

Component Integration Technology for Transforming Vehicle Manufacturing

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Abstract:

This paper discusses the integration of automotive parts aimed at reducing manufacturing costs for vehicle bodies. While emerging automakers are advancing the practical application of large aluminum cast components known as “Mega-casting,” automotive parts suppliers and steel makers are proposing part integration through hot stamping as a countermeasure. These technologies aim to reduce the number of dies for stamping and streamline assembly processes, yet they also present challenges related to logistics and repairability. JFE Steel is developing an alternative approach using ultra-high-strength steel and cold stamping for part integration. This report presents an optimal integrated structure using cold pressing for the door ring outer and rear member module, considering collision safety performance and formability.

1. Introduction

Integration of automotive parts is being actively studied with the aims of simplifying the auto body production process and reducing manufacturing costs. Application of large aluminum cast parts produced by gigacasting to the automobile bodies is expanding, particularly among emerging automakers¹⁾, and is also being studied by Japanese manufacturers²⁾. At the same time, automotive part manufacturers and major steel makers are proposing part integration by hot stamping³⁾. In comparison with the conventional approach of manufacturing parts by cold stamping of automotive steel sheets, the cost of producing one-piece integrated parts by these new technologies tends to increase due to material costs and constraints on production speed. However, the aim of these technologies is to reduce the

number of press dies by substantially reducing the number of parts, reduce production preparation costs, and eliminate assembly processes. Accordingly, in order to maximize the cost reduction effect and reduce costs in comparison with conventional auto body manufacturing, it is necessary to integrate a large number of parts. For example, in gigacasting, it is necessary to integrate as many as several dozen parts in order to realize the desired cost reduction effect. Other issues also include the increased cost of logistics and the deterioration of repairability accompanying the upscaling of modules by parts integration.

As an alternative approach to gigacasting and hot stamping, JFE Steel is studying part integration utilizing ultra-high strength steel sheets (hereinafter, Ultra-HyTensile) and cold stamping. Due to the challenge of formability when press-forming cold materials, the number of parts that can be reduced by part integration is limited. On the other hand, this approach has numerous advantages. Unlike the above-mentioned part integration technologies, cost merits can be expected even by small-scale part integration, and it is possible to select the parts to be integrated, taking into account their effects on the issues of logistics costs and repairability. This paper presents an overview of the study of part integration in JFE Steel, and introduces examples of optimum integrated part structures considering crash performance, as well as a prototype integrated part using Ultra-HyTensile and cold stamping.

2. Concept of Part Integration by Cold Stamping

As shown in **Fig. 1**, JFE Steel is developing integrated part structures utilizing cold stamping for a variety of parts of the automotive white body, includ-

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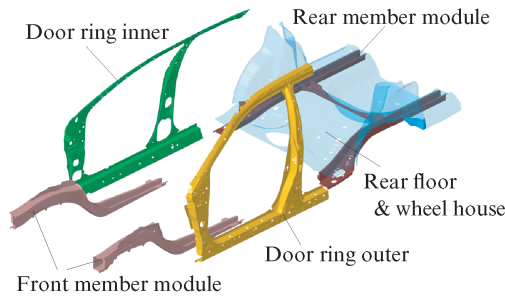


Fig. 1 Target areas for component integration study by JFE

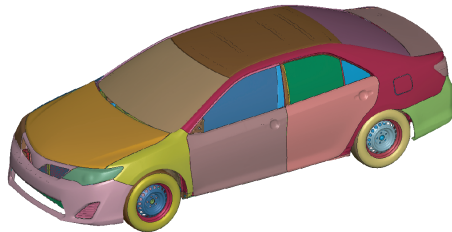


Fig. 2 Full vehicle model for component integration study

ing the front member module, door ring inner, door ring outer, floor panels, rear member module, etc. As described in the previous chapter, due to formability-related issues, it is difficult to reduce the number of integrated parts by cold stamping to the same extent as in gigacasting and hot stamping, but on the other hand, cost merits can be achieved easily, even by small-scale part integration, and the degree of freedom in achieving the optimum design is also high. This paper presents the content of the study of cold-stamped integrated part structures at JFE Steel, particularly for the door ring outer and the rear member module, with a focus on crash performance. For the rear member module, part of the forming technology for achieving the proposed structure is also described, and the results of actual part prototyping are presented. In this study, we used the auto body data (Fig. 2) for crash analysis by LS-DYNA of the 2012 Toyota Camry, which is available on the website of the National Crash Analysis Center (NCAC). The material configuration of the parts was modified as appropriate for the comparative study in each chapter.

