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Technical Review

Development of Next-generation Automobile Concept (NSafe™-AutoConcept ECO³) for Realizing a Carbon-neutral Society

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Abstract

The automotive industry is undergoing major changes, including the strengthening of environmental regulations, the spread of electric vehicles, changes in vehicle body structure, outsourcing of parts design and evaluation, and innovation in manufacturing technology. In response to these changes, Nippon Steel Corporation has developed a new concept, NSafe™-AutoConcept ECO³, aimed at realizing a carbon-neutral society. The new concept is centered on the concepts of ECOnomy–economic efficiency, ECOlogy–lightweight and environmentally friendly, and ECOSystem–optimal production system, and we will contribute to the realization of a carbon-neutral society together with our customers.

1. Introduction

The automotive industry is currently undergoing a once-in-a-century transformation. Governments worldwide are setting stringent CO_2 emission standards to achieve carbon neutrality. For example, the European Union (EU) has set a target to reduce CO_2 emissions from new vehicles by 55% by 2030, with even stricter emission standards introduced starting in 2024. Furthermore, there is a growing movement to evaluate and reduce environmental impact not only from CO_2 emitted during driving but across the entire lifecycle—from raw material sourcing through manufacturing, use, and disposal. Life Cycle Assessment (LCA), effective for quantifying the environmental impact of corporate activities, product manufacturing, and development technologies, is being applied to evaluate completed vehicles and inform product design.[1)]

Amidst this environment, the adoption of EVs is advancing globally. In 2023, EV sales increased by 35% year-on-year, reaching 13.6 million units. The proliferation of electric vehicles has significantly altered the required specifications for vehicle bodies, driving major transformations in automotive body structures. To address stricter collision regulations, increased weight from battery installation, and the need to prevent battery fires during collisions, further body weight reduction and strength enhancement are essential.[2–4)]

Electrification is also profoundly impacting automotive design, evaluation, and manufacturing innovation. Outsourcing and modularization are advancing in component design and evaluation, driving improvements in development efficiency, increased reusability, and cost reductions. By outsourcing component design and evaluation to specialized external firms, automakers can focus on their core technologies and enhance competitiveness.

In manufacturing technology, for example, Tesla's pioneering Gigacast—an innovative die-casting technique for forming large aluminum components as a single piece—has been adopted globally. Tesla leveraged this technology to integrate approximately 70 rear underbody components into a single Gigacast part, improving production efficiency.[5)] Manufacturing Gigacast parts requires the introduction of new large-scale equipment. Challenges have been pointed out, such as reduced repairability in minor collisions and unsuitability for multi-model production due to the consolidation of numerous parts into one component.[6)] However, prompted by these developments, automakers are increasingly re-examining the optimization of their body manufacturing processes.

As described above, the automotive industry is undergoing ma-

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jor transformations: stricter environmental regulations, the proliferation of electric vehicles, changes in body structure, outsourcing of part design and evaluation, and innovations in manufacturing technology. To address these changes, Nippon Steel Corporation has developed a new concept, NSafe™-AutoConcept ECO^3 (NSAC-ECO^3), aimed at realizing a carbon-neutral society. This new concept centers on three pillars: ECOnomy (economic efficiency), ECOlogy (lightweighting and environmental responsiveness), and ECOSystem (optimal production systems). Together with customers, it aims to contribute to realizing a carbon-neutral society. This report outlines the elemental technologies constituting this concept and introduces Nippon Steel's research and development initiatives for next-generation vehicles.

2. Enhancing the Performance of Automotive Battery Packs

In recent years, the adoption of battery electric vehicles (BEVs) has rapidly expanded in the automotive industry. Consequently, the development of low-cost, safe, and environmentally friendly battery packs has become an urgent priority. Steel offers cost advantages over other materials like aluminum and emits fewer greenhouse gases (GHG), making it an ideal material for battery packs. Utilizing Nippon Steel's broad material lineup of hot-stamped and cold-formed high-tensile steel enables the proposal of superior steel battery packs.

Examples of advanced high-tensile steel sheets to be utilized include hot stamping steel sheets with high strength and excellent formability, and collision energy-absorbing steel sheets (EA steel sheets) with high impact resistance and high hole-expansion properties. Applying these to battery pack components enables higher strength thin-walled parts and a reduction in reinforcement members. As one example, we developed two concepts for steel battery packs: a lightweight type and a high-capacity type, as shown in **Fig. 1**.

