Technical Report

Development of Integrated Forming Technology for Automotive Body Structural Components Using Cold Press Forming of Ultra-high Strength Steel Sheets

Nobuo YOSHIKAWA*
Takashi MIYAGI
Toshimitsu ASO
Minoru SUGAWARA
Yasuharu TANAKA
Misao OGAWA
Junki NATORI

Abstract

In automotive body structure, there is a demand for weight reduction, cost reduction, and reduction of GHG emissions while ensuring various performances. Recently, one of the means to meet these requirements is the advancement of component integration. Nippon Steel Corporation is developing ultra-high-strength steel sheets with various strength characteristics and deformation capabilities, along with utilization technologies (structural design, forming methods, etc.) that make use of these properties. This report outlines the development of automotive body structural component integration forming technology using cold press with ultra-high-strength steel sheets, specifically focusing on "In-plane-shear draw-bending (NSafe™-FORM-SS)", "In-plane-shear free-bending (NSafe™-FORM-LT)" and their applications.

1. Introduction

1.1 Background: demands on automobiles

To achieve carbon neutrality by 2050, it is essential to reduce greenhouse gas emissions throughout the entire vehicle lifecycle (life cycle greenhouse gases: LC-GHG). In the automotive sector, the adoption of battery electric vehicles (BEVs), which emit minimal GHG during operation, has accelerated rapidly in recent years.[1] However, the batteries installed in BEVs weigh several hundred kilograms, significantly increasing total vehicle weight. Consequently, body structures must meet higher collision-performance requirements than ever before. In addition, the high manufacturing costs of batteries contribute to an overall increase in vehicle prices. Therefore, automotive bodies must improve collision performance while simultaneously reducing costs. Moreover, declining labor availability—driven by a low birthrate, an aging population, and changing career preferences—has created a growing need for labor-saving technologies in the automotive industry. To address these issues, some automakers, particularly emerging manufacturers, have recently adopted gigacast components made from aluminum alloys. These components integrate multiple platform parts, such as the front and rear under-body modules, into a single large casting. However, manufacturing gigacast components requires the installation of new large-scale equipment. Furthermore, because many parts are consolidated into one component, several challenges arise, including reduced repairability in minor collisions and limited suitability for multi-model production. As a countermeasure to these challenges, it may be feasible to form a single component that integrates multiple small- to medium-sized parts from high-strength steel sheets using existing press-forming production lines. With this perspective in mind, Nippon Steel Corporation developed technologies to integrate multiple small- and medium-sized parts.

This report outlines technologies for cold-press forming of integrated small- and medium-sized components using ultra-high-strength steel sheets.

1.2 Overview of parts integration technology

Nippon Steel proposes a comprehensive solution, NSafe™-Auto Concept, to address various automotive requirements. As shown in

* Senior Manager, Quality Management Div., Nagoya Works
5-3 Tokaimachi, Tokai City, Aichi Pref. 476-8686

Fig. 1, this concept consists of four pillars: new material development, structural optimization, new production technology, and functional evaluation.

The core materials used in NSafe™-AutoConcept are shown in **Table 1**. Dual-phase (DP) and transformation-induced plasticity (TRIP) steels have been developed as highly formable cold-rolled and cold-rolled galvanized steel sheets. Cold-rolled steel sheets with tensile strengths up to 1 470 MPa and cold-rolled galvanized steel sheets with strengths up to 1 180 MPa are already being applied to vehicle body structural components, and research and development on even higher-strength sheets is currently underway. In addition, steel sheets with excellent energy-absorption (EA) performance during collisions have been developed as high-performance products in cold-rolled and cold-rolled galvanized steel sheets, with grades of up to 980 MPa already in practical use. Furthermore, steel sheets for hot stamping, covering a wide strength range from 0.5 to 2.0 GPa, are either in mass production or have completed development. Thus, Nippon Steel offers products with various strength levels and functionalities to meet the diverse requirements of automotive bodies.

The new production technologies within NSafe™-AutoConcept enable proposals for component integration at various scales, from small-scale to large-scale assemblies. Methods for achieving small- to medium-scale integration include tailor-welded blank (TWB) technology, which integrates adjacent parts, and patchwork technology,[2] which integrates overlapping parts. The reduction of reinforcement parts through substitution with high-strength steel sheets can also be regarded as a form of integration. Furthermore, large-scale integration utilizes hot-stamping technology. Target components include door rings, which have been in practical use since the 2010s, and rear modules, which were proposed around 2020.

