

# Development of Technologies to Realize High Performance Automotive Battery Packs Adapted for Electrification

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## Abstract

*Battery packs for electric vehicles are required to have high safety, low CO<sub>2</sub> emission, cost reduction, space-saving, and weight reduction. Nippon Steel Corporation is developing steel sheets with a wide range of strength and various functions, along with utilization technologies (structural design, forming methods, experimental and analytical evaluation methods) that make use of these properties. This paper provides an overview of the comprehensive efforts to realize high-performance steel battery pack cases.*

## 1. Introduction

### 1.1 Background

To achieve carbon neutrality by 2050, it is essential to reduce greenhouse gas (GHG) emissions, including CO<sub>2</sub>, throughout the entire life cycle. In the automotive sector, the adoption of electric vehicles (EVs) is progressing rapidly.<sup>1-3)</sup> Among the core technologies, the battery pack, which supplies power to the drive motor, is of utmost importance. Manufacturers are working to expand production capacity, promote reuse and recycling, and develop next-generation batteries.<sup>4)</sup> However, battery packs emit significant amounts of CO<sub>2</sub> during their manufacturing processes, necessitating further reductions.<sup>5)</sup> Currently, the mainstream battery material is the liquid-type lithium-ion battery (LIB), which poses risks of smoke emission and fire due to water ingress or short circuits. Therefore, ensuring safety—such as watertightness, fire resistance, and protection from impacts or collisions—is an urgent issue.<sup>6)</sup> In addition to these requirements, automakers are striving to enhance the marketability and competitiveness of EVs by developing high-performance (high output and high energy density) batteries, as well as compact, space-saving, and flat designs that maximize interior space utilization. Furthermore, battery packs account for 20–25% of the vehicle weight, making weight reduction crucial for improving driving range and reducing collision energy. On the other hand, battery packs represent approximately 30% of the total EV cost, so achiev-

ing these requirements at low cost remains a significant challenge.<sup>7-14)</sup>

This paper introduces the concept, benefits, and enabling elemental technologies of steel battery packs, considering environmental friendliness, safety, and economic viability.

### 1.2 Nippon Steel group's battery pack technologies

Nippon Steel Corporation proposes a total solution, NSafe™-AutoConcept, to accurately address the diverse needs of the automotive industry (see Fig. 1). This technology is based on four pillars: material development, structural design, process development, and performance evaluation.

Figure 2 shows the core material lineup of NSafe™-Auto Concept. Cold-formed high-tensile steel sheets have been commercialized up to the 1470 MPa grade, and research and development of even higher-strength steel sheets are ongoing. In addition, as high-performance products, we are working on the commercialization and development of steel sheets (hereafter, EA steel sheets) with excellent collision energy absorption and fracture resistance during crashes, as well as steel sheets with extremely high ductility and hole expansion properties even at high strength. Steel sheets for hot stamping (hereafter, HS steel sheets) are being mass-produced or have completed development across a wide strength range from 0.5 to 2.0 GPa. The 0.5 GPa, 1.0 GPa, and 1.3 GPa HS steel sheets

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can absorb high energy during large deformations in collisions. For coating, we have commercialized SUPERNICKEL™ with high chemical resistance and low surface electrical resistance for battery cell cases and current collectors, and propose highly corrosion-resistant coatings such as SuperDyma™/ZAM™ for pack cases and upper covers, which may eliminate the need for electrodeposition coating or fire-resistant materials. Compared to other materials, steel offers superior environmental performance (CO<sub>2</sub> emissions, recyclability), high safety due to high strength (load resistance) and high melting point (fire and heat resistance), and high economic efficiency

due to abundant resources and advanced manufacturing technologies. The Nippon Steel Group offers a wide range of products with various strength levels and functions, enabling us to meet the diverse needs of the automotive industry.