The lightweight type features a cross member made of 2.0GPa-grade hot-stamped steel sheets (2.0GPa-HS) within the battery pack. Leveraging the high strength and excellent formability of the hot-stamped steel sheet enables a high-strength cross member with notch-less flanges, promising improved rigidity and load-bearing capacity. This allows for the reduction of other components necessary for safety assurance, enabling battery pack weight reduction.

The high-capacity type concept increases battery pack volume by reducing components traditionally placed inside the pack. This is achieved by positioning a frame made of advanced high-tensile steel sheet (GA1470) on the battery pack's rear surface. The frame's high strength allows sufficient load-bearing capacity even with a smaller cross-section, enabling a structure that fits within the space on the battery pack's rear surface. This concept allows design considerations for safety to be focused on the rear surface of the battery pack, making it less susceptible to the influence of the internal battery layout and enabling flexible application.

Furthermore, as elemental technologies applicable to both concepts: –The electrocoating-free upper cover (**Fig. 2**) utilizes Super Dyma™, a corrosion-resistant coated steel sheet developed by Nippon Steel, eliminating the need for electrocoating and offering potential cost savings. –The small-radius corner tray (**Fig. 3**) achieves high volume through reduced ridge line dimensions. and a side frame with wave-shaped EA structure (**Fig. 4**) that ensures collision performance and rigidity through the use of advanced high-tensile steel sheets.[7,8] Additionally, an integrated module case capable of achieving high volume and high watertightness was developed.[9,10]