As described above, NSafe™-AutoConcept proposes various steel grades and integrated forming technologies. By combining these, it becomes possible to realize integrated structures that consider component functions while addressing challenges such as weight reduction, component cost reduction, and GHG emission reduction.

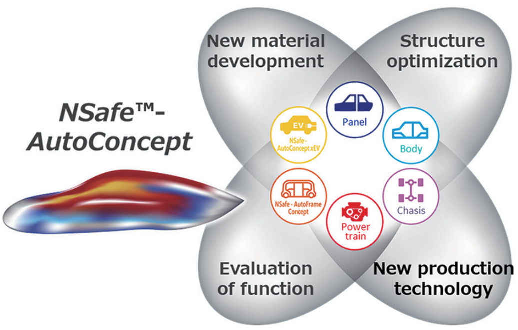

Fig. 1 Nippon Steel's total solution for automobiles

Table 1 Nippon Steel's material lineup

		Type	Tensile Strength (TS) Grade [MPa] 980	1180	1310	1470	1760	2000
Cold rolled	Uncoated	Dual Phase, Multi Phase	●	●	●	●		
		TRIP	●	●				
		High Crash Energy Absorption	●					
	Coated (GA)	Dual Phase, Multi Phase	●	●				
		TRIP	●	●				
		High Crash Energy Absorption	●					
For Hot Stamping		Uncoated				(●)	(●)	(●)
		Coated (Al–Si)	(○)		(●)	(●)	(●)	(●)
		Coated (Zn)	(○)		(○)	(●)		(●)

●: In mass production, ○: Developed, ( ): After hot stamping

This report first introduces cold-press forming methods for ultra-high-strength steel sheets used to integrate multiple components. Next, examples of integrated structures—designed by appropriately positioning high-strength steel sheets according to the functional requirements of automotive body parts—are presented. For elemental technologies related to hot stamping, please refer to the immediately preceding report (No. 6).

2. Forming Technologies for Component Integration

2.1 Challenges in production of integrated components using ultra-high strength steel sheets

This section describes cold-press forming methods for manufacturing integrated components using ultra-high-strength steel sheets.

In recent years, automotive body structural parts have increasingly adopted ultra-high-strength steel sheets, not only in the 980–1 180 MPa range but also up to 1 470 MPa. However, as steel sheet strength increases, ductility generally decreases, making cracks and wrinkles during press forming a persistent challenge. Furthermore, components that integrate multiple parts into a single unit tend to have more complex shapes, which increases forming difficulty. Therefore, to achieve integrated components using ultra-high-strength steel sheets, forming techniques distinct from conventional methods are required. Nippon Steel has developed new forming methods—"In-plane-shear draw-bending (NSafe™-FORM-SS)"[3, 4] and "In-plane-shear free-bending (NSafe™-FORM-LT)"[4, 5]—, which actively utilize in-plane shear deformation of steel sheets. The following sections outline these forming methods.

2.2 In-plane-shear draw-bending (NSafe™-FORM-SS)

When forming a curved hat shape by drawing, as shown in **Fig. 2**(a), the material flows perpendicular to the holder surface. This causes the material to stretch longitudinally, leading to fracture at the top surface of the convex curvature, while compression at the top surface of the concave curvature results in wrinkling. To achieve successful forming, the material must instead flow parallel to the forming direction, as illustrated in Fig. 2(b). To realize this, we developed the cold-press forming method "In-plane-shear draw-bending (NSafe™-FORM-SS)". In this method, a die set with the configuration shown in **Fig. 3** is used. Material displacement in the top section is restricted by pressing the sheet with a pad, thereby suppressing both elongation and compression. This enables the curved hat shape to be formed by inducing pure in-plane shear deformation in the vertical-wall section. Furthermore, to suppress wrinkles caused by compression along the direction of minimum principal shear strain (shear wrinkles), it is necessary to form the vertical wall at a perpendicular angle and eliminate the clearance between the dies and the steel sheet during forming. This suppresses out-of-plane deformation of the sheet.

Figure 4 shows a prototype of an integrated front-side member rear manufactured from a 1 470 MPa-grade steel sheet formed by in-plane-shear draw-bending. Achieving high strength in curved hat-shaped components with complex geometries enable the reduction of reinforcement parts placed in curved sections to prevent buckling during crash deformation. Consequently, component integration becomes possible.