**Table 1** summarizes the battery pack solution technologies proposed by Nippon Steel. For example, the battery pack structure concept using ultra-high-strength steel sheets enables the realization of lightweight and low-cost battery pack cases with high safety and layout flexibility. Highly corrosion-resistant coated steel sheets contribute to significant cost reduction and improved safety by omitting

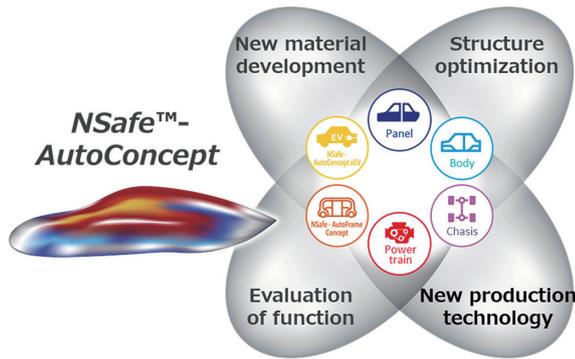


Fig. 1 Nippon Steel's total solution for automobiles

	Type	Tensile Strength (TS) Grade [MPa]					
		980	1180	1310	1470	1760	2000
Cold rolled	Uncoated	●	●	●	●	△	
	Coated (GA)	●	●		△		
For Hot Stamping	Uncoated				(●)	(●)	(●)
	Coated (Al-Si)	(○)		(●)	(●)	(●)	(●)
	Coated (Zn)	(○)	(○)	(●)	(●)	(●)	(●)

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

Fig. 2 Nippon Steel's material lineup

Table 1 Nippon Steel's solution technologies for the electric vehicle battery packs

Advantages	Solution	Material/Technology
<b>Design</b>		
Collision resistance, layout flexibility	High-efficiency energy-absorbing components	High-energy-absorbing ultra-high-tensile steel, wave-shaped EA structure
Load-bearing performance	Inner-frame structure	Cold-rolled ultra-high-strength steel sheet, steel sheet for hot stamping, optimization of material layout, part geometry, and frame structure
Load-bearing performance, stiffness	Hot stamping continuous flange part	Steel sheet for hot stamping, hot-stamping notch-less flange forming method
Load-bearing performance	High-strength module case	Cold-rolled ultra-high-strength steel sheet, optimization of material layout and part geometry
Load-bearing performance, heat/fire resistance	Highly corrosion-resistant cell case	SUPERNICKEL™, stainless steel sheet
Durability	Cathode/anode collectors	SUPERNICKEL™ foil, stainless steel foil
Process omission, heat/fire resistance	Electrocoating-free upper cover	SuperDyma™/ZAM™, stainless steel sheet
Watertightness	Single-piece tray	High-deep-drawability steel sheet
Cell installation efficiency, layout flexibility	Underframe structure	Cold-rolled ultra-high-strength steel sheet, steel sheet for hot stamping, optimization of material layout, part geometry, and frame structure
Cell installation efficiency, layout flexibility	Integrated small-radius corner tray	Integrated small-radius corner tray forming method
<b>Analysis</b>		
Development time shortening	High-precision collision analysis	NSafe™-MAT/SPOT
Development time shortening	Stiffness visualization	NSafe™-SV
Development time shortening	Springback cause stress analysis	NSafe™-SD-Analyzer
<b>Evaluation</b>		
Various mechanical tests for battery pack case (load, crush, impact, bottom impact) ※For development evaluation development		
Battery characteristic evaluation and testing, mainly for Li-ion batteries, an integrated contract system that covers the analysis of battery components and materials		
Life cycle assessment evaluation		

processes for upper covers and battery cases and ensuring heat and fire resistance. In addition, we propose proprietary manufacturing methods and optimal joining techniques to enhance feasibility. Analytical and evaluation technologies can reduce the need for physical verification processes such as prototyping and testing, thereby shortening development time and reducing costs in response to increasing performance and safety requirements.

The comprehensive capabilities of the Nippon Steel Group, we provide integrated solutions from upstream (advanced development) to downstream (mass production support) in vehicle manufacturing, aiming to achieve improved safety, cost reduction, and weight reduction.

## 2. Battery Pack Cases and Module Cases

### 2.1 Concept

Figure 3 illustrates examples of battery pack case concepts proposed by Nippon Steel, comprising a lightweight type and a high-capacity type.

The lightweight type features cross members made of 2.0 GPa HS steel sheets installed within the battery pack. In addition to the exceptionally high strength of the HS steel sheets, the notch-less flange achieved through its superior formability offers an improvement of load-bearing performance and structural stiffness. This allows the reduction of other components previously installed for safety purposes, making to weight reduction feasible.