Material TS : 270 MPa Thickness : 0.8mm

Fig. 2 SuperDyma™ battery pack top cover prototype

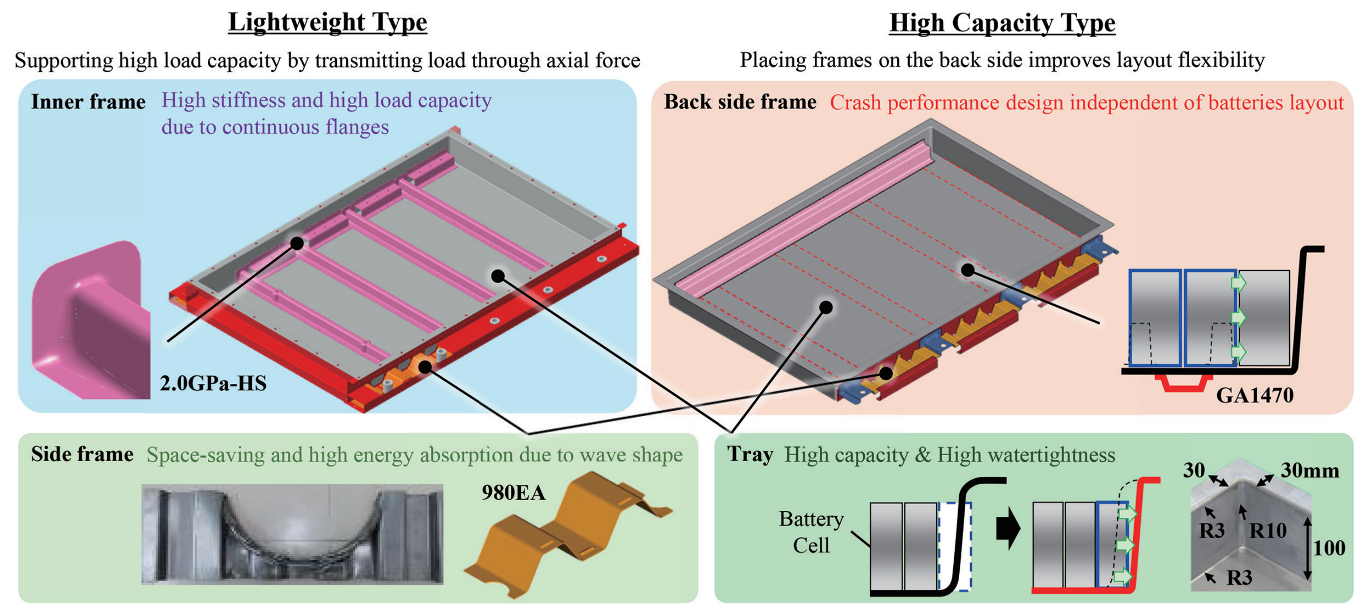


Fig. 1 Examples of Nippon Steel's battery pack case concept

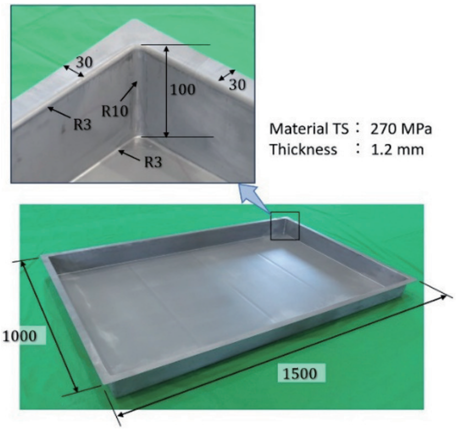


Fig. 3 High-capacity and high-watertightness tray prototype

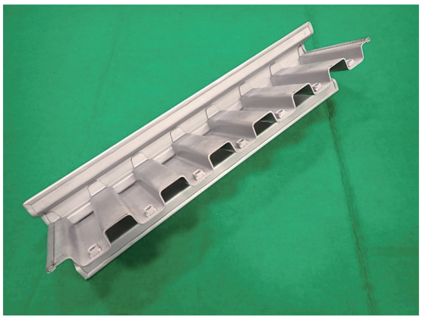


Fig. 4 Energy absorption member with wave structure

3. Elemental Technologies for Steel Component Integration

In addition to the progress of electrification driven by stricter environmental regulations, the rise in vehicle costs due to advanced features such as autonomous driving, and the demand for labor-saving measures resulting from population decline, body component integration technologies that help reduce total cost and the number of manufacturing processes are attracting attention.

Automotive components require varying strength characteristics and deformation capabilities depending on the specific body part. In response, Nippon Steel provides a broad lineup of steel grades for both hot-stamping steel sheets and cold-rolled high-tensile steel sheets. Moreover, we offer comprehensive solution technologies covering structural design, forming methods, and performance evaluation techniques to maximize the effective use of these steels in automotive applications. By leveraging these technologies, we have developed high-performance integration techniques ranging from small-to-medium-scale component integration to large-scale integration, capable of addressing diverse needs.

Hot stamping technology enables the elimination of reinforcement parts through material strengthening, the integration of reinforcement components by patchwork, and the reduction of press loads. Furthermore, these advances allow for large-scale component integration that shortens processes on the vehicle assembly line. In terms of material development, Nippon Steel has developed hot-stamping steel with a strength class of 2.0 GPa, as well as high energy-absorbing steel sheets with superior deformability and excellent crash performance. In addition, tailored welded blank technology has been developed to join these various steel sheets according to the requirements of each specific area. Comprehensive utilization of

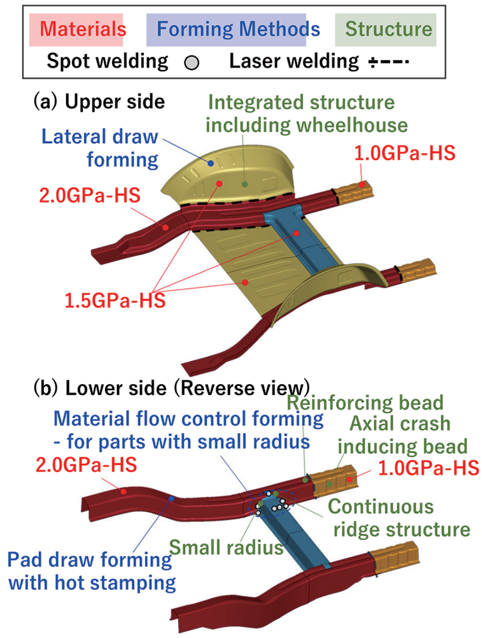


Fig. 5 Integrated rear under module concept with large-scale hot stamping

these technologies enables significant weight reduction and GHG emission reduction.[11–13] In addition, the following technologies have been developed: structural design technologies that enhance deformation performance during collisions; manufacturing technologies that expand the freedom of component integration, achieved through efforts to integrate the rear underbody module including the wheelhouse; and forming technologies that reduce the curvature radius at the joints of T-shaped integrated frame parts, thereby increasing design flexibility (**Fig. 5**).