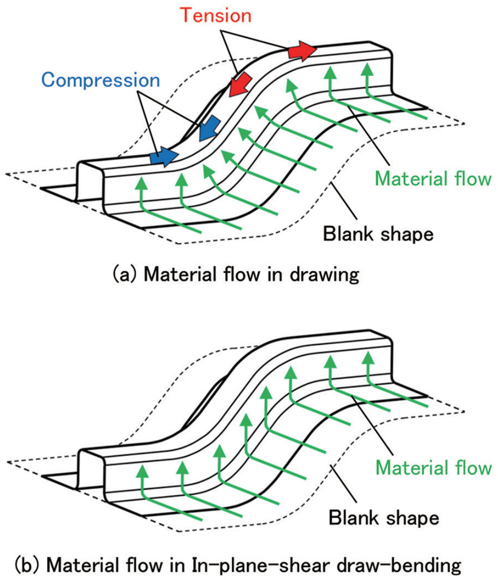

Fig. 2 Material flow in drawing and In-plane-shear draw-bending[4)]

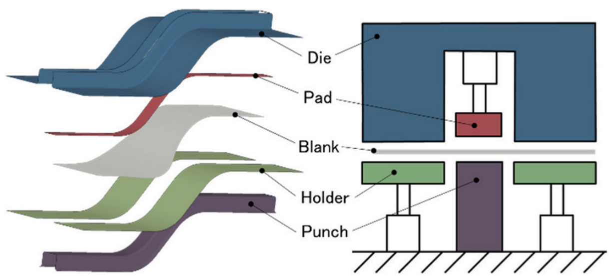

Fig. 3 Die construction in In-plane-shear draw-bending[4)]

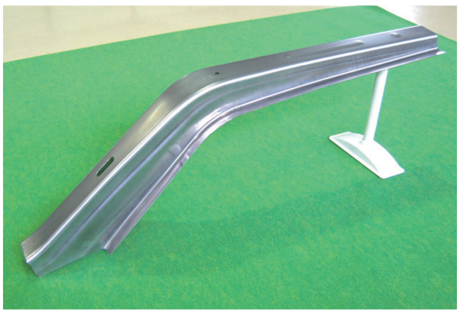

Fig. 4 Prototype of front side member rear[4)]

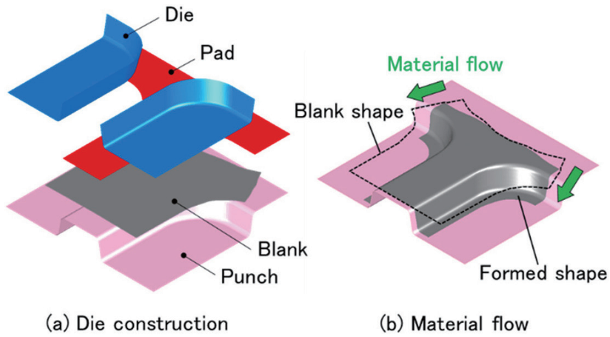

Fig. 5 Die construction and material flow in In-plane-shear free-bending[4)]

Fig. 6 Prototype of center pillar

2.3 In-plane-shear free-bending (NSafe™-FORM-LT)

When drawing a steel sheet into an L- or T-shaped configuration with a curved vertical wall and flange, significant wrinkling occurs near the curved section on the top surface, and large plane-strain deformation arises in the vertical wall, leading to fracture. These defects result from differences in material flow depending on the position within the formed shape. To form parts with such complex geometries, we developed the cold-press forming method In-plane-shear free-bending (NSafe™-FORM-LT)".

Figure 5 (a) shows the die set configuration for this method. Unlike conventional drawing using a blank holder, this forming method is based on bending, which reduces tension during forming and prevents breakage. Wrinkling is further suppressed by pressing the top surface with a pad from the initial stage of bending. As shown in Fig. 5 (b), material from the top surface flows into the curved section during forming, allowing the vertical wall to be shaped with reduced material elongation and suppressing fracture in the vertical wall.