3. Examples of Study of Integrated Part Structures

3.1 Part Integration of Door Ring Outer

For the door ring outer, many automotive parts manufacturers and steel makers have shown an orientation toward part integration by hot stamping, and multiple companies have released study results and exhibition parts. However, in addition to formability, the

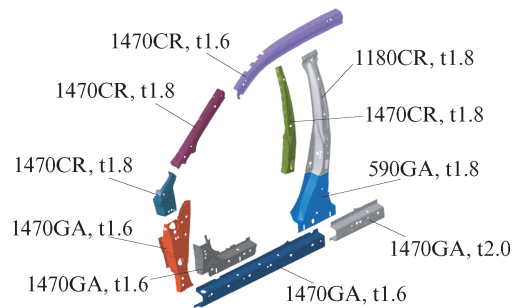


Fig. 3 Conventional door ring structure using cold stamping

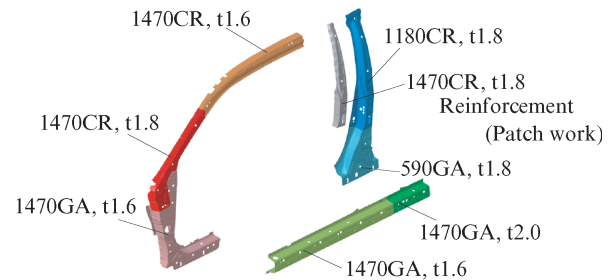


Fig. 4 Semi-integrated (three-piece) door ring structure using cold stamping

focus when studying part integration by cold stamping also includes the performance required in the door ring outer in various crash modes. Therefore, a structure that satisfies the required crash performance was devised under the constraint that forming by cold stamping must be possible.

First, the targeted door ring outer consists of a total of 10 parts (Fig. 3). The material notations in this figure show numbers indicating the tensile strength grade, followed by the steel grade (CR: uncoated cold-rolled steel, GA: galvanized coated material), together with the sheet thickness. For example, “t1.0” indicates a sheet thickness of 1.0 mm. In this chapter, the structure shown in Fig. 3 is called the “conventional structure.” The total weight of the door ring outer with the conventional structure was 36.7 kg/piece. Next, the developed structure is shown Fig. 4. The parts from the front pillar lower to the roof side rail were integrated as one part, and the side sill and center pillar were each one part. The developed structure (hereinafter, three-part structure) comprises the total of these 3 parts and had a total weight of 32.9 kg/piece. Tailor welded blanks (TWBs) were fabricated by laser welding the boundaries of parts with different strength levels and thicknesses while still in the blank form (i.e., before forming). For the reinforcement part of the center pillar, the “cold patchwork method” was applied. In this method, the blank is spot welded and then overlapped on the pillar part and formed. For comparison, Fig. 5 shows a hot-stamped fully-integrated structure (hereinafter, hot-stamped structure). Here, the strength is a uniform