Regarding cold-rolled steel sheets, we currently provide steel sheets with a wide strength range from 270 MPa to 1 470 MPa. Selecting the appropriate strength and thickness for each location from these steel sheets enables the realization of optimal structures from various perspectives—including cost, weight reduction, and GHG emissions—while utilizing existing production lines and equipment. In cold press forming of integrated components using ultra-high-strength steel sheets, forming failures such as cracks and wrinkles easily occur because material elongation decreases as steel strength increases and component shapes become more complex. As countermeasures, we have developed new cold press forming methods utilizing in-plane shear deformation: the "In-plane-shear draw-bending (NSafe™-FORM-SS)"[14] and the "In-plane-shear free-bending (NSafe™-FORM-LT)"[15]. Applying these new forming methods, we have established technologies for forming integrated rear side members (**Fig. 6**).

4. Solutions for Achieving High-Functionality in Chassis Components

With the electrification of automobiles, challenges include increased vehicle weight due to battery installation, rising vehicle costs, and stricter collision requirements for battery protection. Consequently, aluminum components are sometimes applied to chassis parts for weight reduction. However, compared to steel components, this not only increases part costs but also leads to higher GHG emissions.

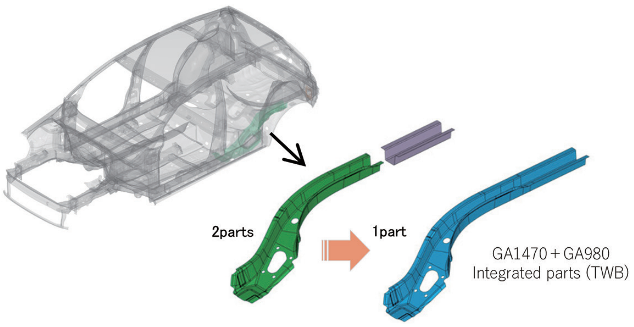


Fig. 6 Integrated rear side member

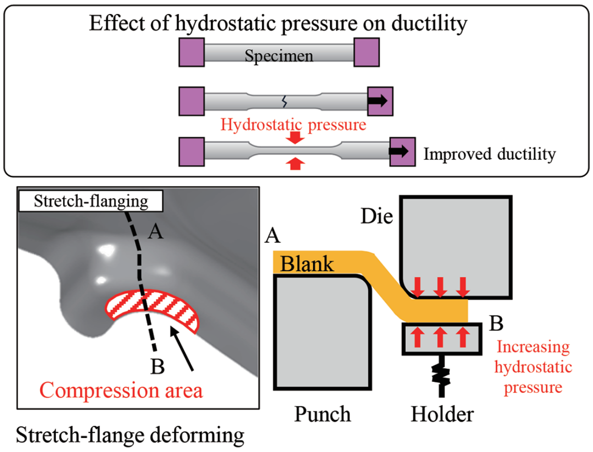


Fig. 7 Edge compression flanging method

To address these challenges, we explored proposals for various chassis components utilizing advanced steel materials.

The front lower arm, a representative chassis component, requires collision performance and thus has seen the most advanced application of high-strength steel plates among chassis parts. However, thinning the material poses challenges of reduced rigidity and fatigue durability, becoming a barrier to further weight reduction. As a countermeasure technology for these challenges, Nippon Steel's proprietary plate thickness compression process (**Fig. 7**) enhances the material's fracture limit. Concurrently, utilizing Nippon Steel's developed 980MPa-grade high-formability steel plate (980HF) enables unprecedented forming heights in curved sections. This increases component rigidity, allowing simultaneous thinning and high-strength enhancement (**Fig. 8**).

Furthermore, recent changes in vehicle body structures accompanying automotive electrification are progressing. Increased vehicle weight due to battery installation and the trend toward lower centers of gravity mean subframes are expected to function as load path members and energy absorption components during collisions. Additionally, changes in power unit configurations may necessitate different mounting methods for subframes. Considering the placement of motor mounts, a "U-shaped" subframe configuration with beams front, rear, left, and right to accommodate center-of-gravity mounting is anticipated to be necessary. Within this context, subframe structures extensively utilizing aluminum die-cast and extruded materials are observed in mass-produced EVs.[16)]

In response to these aluminum subframe structures, we developed a lightweight steel subframe that reduces "weight", "number of parts", and "weld length" while enabling efficient manufacturing