The feature of the high-capacity type is the placement of a cross member made of cold-formed ultra-high-strength steel sheets, such as GA1470, on the rear surface of the battery pack. Leveraging the high strength of cold-formed ultra-high-strength steel sheets ensures high load-bearing capacity even with a small cross-section. Since the space previously occupied by the cross members can be utilized, improvements in cell installation efficiency and layout flexibility are achieved, enabling the downsizing of the battery pack. Furthermore, since collision safety is designed based on the rear surface of the battery pack, rework caused by modifications in the internal layout of the battery pack can be avoided, thereby contributing to a reduction in overall project lead time.

As Common elemental technologies, these include: an upper cover that reduces costs by omitting the electrocoating process; A tray that achieves both high cell installation efficiency and watertightness through integral forming of ridgelines with extremely small radius size; a side frame that achieves high energy absorption and high space efficiency through the use of EA steel sheets and the wave shape. The Details of these elemental technologies are described in the following sections.

### 2.2 Electrocoating-free upper cover

Since components constituting the battery pack are often electrocoated in a separate process from the body, omission this electrocoating process is highly effective from environmental and economic perspectives. However, as battery packs are frequently installed under the vehicle floor, they may suffer surface damage such as chipping. Therefore, corrosion resistance must be maintained even in such damaged areas.

Figure 4 shows the corrosion resistance evaluation results for samples with simulated surface damage (cross-cuts) applied to alloyed hot-dip galvanized steel sheets with electrocoating (E-coated

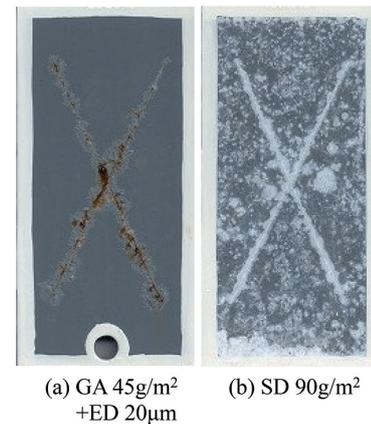


Fig. 4 Results of corrosion tests (JASO M609-91 400 cycles)