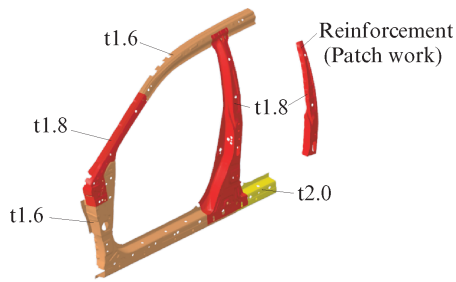


Fig. 5 Fully-integrated door ring structure using hot stamping

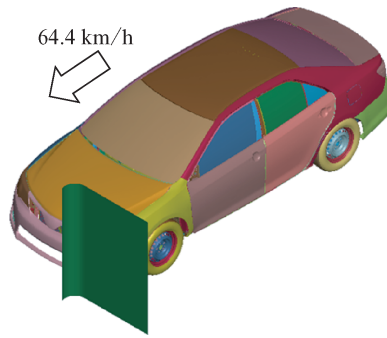


Fig. 6 Analysis model of small overlap front crash

1 500 MPa, and TWB was applied at positions with different thicknesses. A patchwork structure was also assumed in the center pillar reinforcement part of the hot-stamped structure. Although the sheet thickness configuration was the same as in the three-part structure, the total weight was lighter, being 29.6 kg/piece.

The following sections describe the evaluation results of small overlap frontal crash, pole side impact and moving deformable barrier (MDB) side impact using finite element method (FEM) analysis. The crash analysis solver used here was LS-DYNA R9.2.0 (ANSYS, Inc.).

3.1.1 Small Overlap Frontal Crash

The analysis model of small overlap frontal crash is shown in Fig. 6. The vehicle was crashed into a rigid wall at a vehicle speed of 64.4 km/h. Based on these conditions, the response of the auto bodies having the three types of door ring structures shown in section 3.1 were compared using load-stroke diagram. The results are shown in Fig. 7. Comparing the loads at strokes of around 1 000 mm to 1 200 mm, where the contribution of the door ring is large, the loads of the conventional structure and three-part structure were almost the same, while the hot-stamped structure showed a 10.3% lower value.

3.1.2 Pole Side Impact

The analysis model for pole side impact is shown in Fig. 8. The vehicle was crashed into a rigid pole with a diameter of 254 mm at an approach angle of 75° and a

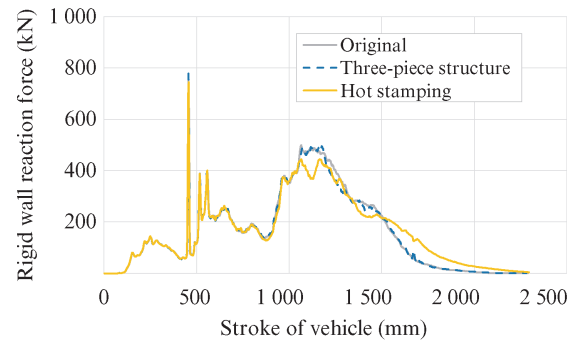


Fig. 7 Load-Stroke diagram of small overlap front crash

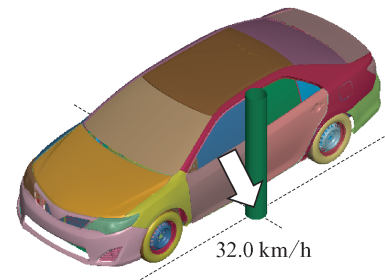


Fig. 8 Pole side-impact analysis model

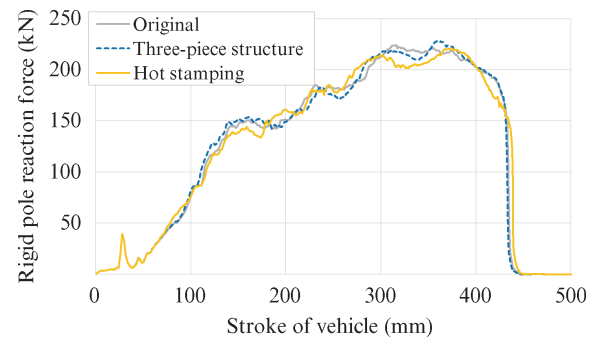


Fig. 9 Load-Stroke diagram of pole side-impact

vehicle speed of 32.0 km/h. Based on these conditions, the response of the auto bodies having the three types of door ring structures in section 3.1 were compared using load-stroke diagram. Load was defined as the reaction force of the pole, and stroke was defined as the amount of movement of a point on the side sill on the opposite side, where deformation did not occur. The results are shown in Fig. 9. Comparing the loads at a stroke of around 350 mm to 400 mm, where the contribution of the door ring is large, the loads of the conventional structure and three-part structure were similar, while the hot-stamped structure showed an approximately 3.0% lower value.