Figure 6 shows a prototype center pillar with an integrated upper and lower section formed using in-plane-shear free-bending from a 1 470 MPa-grade steel sheet. Conventionally, the upper section of a center pillar uses steel sheets with strength grades of 980–1 180 MPa, while the lower section uses sheets with strength grades of 440–590 MPa. However, this method enables the formation of an integrated center pillar in which both the upper and lower sections are produced from higher-strength 1 470 MPa-grade steel sheets.

3. Development of Forming Technology for Integrated Rear Side Members

3.1 Development concept

This section describes an example of an integrated component in which high-strength steel sheets are optimally positioned according to the functional requirements of the vehicle body structure. The example focuses on a component formed by in-plane-shear free-bending, in which the front and rear sections of the rear side member are integrated into a single unit.

Figure 7 shows the component shapes. The front section uses 1 470 MPa-grade steel sheets, which are effective in suppressing deformation, whereas the rear section uses 980 MPa-grade EA steel sheets to ensure sufficient energy absorption during rear collisions. Forming the component from a TWB blank by joining these ultra-high-strength steel sheets enables component integration, achieving both weight reduction and a reduction in the number of parts.

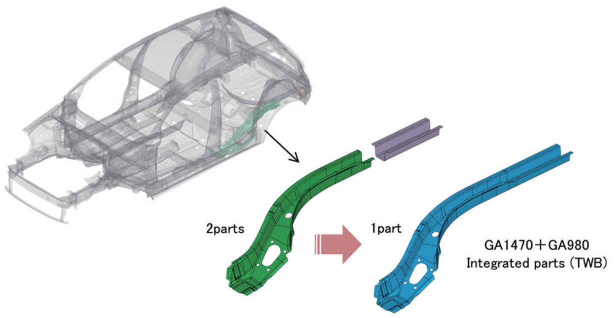

Fig. 7 Integrated rear side member

3.2 Study of forming method by FEM analysis

The forming methods for this component were evaluated using FEM analysis. The dynamic explicit solver LS-DYNA (R7.1.2) was used for the analysis. A shell element was employed, with an element size of 2 mm, seven integration points through the thickness, and a Coulomb friction coefficient of 0.1. Because fracture and buckling are primary concerns in the front section of the component under study, the analyses were conducted only for that section. A steel sheet with a tensile strength of 1470 MPa was used as the material.

First, an FEM analysis of the bending-based forming process shown in **Fig. 8** was conducted to investigate the forming challenges. The first and second processes involve bending using pads, while the third process involves stamping. Trimming was performed between the first and second processes, between the second and third processes, and again after the third process. **Figure 9** shows the distribution of thickness-reduction rates after final trimming. A thickness reduction rate exceeding 10% occurred at the edge of the stretch flange, indicating that satisfactory forming was difficult to achieve with this process.

Next, an FEM analysis was conducted on the forming process using in-plane-shear free-bending, and the reduction in the thickness-reduction rate at the extension flange was evaluated. **Figure 10** shows the forming process using in-plane-shear free-bending. The only difference between this process and the bending-based forming process shown in Fig. 8 is the application of in-plane-shear draw-bending in the former. **Figure 11** shows the distribution of thickness-reduction rates after the final trimming. By incorporating a material-flow–promoting bead in the first process and using the free-bending method to enhance material flow from the top surface to the curved section, the maximum thickness-reduction rate in the stretch flange decreased to 4.8%. These results confirm that an integrated rear-side member can be successfully formed using a 1470 MPa-grade steel sheet.

3.3 Verification of development forming method by trial production

In the previous section, FEM analysis confirmed that an integrated rear-side member made from a 1470 MPa-grade steel sheet could be successfully formed using the developed forming method. Therefore, trial production of the component was conducted using the aforementioned press-forming process to verify the method experimentally. **Figure 12** shows a photograph of the trial product. As predicted by the FEM analysis, the prototype was successfully formed without fracture or significant wrinkling. This confirms that in-plane-shear free-bending enables the formation of an integrated rear-side member using ultra-high-strength steel sheets.