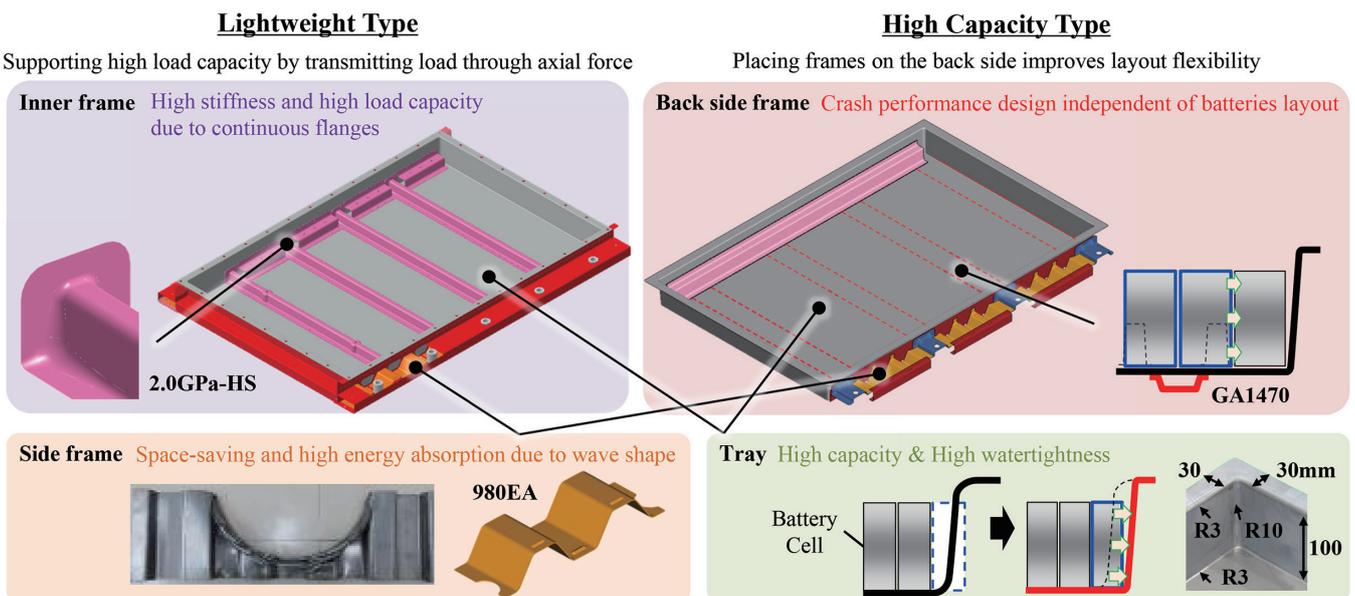


Fig. 3 Examples of Nippon Steel's electric vehicle battery pack case concepts



Material TS : 270 MPa  
Thickness : 0.8mm  
**Fig. 5 Prototype of battery pack top cover**

GA) and SuperDyma™ (SD),<sup>15)</sup> a high corrosion-resistant coated steel sheets developed by Nippon Steel. Although white rust developed over the entire surface of SD, the cut areas did not progress to red rust. In fact, SD demonstrated superior resistance to red rust compared to E-coated GA, which is also widely used on vehicle underbodies. Since battery packs require watertightness, the slow progression to red rust—which can lead to perforation corrosion of the base steel sheet—is a critically important property. SD exhibits five times the corrosion resistance of pure Zn-based coating.<sup>16)</sup> For applications requiring higher corrosion resistance, thicker plating can be applied.

Additionally, Nippon Steel has developed a surface treatment with excellent lubricity specifically for SD. Using SD with this lubricity-enhanced surface treatment enables the oil-free forming of battery pack upper covers, as shown in Fig. 5. Achieving oil-free forming omits the need for a degreasing process, promising further improvements in environmental performance and cost efficiency.

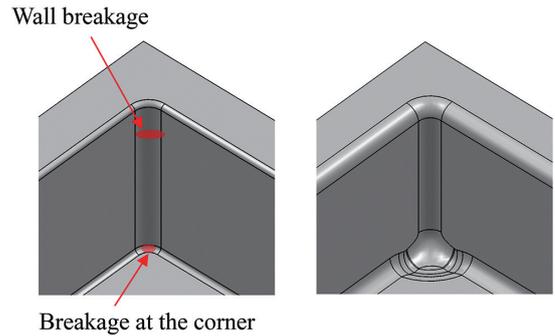
Thus, by using high corrosion-resistant coated steel sheets or steel sheets with lubricating surface treatments, it has become possible to develop battery packs with high environmental and economic benefits, such as omission electrocoating, omission oil application during forming, and omission degreasing.

### 2.3 Integrated small-radius corner tray

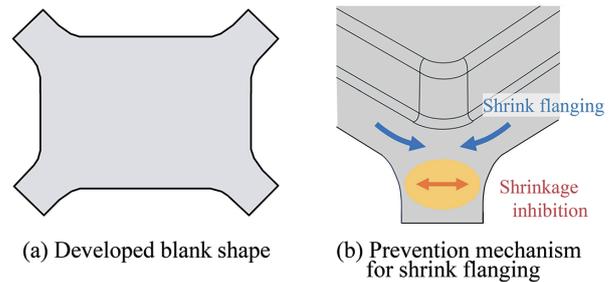
From the perspective of cell installation efficiency, the tray must have a shape with a small curvature radius at the ridges and vertical walls that are as perpendicular as possible (small-radius corner shape). From the perspective of watertightness, the tray should be integrally formed from a single sheet of material with no joints. Furthermore, considering the joining with other components and the cost, achieving this shape through the press forming of steel sheet is desirable. However, suppressing cracking during the press forming of such a shape is extremely difficult. Nippon Steel has developed a forming method to realize an integrated small-radius corner tray.<sup>17,18)</sup>

As shown in Fig. 6, the challenges in press forming an integrated small-radius corner tray include cracking at the corner apex and the vertical wall section. Cracking at the corner apex occurs because of localized stretching deformation. Therefore, a method in which sufficient material flowed into the vicinity of the corner apex through preforming was investigated, followed by the formation of a small radius in a subsequent process. In this case, the excessive material flow during preforming caused wrinkling. Therefore, we developed an optimization technique for preforming shapes that suppressed both cracking and wrinkling (Fig. 7). Cracking in the vertical wall sections occurred because of insufficient material flow caused by inflow resistance due to shrinkage flange deformation. To address this issue, we developed a method that improves material flow by the protrusion of the corners of the blank to suppress flange deformation (Fig. 8).