3.1.3 MDB Side Impact

The analysis model of MDB side impact is shown in Fig. 10. A crash cart, representing the front of another vehicle, was crashed into the stationary test vehicle from the side at a speed of 55.0 km/h. Based on

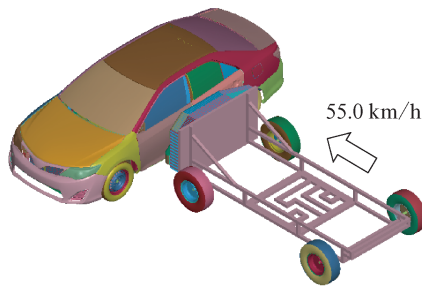


Fig. 10 MDB side-impact analysis model

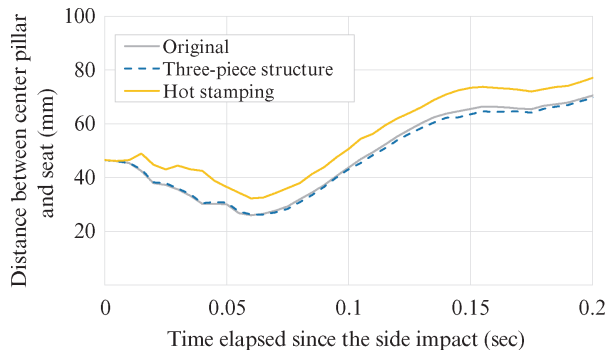


Fig. 11 Distance between center pillar and seat in side impact

these conditions, the response of auto bodies having the three types of door ring structures in section 3.1 were compared based on the change over time in the distance between the center pillar and the driver's seat. The results are shown in **Fig. 11**. Although the results of the conventional structure and three-part structure were substantially the same, the intrusion amount with the hot-stamped structure was approximately 12 mm smaller, indicating superior performance. This difference is attributed to the higher strength of the fully-integrated hot-stamped structure, which had a uniform material strength of 1 500 MPa. This higher strength was directly reflected in the results, as the material thickness configuration was the same as in the other structures.

3.1.4 Superiority of Cold-Stamped Three-Part Structure

As noted above, the hot-stamped structure displayed superior performance in the MDB side impact analysis because its higher material strength directly affected crash performance. However, in the small overlap frontal crash and pole side impact, the performance of the conventional structure and the three-part structure was superior in spite of their lower material strength configurations. One reason for this is thought to be the difference in deformation state of the lower part of the center pillar. **Figure 12** shows a comparison of the deformation state of the lower center pillar at a stroke