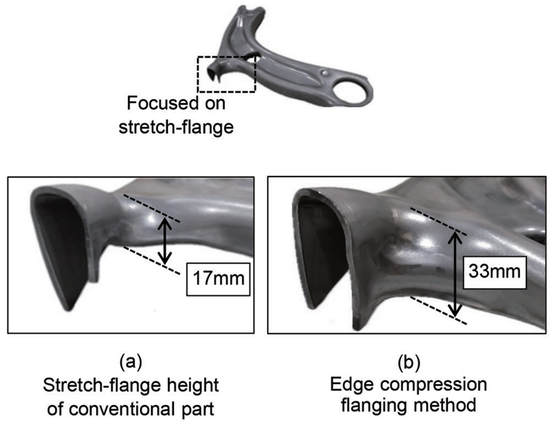
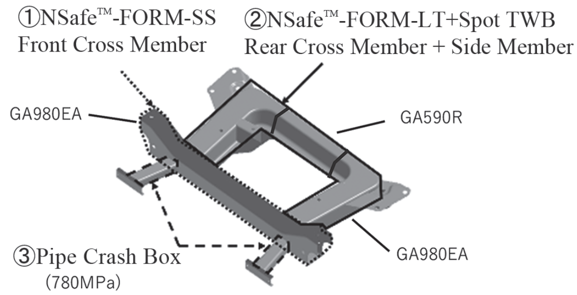


Fig. 8 Results of press forming test



	Aluminum front subframe	Steel front subframe (conventional)	Steel front subframe (developed)
Weight [kg]	16.3	20.3	16.3
Number of parts	25	35	17
Welding length [mm]	6828	9636	8572

(Estimated in case of front axle load 930 kg)

Fig. 9 Developed front subframe

(**Fig. 9**).

This subframe utilizes Nippon Steel's proprietary forming methods, such as NSafe™-FORM-SS[14)] and NSafe™-FORM-LT[15)], to improve forming limits. This enables the use of high-strength steel sheets like GA980EA while integrating multiple components, such as brackets, into a single part. Furthermore, the adoption of a pipe-type crash box reduces the number of parts and enables a lightweight structure with high production efficiency.

5. Model-Based Development Technology to Enhance the Performance of Steels for Automobiles

Electrification has a significant impact on automotive design and evaluation. Component design and validation are increasingly outsourced and modularized, resulting in higher requirements for development efficiency, reusability, and cost reduction. In this context, the importance of Model-Based Development (MBD) technologies is rapidly increasing within the automotive industry.[17)] MBD integrates design, simulation, and verification processes primarily through Computer-Aided Engineering (CAE) tools. Compared with conventional trial-and-error approaches that rely on iterative design and prototype testing, MBD enables more efficient workflows and higher design accuracy.

Nippon Steel has developed a stiffness evaluation technology

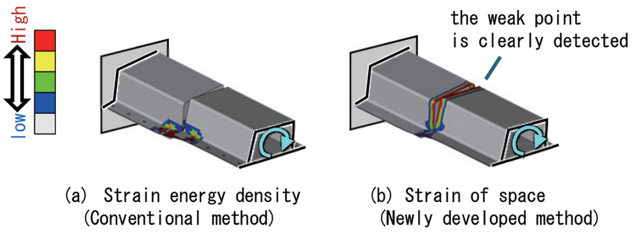


Fig. 10 Rigidity evaluation technology to identify weak points in vehicle body rigidity (NSafe™-SV)

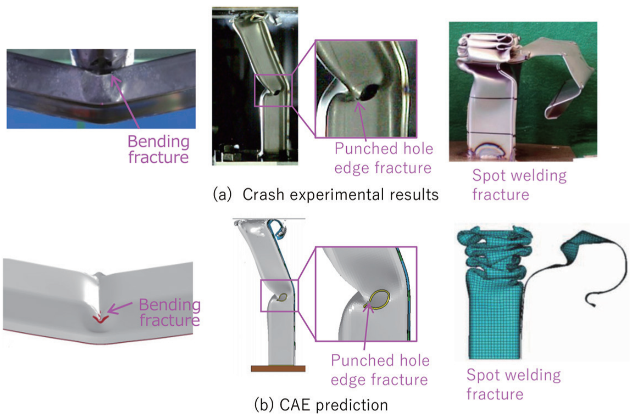


Fig. 11 Material and spot weld fracture prediction technology (NSafe™-MAT, NSafe™-SPOT)

(NSafe™-SV)[18] (**Fig. 10**) that employs numerical analysis to identify weaknesses in body stiffness, which are critical for improving vehicle handling stability and Noise and Vibration (NV) performance. This approach maximizes the mechanical properties of steel products to enhance automotive performance. Unlike conventional analysis methods using strain energy, NSafe™-SV provides clearer identification of regions exhibiting significant inter-component displacement. Additionally, Nippon Steel has developed technologies for predicting component deformation resistance during collisions and material/spot weld fracture (NSafe™-MAT, NSafe™-SPOT)[19] (**Fig. 11**). These technologies have been refined to achieve higher accuracy, enabling prediction of fracture initiation at holes in addition to bending and spot weld fractures. Furthermore, Nippon Steel has advanced several MBD technologies from the perspective of a steel manufacturer, such as technologies for predicting material forming limits and part geometry accuracy during press forming processes for automotive component,[20] and a high-precision spot welding FEM analysis system[21] based on coupled analysis of electric, thermal, and stress fields considering material phase transformation in steel sheet spot welding. These technologies provide effective support for technical challenges in automotive development.