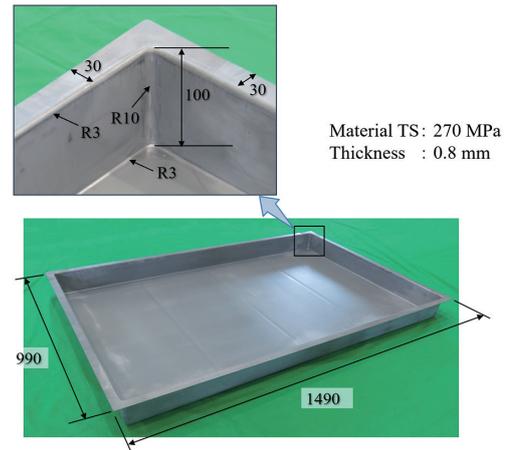
These technologies enabled the realization of an integrated small-radius corner tray with high cell installation efficiency and



**Fig. 6 Crack-susceptible regions Fig. 7 Optimal pre-processing shape**



**Fig. 8 Prevention of shrink flanging by developing blank shape**



**Fig. 9 Prototype of high-capacity and high-watertightness tray**

watertightness, as shown in Fig. 9.

### 2.4 Wave-shaped EA structure

Since battery packs are often mounted under the floor, EV collision safety requires not only occupant protection but also battery protection. Therefore, side sills and battery pack side frames incorporate structures (collision EA components) that absorb energy during side impacts within or around them. Nippon Steel has developed wave-shaped EA structure as collision energy absorption members that maximize the performance of EA steel sheets, which possess the excellent energy absorption performance and fracture resistance during crashes characteristics described in Section 1.2.<sup>19, 20)</sup>

Improving the energy absorption performance of impact absorption components requires careful section design and control of the resulting buckling behavior. Among buckling behaviors, axial compression failure—where fine buckling repeats and the structure col-

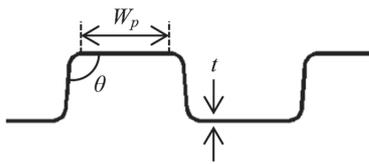


Fig. 10 Section view



Fig. 11 Prototype of energy absorption member with wave structure

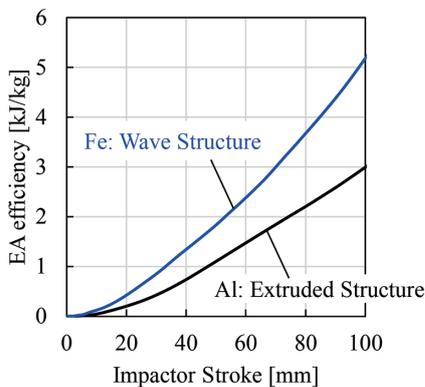


Fig. 12 Comparison of energy absorption efficiency

lapses in a corrugated pattern—exhibits superior energy absorption performance. To achieve even higher performance, increasing the buckling reaction force is effective. This can be achieved by inducing opposite buckling behavior in adjacent planar sections. This is thought to occur because the amplitude of the buckling wave (out-of-plane deformation relative to the crushing direction) becomes smaller, making it easier to receive loads in the crushing direction. It has been clarified that such buckling behavior can be controlled by the angle  $\theta$  between the plate thickness  $t$  of the section perpendicular to the crushing direction and the plane length  $W_p$  of the adjacent flat section separated by the bending ridge (Fig. 10).

Figure 11 shows a prototype of a wave-shaped EA member designed using the above findings and 980 MPa-grade EA steel sheets.

Figure 12 shows the energy absorption performance per unit mass of this prototype during a crushing test where an impactor was pressed against the energy-absorbing member. The results for an aluminum extruded member with a lattice cross-section are also shown in the same figure. Compared to the aluminum extruded member, the wave-shaped EA member exhibits higher energy absorption performance. Specifically, it was found that the wave-shaped EA member requires a smaller stroke to absorb the same amount of collision energy.