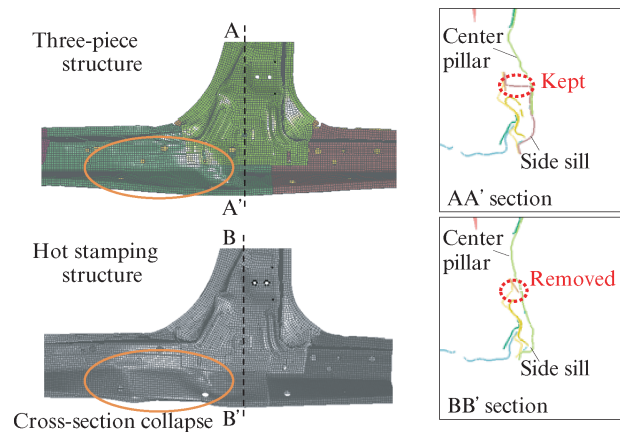


Fig. 12 Deformation of lower center pillar in pole side-impact

of 250 mm in pole side impact, as seen from the side of the vehicle body. The figure also shows the AA' cross section at this time. As is clear in the side view, in the hot-stamped structure, large deformation occurred in the bottom part of the side sill at the lower left in this figure. This is one factor in the load decrease. However, the presence or absence of the upper surface of the side sill and the ridge line connecting the upper surface and side surface in the AA' and BB' cross sections is thought to be a reason for the difference in the deformation state. These parts do not exist in the hot-stamped structure because side sill and center pillar are integrated. A figure showing the deformation state in the small overlap frontal crash is omitted here. However, as in pole side impact, these parts also play a crucial role in a small overlap frontal crash. Since a cost merit can be expected by part integration by cold stamping, even in small-scale part integration, the designer can intentionally choose not to integrate parts that have an important crash performance function, and can easily treat such parts as separate design elements.

3.2 Part Integration of Rear Member Module

The rear member module, like the door ring outer, is considered to be a target of study as an integrated structure by hot stamping by multiple automakers and parts manufacturers. JFE Steel proposed two types of structures which are suitable for part integration by cold stamping. First, the targeted rear member module, which consists of 11 parts, is shown in **Fig. 13**. The notation in this figure is the same as that used with the door ring outer in section 3.1. The rear member module is a component which has the role of protecting the vehicle from rear impact. Focusing on the side members of the module, since the vehicle front side of the module is a nondeforming part, thick sheets are used, including in the reinforcement members, to secure high strength in this part. In contrast, the vehicle rear side is

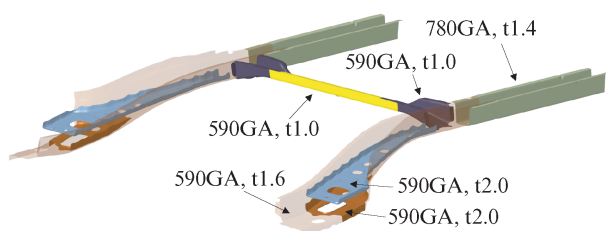


Fig. 13 Conventional rear member module structure

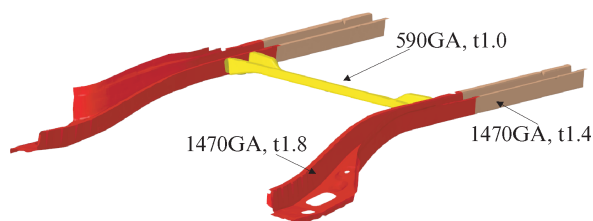


Fig. 14 1470 TWB structure

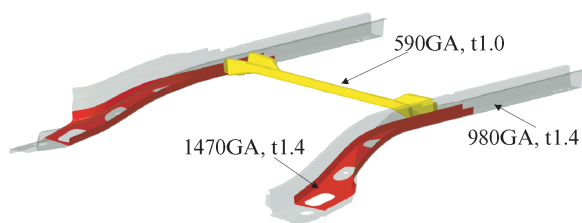


Fig. 15 Patchwork structure

designed to be an energy-absorbing part, so its strength is relatively low. The total weight of the rear member module was 14.8 kg. In the following, this structure is referred to as a “conventional structure.” Next, the two types of developed structures proposed by JFE Steel will be described. Both of the proposed structures comprise a total of three parts, that is, the right and left pair of side members and one cross member connecting them. In the conventional structure, the cross member part consists of three parts with a uniform strength of 590 MPa and thickness of 1.0 mm, including the connections with the side members, and is integrated into one part with the same strength and thickness. However, the two developed structures differ in the design of the side members. While both structures use integrated side members, two different designs were developed to create a difference in the strength of the vehicle front and rear sections of the side members. Specifically, in the structure shown in **Fig. 14**, the side members consist of 1 470 MPa grade steel sheets, and a difference in the sheet thickness of the vehicle front and rear sections is provided by TWB. This structure is called the 1470TWB structure, and its total weight, including the cross member, was 11.5 kg. In the second developed structure, shown in **Fig. 15**, the “cold patchwork method” was applied, in which the part was inte-