6. Quantifying Environmental Performance of Steel Vehicle Bodies Using LCA

Traditionally, steel components have been regarded as heavier than those made from other lightweight materials. However, considering that steel materials impose a lower environmental load during manufacturing compared to other metals, the application of the solution technologies described above—particularly the use of advanced high-tensile steel sheet (AHSS) for substantial vehicle weight reduction—is expected to deliver superior environmental performance, including significant reductions in GHG emissions over the entire

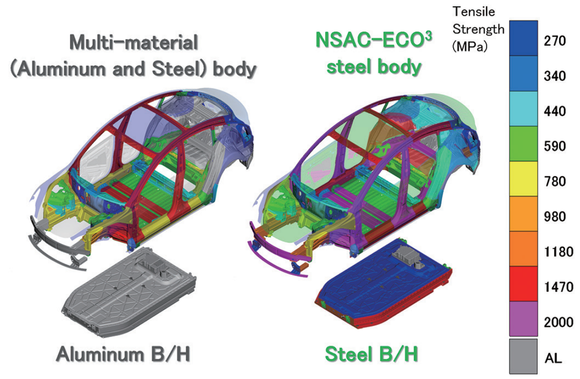


Fig. 12 Comparison of material distribution between multi-material body and NSAC-ECO^3 steel body

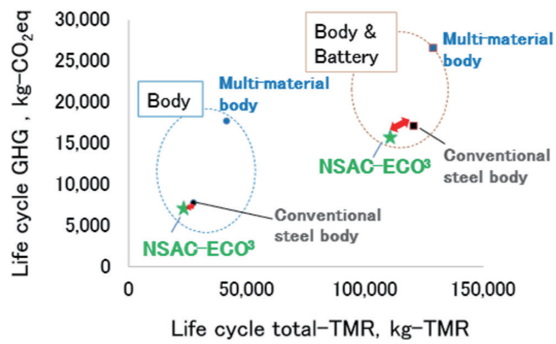


Fig. 13 Result of GHG emission and TMR of car body and battery

lifecycle.

Therefore, following the LCA evaluation methodology in ISO 14040/44 LCA methodology to quantify the GHG emissions and Total Material Resources (TMR) (the flow of natural resources including economic flows such as hidden flows like soil during mining)[22] for advanced steel bodies and components (**Fig. 12**). This quantified the environmental performance of automotive lightweighting solution technologies contributing to achieving a Carbon Neutral-Circular Economy (CN-CE). The results demonstrated advantages not only in GHG emissions but also from a resource perspective (**Fig. 13**). By integrating AHSS with accumulated expertise in sheet metal forming and related technologies, the NSAC-ECO^3 body was realized, achieving minimal environmental impact. This approach to automotive lightweighting using steel is expected to be the most effective means of simultaneously achieving a CN-CE objective.

7. Conclusion

This report introduced the various solution technologies comprising the structural/functional design, manufacturing method development, and performance evaluation that form the newly established NSAC-ECO^3 concept by Nippon Steel. This concept addresses the automotive industry's response to stricter environmental regulations, the rise of electric vehicles, and changes in vehicle body structures. It also introduced methods for evaluating the GHG emissions and TMR of steel vehicle bodies and components throughout their lifecycle when applying these technologies and the latest materials, and discussed their reduction effects.

Details of the various technologies introduced in this report are described in depth in the individual technical papers comprising this automotive special feature. We encourage readers to refer to them.

As described in this report, NSAC-ECO³ is a comprehensive proposal encompassing not only the latest steel materials but also the technical domains of structural and functional design, production process development, and performance evaluation. We believe it can contribute to ECOnomy (economic efficiency), ECOlogy (weight reduction and environmental responsiveness), and ECOSystem (realization of an optimal production system). By leveraging these technologies, Nippon Steel intends to engage more deeply than ever in vehicle manufacturing while working alongside customers to contribute to the realization of a carbon-neutral society.

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