Based on these results, it has become possible to develop a steel



Fig. 13 Examples of battery module case

sheet collision energy absorption component that offers high impact resistance in a compact space.

### 2.5 Module case

As shown in Fig. 13, the module case is a component that bundles and restrains cells, that is composed of bindbars (side plates) and end plates. In recent years, driven by the demand for higher energy density, bindbars have become longer, and the expansion and contraction of cells has become more significant during charging and discharging. In order to keep the busbar deformation within the allowable dimensional limits and prevent deterioration of cell performance, it is desirable to minimize dimensional changes in the module case caused by expansion and contraction.

Since the load caused by the swelling is applied to the bindbars as in-plane tensile stress, enhancing the bindbar's load capacity while achieving weight reduction can be effectively accomplished by using materials with higher strength. Furthermore, when the bindbar has a bent section, the smaller bend radius at the section, the smaller the clearance required to avoid interference with cells and other components. Therefore, materials with high strength and bendability are desirable for bindbars. An example of such a material is Nippon Steel's high-strength EA steel sheet.

End plates must withstand bending loads from cell swelling, requiring high bending stiffness as a component. Pressed parts can achieve three-dimensional structures through forming and assembly. Combined with the high strength of steel sheets, this enables optimal component performance, such as providing battery protection during collisions.

## 3. Cell Case

### 3.1 Steel cell cases

Battery casings, i.e., cell cases, are classified by shape into cylindrical, prismatic, and pouch types. Materials used include nickel-plated steel sheets and aluminum. Nickel-plated steel sheets, in particular, have been adopted for the casings of various batteries using high-concentration alkaline solutions as electrolytes—such as alkaline batteries, Ni-Cd batteries, and Ni-MH batteries—due to Ni's high chemical resistance and low surface electrical resistance. Furthermore, nickel-plated steel sheet is also used for cylindrical lithium-ion cell cases, which are widely adopted in automotive applications, notebook computers, power tools, and similar devices.<sup>21)</sup> On the other hand, aluminum is primarily used for prismatic and pouch cell cases.

Performance characteristics expected of cell cases include heat

resistance (such as resistance to fire propagation during thermal runaway), fatigue properties to withstand expansion and contraction during repeated charge-discharge cycles, and improved volumetric energy density through thinner walls. Using steel sheet, which has a higher melting point than aluminum and superior strength at the same thickness, for prismatic and pouch cell cases has the potential to enhance these performance characteristics.

**3.2 Heat resistance**

Figure 14 shows the appearance of a prismatic battery after a fire propagation test. Forcing a short circuit in a fully charged battery causes it to heat up to over 800°C, raising the temperature of adjacent batteries as well. No damage was observed in the nickel-plated steel sheet (SUPERNICKEL™) cell case, whereas melting was observed in the aluminum alloy (A3003) cell case. Furthermore, the nickel-plated steel sheet battery took approximately twice as long as the aluminum alloy battery to ignite adjacent batteries. This occurred because the nickel-plated steel sheet cell case prevented its wall melting, thereby suppressing heat transfer from the ignited cell. In contrast, the aluminum alloy cell case melted, increasing heat transfer to adjacent cells. This confirmed the superior heat resistance of steel cell cases with a higher melting point than aluminum alloy.<sup>22)</sup>

Figure 15 shows the appearance of batteries after crush testing (UL1642 compliant) using laminated steel sheet (thin Cr-plated steel sheet) and aluminum laminate as pouch-type cell cases. Polypropylene film is laminated on the battery’s inner surface, and PET film is laminated on the outer surface. In the laminated steel sheet battery, although the cell case deformed, no smoke emission or thermal runaway due to short-circuiting was observed. Conversely, in the battery using aluminum laminate, the cell case fractured at the crush point, and white smoke and thermal runaway were observed immediately after crushing. This difference is thought to be due to steel exhibiting less strength reduction than aluminum when heated.<sup>23)</sup>

**3.3 Fatigue characteristics**

Figure 16 shows the results of a single-end fatigue test. The test specimen simulated the laser-welded joint between the body and lid of a prismatic cell case. Materials tested were nickel-plated steel sheet, stainless steel sheet (SUS430LX), and aluminum alloy (A3003). The laser weld penetration depth was approximately 0.4 mm. Despite their thin gauge, nickel-plated steel sheet and stainless steel sheet exhibited fatigue life more than 10 times greater than that of aluminum alloy confirming their superior fatigue performance. Furthermore, while the fractures in the aluminum alloy occurred in the weld metal, the fractures in both the nickel-plated steel sheet and stainless steel sheet occurred in the base metal. This suggests that fatigue strength is less dependent on weld quality.