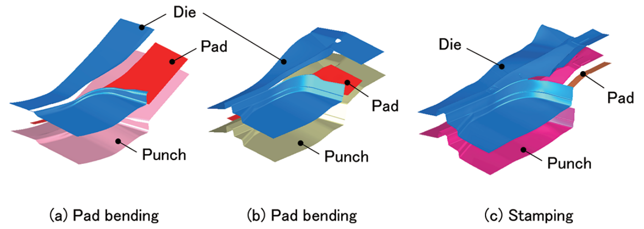

Fig. 8 Forming process mainly focused on bending

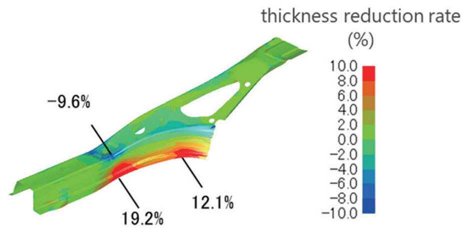

Fig. 9 Thickness reduction rate in FEM analysis

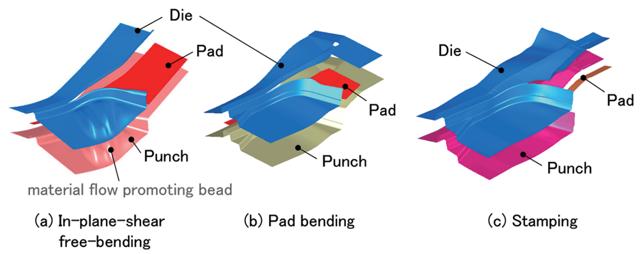

Fig. 10 Forming process mainly focused on In-plane-shear free-bending

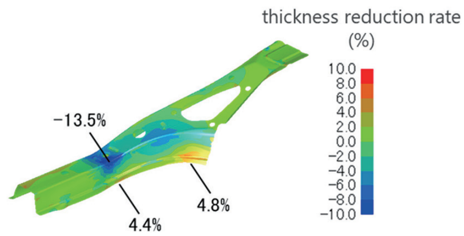

Fig. 11 Thickness reduction rate in FEM analysis

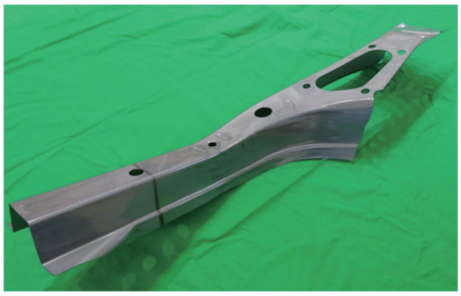

Fig. 12 Prototype integrated rear side member

4. Conclusion and Future Prospects

In-plane-shear draw-bending and in-plane-shear free-bending were introduced as cold-press forming methods for ultra-high-strength steel sheets. In addition, trial production of an integrated rear-side member using these ultra-high-strength steel sheets was successfully achieved using in-plane-shear free-bending. In the future, we plan to expand the application of the part-integration forming technologies introduced here to other components, while further advancing the development of new forming techniques. Through these efforts, we will contribute to achieving automotive weight reduction, manufacturing cost reduction, and lifecycle GHG emission reduction at a high level.

References

1) Kubo, M., Iguchi, K., Hiwatashi, S.: 2022 JSAE Congress Proceedings (Autumn). 20225281 (2022)
2) Nippon Steel Corporation: News Release, https://www.nipponsteel.com/news/20220622_100.html (2022)
3) Tanaka, Y., Miyagi, T., Ogawa, M., Natori, J., Sugawara, M.: The Proceedings of the 69th Japanese Joint Conference for the Technology of Plasticity. 247–248 (2018)
4) Tanaka, Y., Ogawa, M., Nishimura, R., Ito, Y., Yonebayashi, T., Natori, J., Sugawara, M.: Bulletin of the Japan Society for Technology of Plasticity. 6 (72), 725–729 (2023)
5) Tanaka, Y., Miyagi, T., Ogawa, M., Natori, J., Sugawara, M.: Materials Transactions. 63 (1), 82–87 (2022)

Nobuo YOSHIKAWA
Senior Manager
Quality Management Div.
Nagoya Works
5-3 Tokaimachi, Tokai City, Aichi Pref. 476-8686

Yasuharu TANAKA
Dr. Eng., Chief Manager
Quality Management Div.
Nagoya Works

Takashi MIYAGI
Senior Manager
Quality Management Div.
Nagoya Works

Misao OGAWA
Senior Manager
Quality Management Div.
Nagoya Works

Toshimitsu ASO
Senior Manager
Quality Management Div.
Nagoya Works

Junki NATORI
Senior Manager
Chugoku Marketing Branch

Minoru SUGAWARA
Manager
Quality Management Div.
Nagoya Works