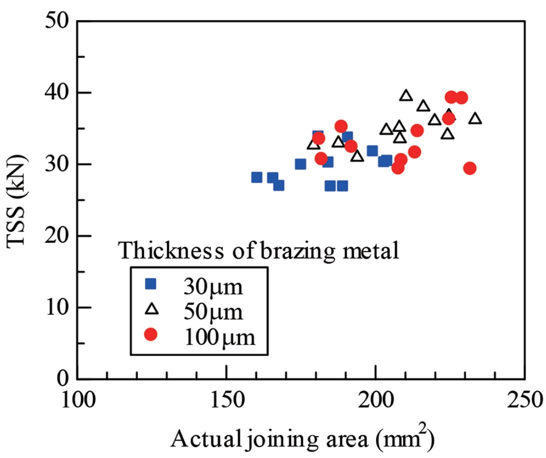

Fig. 13 Effect of actual joining area to TSS

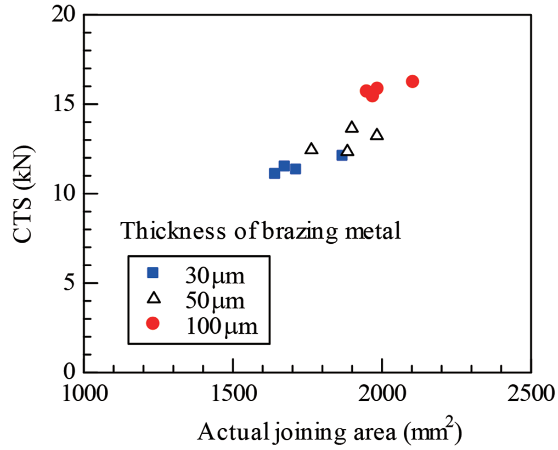

Fig. 14 Effect of actual joining area to CTS

4.5 2D brazing for Zn-coated hot stamping steel sheet

Study up to section 4.4 focused on non-coated steel sheets. However, the Zn-coated HS steel sheet for rust-prevention purposes is used for actual channels in many cases. Therefore, the applicability of the 2D brazing method to the Zn-coated hot stamping steel sheet was studied. Brass (Cu-Zn) that contains the major composition of Zn of coating of the coated steel sheet was employed as the brazing metal. The joining condition was set at 1 000°C, 10 min and 50 μm based on the study result of non-coated HS steel sheets.

The cross section of the brazing area is shown in **Fig. 15**. The Zn coating layer of 10 μm or less in thickness that existed before brazing disappeared, and brazing between the brazing metal and the base metal was confirmed as feasible. It is considered that the Zn coating mingled with the brazing metal and acted as a single brazing metal, and brazing was made feasible accordingly.

Next, TSS and CTS were evaluated. The joining condition was 1 000°C, 10 min, the same as that for the study on applicability. The brazing metal thickness was 50 μm, and the joining area for TSS was 20 mm in width and 20 mm in length. The result of the tensile strength test is shown in **Fig. 16**. For comparison purposes, the jointing strength of the non-coated HS steel sheet under the same condition is also shown. TSS and CTS of the brazed joint of the Zn-coated steel sheet were 35.7 kN and 4.1 kN, respectively. Although they were lower than 40.6 kN of TSS and 9.3 kN of CTS of the non-coated steel sheet, joint strength comparative to that of the SP-welded joint was obtained.

The above result confirmed that the application of the 2D brazing method to Zn-coated HS steel sheet is feasible. It was also suggested that, as strength equivalent to that of SP-welding was obtained, application to the manufacturing of parts is feasible. However, at present, study on the condition of brazing for the Zn-coated HS steel sheet is still insufficient; therefore, further efforts are required to optimize the condition.

4.6 Result of three-point bending test of hat channel

The relationship between three-point bending load and stroke is shown in **Fig. 17**, and that between absorbed energy and stroke is shown in **Fig. 18**.