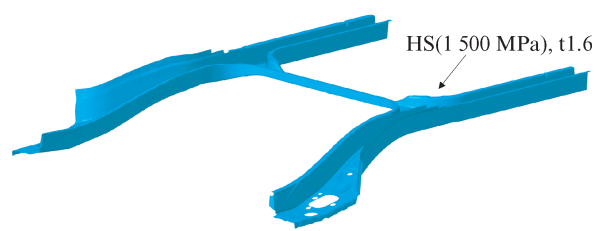


Fig. 16 Hot stamping structure

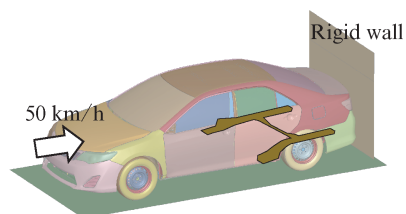


Fig. 17 Full vehicle model for component integration study

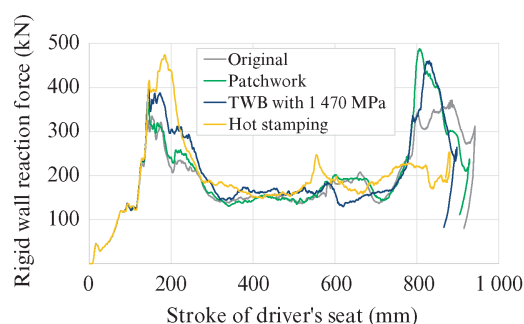


Fig. 18 Rear impact analysis model

grated by spot welding the reinforcements of the front section of the side members in the blank stage. This structure is called the “cold patchwork structure” (or simply “patchwork structure”), and its total weight was 12.3 kg. For comparison, **Fig. 16** shows a one-piece hot-stamped structure. In this structure, the geometry of the connections with the cross member is different from that in the other structures. The strength of the material was a uniform 1 500 MPa, and the sheet thickness was also uniform, at 1.6 mm, so that the weight would be roughly equivalent to that of the 1470TWB structure. The weight of the hot-stamped structure was 11.3 kg.

3.2.1 Rear Impact Performance of Rear Member Module

The rear impact performance of auto bodies with the various rear module structures described in the previous section was compared by an FEM analysis. The rear impact model is shown in **Fig. 17**. The vehicle body was crashed into a rigid wall while moving backward at 50 km/h. As the analysis results, the load-stroke diagrams are shown in **Fig. 18**. Here, stroke is

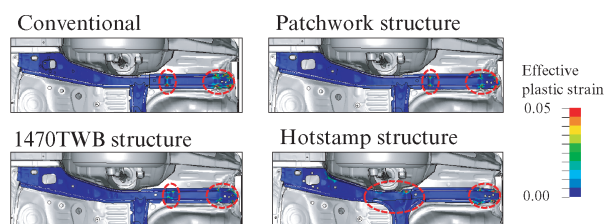


Fig. 19 Comparison of rear member module deformation during rear impact

defined as the movement of the driver's seat, and load is the reaction force of the rigid wall. In comparison with the conventional structure, the total strokes of all the other structures were smaller, indicating superior rear impact performance. Although the weights of the two developed structures and the hot-stamped structure were all lighter than the weight of the conventional structure, this result was influenced by the use of Ultra-HyTensile steel. Furthermore, in both of the developed structures, the load increased at strokes of approximately 100 mm to 200 mm and 800 mm to 900 mm. However, this load increase in the latter part of the stroke did not occur with the hot-stamped structure. This is considered to be due to the significantly larger maximum load in the 100–200 mm region compared to the other structures. Next, Fig. 19 shows the condition of deformation around the stroke of 200 mm as a contour diagram. In the conventional structure and the two developed structures, deformation occurred in the rear part of the rear side members, but in the hot-stamped structure, deformation occurred in the cross member connections near the rear wheels. However, deformation of parts near the cabin before deformation of the rear section is completed is undesirable. The fact that the hot-stamped structure deformed in this manner is considered to be caused by the omission of the side walls and ridge line near the connections between the side members and the cross member. While it is necessary to avoid early deformation of this part by addition of reinforcements, etc., the possibility of further cost increases as a result of this measure is a concern.

The FEM analysis in this study did not consider material fracture, but in actual situations, fracture can cause a decrease in the energy-absorbing performance of the component. However, it may be possible to avoid material fracture by applying high tensile strength steel⁴⁾ with high ductility and a high hole-expanding ratio to the rear section of the side members. From this viewpoint, easy arrangement of the most suitable materials for each part, and a wide range of options in material selection, are also considered to be significant advantages of the developed structure using cold stamping.

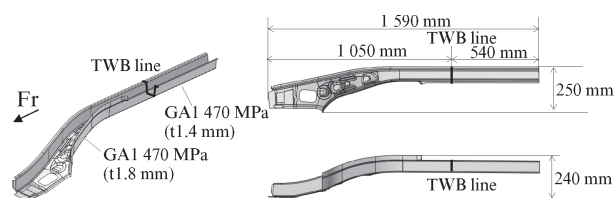


Fig. 20 Side member of 1470 TWB structure

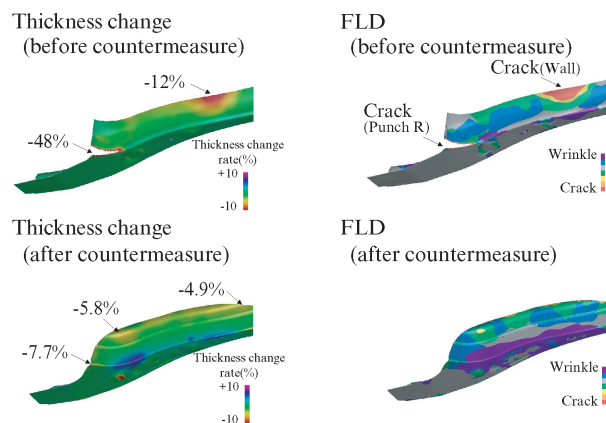


Fig. 21 Comparison of thickness reduction rate and FLD judgment before and after countermeasures

3.2.2 Issues in Forming of 1 470 MPa Steel Sheet TWB Structure and Countermeasures

As shown in Fig. 20, the side members of the 1470TWB structure have a one-piece structure welded by TWB, in which GA1470 MPa material (t1.8 mm) was applied in the front section of the vehicle, and GA1470 MPa material (t1.4 mm) was applied in the rear section of the vehicle. As the part geometry, the parts are 1 590 mm in length, 250 mm in width and 240 mm in height, and are curved in the top view and the side view. Press forming of 1 470 MPa grade steel sheets has an extremely high degree of difficulty, and is prone to numerous problems, including cracking, buckling wrinkles and poor dimensions due to springback. However, these problems were solved by applying various press forming method for Ultra-High strength steel developed by JFE steel. Here, Fig. 21 shows the results of cracking countermeasures. Before the countermeasures, a prediction indicated that fatal cracking would occur at a thickness reduction ratio of 48%. To address this concern, the sheet thickness reduction was substantially reduced by a method that controls material flow direction during press forming and other countermeasures such as optimization of the blank geometry, etc. The results after these countermeasures showed that press forming would be possible without problems, even when cracking was judged by the forming limit

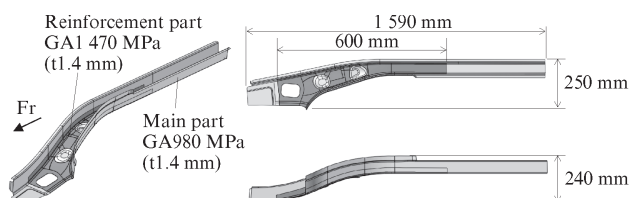


Fig. 22 Side member of patchwork structure



Fig. 23 Weld nugget fracture during press forming

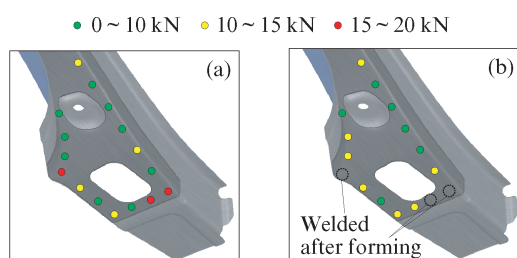


Fig. 24 Maximum shear load at welding spots during 1st and 2nd forming; (a) all welding spots, (b) selected welding spots

diagram (FLD).