When the maximum bending load of hat (C) made using the SP PW-TWB method is compared with that of hat (B) made using the conventional method, there was an increase of 22% (from 50 kN to 61 kN). Furthermore, the maximum load of hat (A) made using the HS-2D-brazing method showed a 100% increase from that of hat (B)

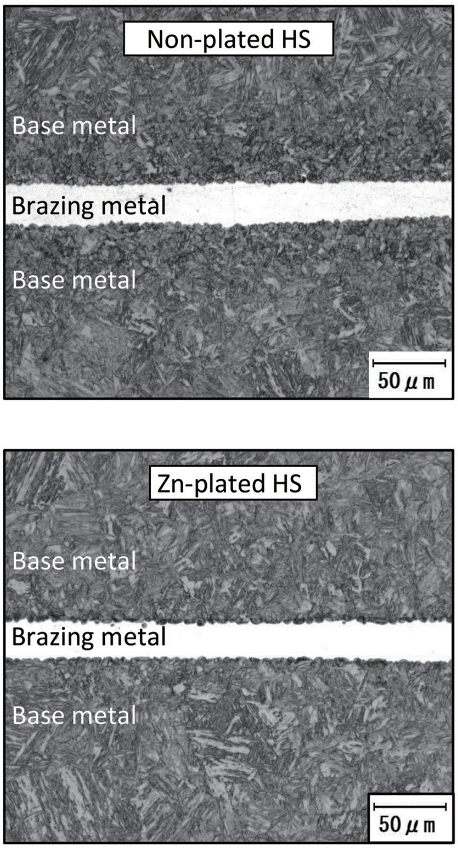

Fig. 15 Cross section of brazing area

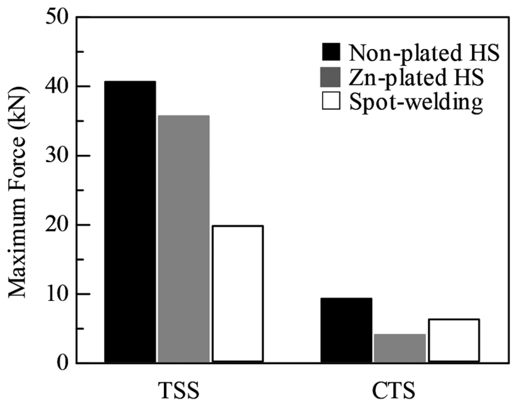

Fig. 16 Comparison of joint strength

(from 50 kN to 100 kN), and a 63% increase from that of hat (C) (from 61 kN to 100 kN). In addition, hat (A) had a maximum bending load equivalent to that of hat (D) that was made from a single sheet with a thickness of 2.6 mm for comparison purposes. When absorption energy is compared, the absorption energy of hat (A) made using the HS-2D-brazing method was 3.79 kJ, and showed a 176% increase from that of hat (B) (from 1.37 kJ to 3.79 kJ), and a 63% increase from that of hat (C) (from 2.32 kJ to 3.79 kJ). This result means that, when the same bending load is exerted on the 2D-brazed hat (A) and hat (B) that is made using the conventional method, hat (A) endures the load with a deformation smaller than that of hat (B).

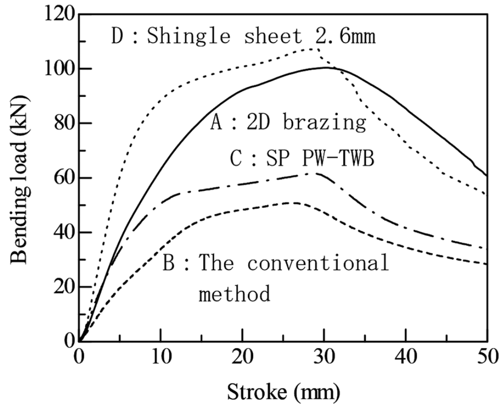

Fig. 17 Comparison of bending loads in a three-point bending test

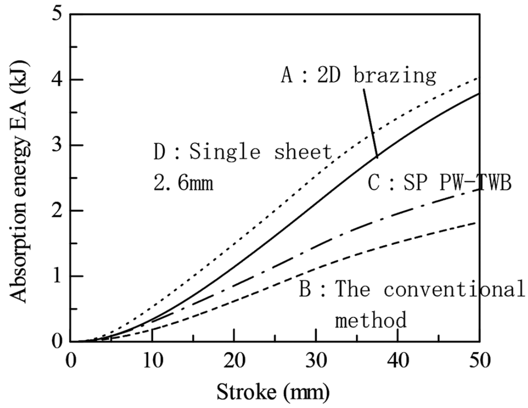

Fig. 18 Comparison of absorption energy in a three-point bending test

Even when compared with hat (C) made using the SP PW-TWB method, 2D-brazed hat (A) exhibited higher maximum bending load and higher absorption energy. This result suggests that even if the gap between the main parts and the reinforcing parts of a channel is eliminated in the PW-TWB method, the difference in deformation between the main parts and the reinforcing parts during deformation cannot be suppressed and the effect of reinforcing is not sufficiently utilized. In addition, the 2D-brazed hat (A) had bending performance equal to that of single-sheet hat (D). This result suggests that the entire deformation difference in a channel between the main part sheet and the reinforcing part sheet was suppressed to the maximum extent possible, and the effect of joining parts sheets on the increase in bending performance was exerted fully as the joined parts sheets behaved as if they were a one-piece during deformation.