3.2.3 Issues in Forming of Patchwork Structure and Countermeasures

In the cold patchwork structure, as shown in Fig. 22, a 980 MPa grade GA steel sheet with a thickness of 1.4 mm is applied in the side members, and reinforcement parts consisting of a 1 470 MPa grade GA steel sheet with a sheet thickness of 1.4 mm are overlapped at a position corresponding to the nondeforming part of the structure. The external geometry is the same as the side members with the 1470TWB structure. Although the patchwork structure also has various forming-related issues, the following describes a countermeasure for nugget fracture of spot-welding points.

As noted above, the patchwork method is a method in which blanks consisting of two overlapped sheets are spot-welded in advance and are then press-formed. However, press forming causes a shift in the positions (relative displacement) of the two blanks, as illustrated in Fig. 23, and the resulting shear deformation can cause nugget fracture at the weld spots. Figure 24 shows the maximum shear load subjected by each welding spot during forming. At the welds located near the bend ridge line and at the edge, the relative displacement between the two blanks became large, resulting in

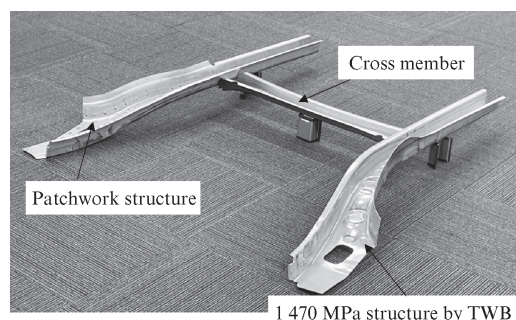


Photo 1 Prototype of rear member module using cold stamping

excessive shear loads. From the results of tensile tests of welded specimens conducted in the past, the threshold of the shear load where nugget fracture occurs was set at 15 kN, and there was judged to be a risk of fracture at welding spots that exceeded this threshold. When welding of spots where there is a risk of fracture is omitted before forming, the results showed that the shear load of welding spots near the omitted spots will increase, but since the maximum load does not exceed 15 kN, it was judged that fracture will not occur. In this approach, the omitted welding spots are spot welded after forming. This countermeasure eliminated the risk of weld nugget fracture in spot welds.

3.2.4 Results of Part Prototyping of Rear Member Module

Part prototyping by cold stamping was carried out using the two types of rear side member structures and forming method described above. In both cases, a two-step cold stamping process was used. In the cross members, three parts were integrated, including the connections with the rear side members, and were then fabricated by a two-step cold stamping process, as in the case of the rear side members. A photograph of the prototype part is shown in Photo 1. All parts could be formed without cracking and wrinkling, which are problems in actual production, and dimensional accuracy was also satisfactory, as no section opening or twisting was observed because springback countermeasures were taken to control stress.

4. Conclusion

This paper introduced a study of part integration at JFE Steel using Ultra-HyTensile steel sheets and cold stamping.

Since part integration by gigacasting or hot stamping raises various concerns and requires a large capital investment, many manufacturers have adopted a cautious stance toward introduction. On the other hand, since part integration by cold stamping can be applied

using the existing equipment, except when it is necessary to address some forming problems, such as an increased forming load, etc. This means that the barriers to introduction are significantly lower, and cost benefit can be obtained more easily.

To achieve part integration by cold stamping, the development of suitable materials is naturally necessary, and further deepening of steel sheet application technologies, namely, press-forming technology and welding technology, is required. JFE Steel will continue to develop those elemental technologies, and study the application of elemental technologies such as the development of the door ring outer and development of the rear side member module introduced in this paper, in order to contribute to cost reduction and quality

improvement in auto body manufacturing.

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