5. Result of X-ray Radiograph Examination

In **Fig. 19**, results of the sensory evaluation of the fracture surface appearance and X-ray radiograph examination are shown. The X-ray radiograph image most clearly obtained under a test condition is shown.

In the case of a steel sheet of 0.8 mm with the brazing metal 10 μm in thickness, unfilled areas are observable distinctively to some extent on the X-ray radiograph image, and by comparing the image with the fracture surface, an unfilled area in the center could be detected by the X-ray radiograph image. However, in the case of a sheet thickness of 2.3 mm, the X-ray radiograph image became unclear as a whole, and the detection was difficult regarding the un-

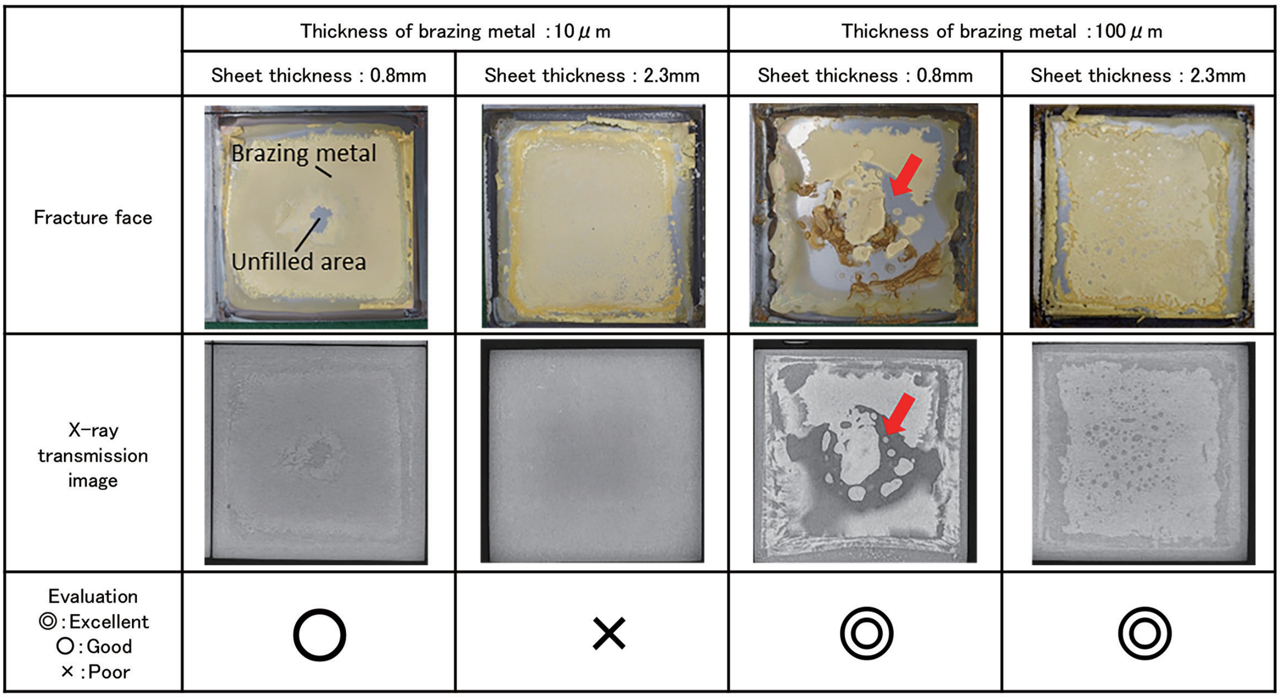

Fig. 19 Observation results of fracture face and X-ray transmission image

filled areas that were confirmed to exist inside and at the outer periphery through observation of the fracture surface. In the case of the brazing metal 100 μm in thickness, unfilled areas were clearly observable regardless of sheet thickness, and the observation of unfilled areas, comparable to observation based on fracture surface, is possible by X-ray radiograph examination.

In the case of brazing metal in a small amount, observation with X-ray becomes difficult because the distance of the gap between the base sheets filled in with brazing metal influences damping of the X-ray. In such a case, the distance of the gap between the base sheets is small, the difference in damping of the X-ray in the brazed area and that in the unfilled area (genuine gap) is small, and therefore, the contrast of the image becomes indistinct. On the other hand, in the case of brazing metal in a large amount, the distance of the gap between the base sheets is large; damping of the X-ay in the brazed area is large. As a result thereof, the difference in damping of X-ray in the brazed area and that in the unfilled area (genuine gap) became large. Even under the condition of brazing metal 10 μm in thickness and base sheets 2.3 mm in thickness in the scope of the experiment, as obtaining a good observation result by optimizing the observing condition of the equipment is expected, we are determined to continue the study.

Incidentally, under the condition of brazing metal 100 μm in thickness and base sheets 0.8 mm in thickness, as shown by arrows, a grazed area observable on the radiograph examination image is not found on the fracture surface. The grazing metal in this area was found on the opposite side fracture surface of the test specimen shown in Fig. 19. This result meant that only the presence of the brazing metal is detectable on the radiograph examination image, and that it is difficult to judge whether the brazing metal securely joins the base metal sheets. As described previously, in this experiment, test specimens were not pressurized in the furnace. However, to examine the state of brazing by X-ray radiograph examination in actual channels, it is important to apply pressurization to brazing areas in the furnace to ensure joining of base sheets. Thereby, the state of brazing metal detected by X-ray radiograph examination can be used for judging whether the base metal sheets are joined properly in the brazing method.

6. Conclusion

To realize the optimum thickness distribution of components to reduce the weight of steel car bodies, a technology for partially increasing the thickness of a channel by the 2D-brazing method that utilizes the heating process in the HS process was developed, and the following result was obtained.

(1) By heating in a furnace under pressurization, and by controlling the quenching temperature to suppress the LME crack, the 2D brazing method that utilizes the HS process was proven as feasible.

(2) The brazing condition of the joining temperature of 1 000°C, joining time of 10 min and the brass brazing metal of 100 μm in thickness was the best for non-coated HS steel sheets, and the Tensile Shear Strength and the Cross Tensile Strength of the 2D-brazed joint 2.2 times and 2.7 times higher than those of the SP-welded joint (one point) were obtained.

(3) Under the abovementioned joining condition, the jointing strength of a 2D-brazed Zn-coated HS steel sheet was examined, the result of which showed a jointing strength comparable to that of the SP-welded joint (one point).

(4) In the three-point bending test of a hat channel made using the 2D brazing method, the maximum bending force 2 times higher than that of the hat channel made using the conventional process was obtained, and further, absorption energy 2.7 times higher was obtained.

(5) A hat channel made using the 2D brazing method was equipped with the three-point bending performance equivalent to that of a hat channel made of a single steel sheet having the thickness of the summed thickness. From this fact, increase in

the thickness of a channel using the 2D brazing method is expected to maximize the effect of reinforcement by increasing sheet thickness.

(6) It was confirmed that the detection of the state of brazing metal is feasible with relative ease under almost all conditions by conducting X-ray radiograph examination.

For automobile channels, conventional spot welding that welds by spot has been widely used. However, in spot welding, on account of the confined weld area, improvements in jointing strength and the performance of channels are becoming difficult, and in future, the application of linear welding (laser welding, arc welding and so on), 2D jointing (with adhesive agent and so on) is considered to increase. To address such viewpoints, we developed the 2D brazing method that enables jointing in a wide area by applying it to Patch-Work Technology, and proposed the feasibility of improving the performance of channels by improving the joining method. We are determined to continue to promote research and development on joining technologies that maximize the excellent performance of high strength steel.

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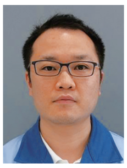
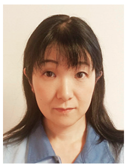


Tasuku ZENIYA
Researcher
Application Technology Research Lab.
Steel Research Laboratories
1-8 Fuso-cho, Amagasaki City, Hyogo Pref. 660-0891

Shinji KODAMA
Senior Researcher, Dr. Eng.
Welding & Joining Research Lab.
Steel Research Laboratories



Hitomi NISHIBATA
Senior Researcher, Dr. Eng.
Fundamental Metallurgy Research Lab.
Advanced Technology Research Laboratories

Masanori YASUYAMA
Chief Researcher
Welding & Joining Research Lab.
Steel Research Laboratories