These results suggest that using steel sheet for the battery cell case significantly improves joint fatigue resistance during expansion and contraction from charge–discharge cycles. This indicates enhanced fatigue reliability.

**3.4 Efforts toward practical application of steel cell cases**

For the practical application of steel cell cases, mass production technology development is required for forming the lid and body, as well as for sealing. For prismatic cases, we are working on drawing and bending, and for sealing, in addition to welding methods, we are also working on methods such as seaming. We expect steel sheets to be applied to various cell cases.

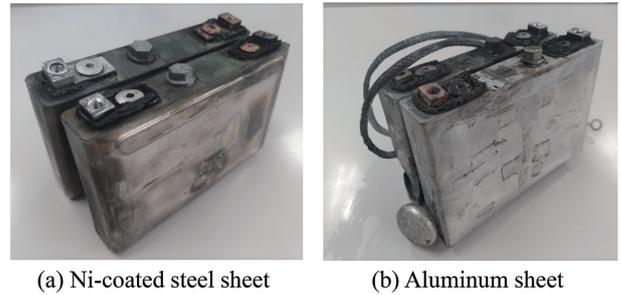


Fig. 14 Appearances of lithium-ion batteries after thermal runaway propagation tests

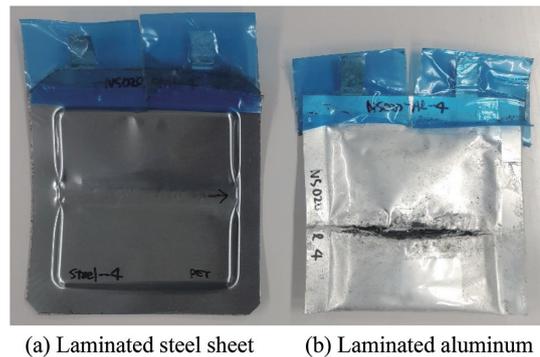


Fig. 15 Appearances of lithium-ion batteries after crush tests

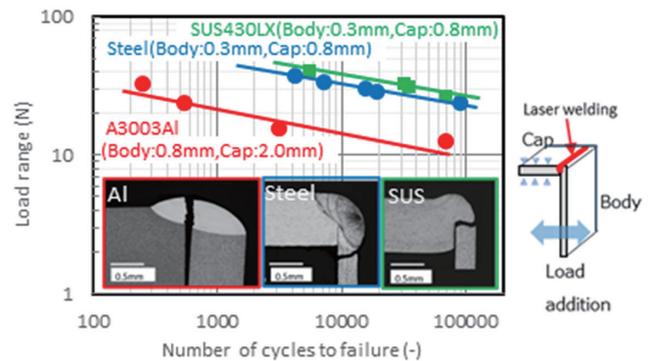


Fig. 16 Result of fatigue test

**4. Future Outlook**

Battery pack cases contribute to enhanced competitiveness of battery packs by integrating component functions, thereby further cost reductions through reductions in the number of parts and production processes. One example is the integration of cross members and trays, as shown in Fig. 17(a), achieved by the excellent formability of hot stamping and utilizing of tailored weld blanks. Other possibilities include integrating cross members with cooling components by enhancing their strength, as shown in Fig. 17(b), and integrating the upper cover with the floor by increasing its strength.

Also, technological development of module cases and cell cases is essential for the practical application of all-solid-state batteries. Because all-solid-state batteries are required to apply higher pressure to the cell compared to lithium-ion batteries. The high pressure is necessary to maintain the interfacial contact state between the solid electrolyte particles constituting the cell, and to enhance the ability to accommodate the deposition–dissolution reactions of the lithi-

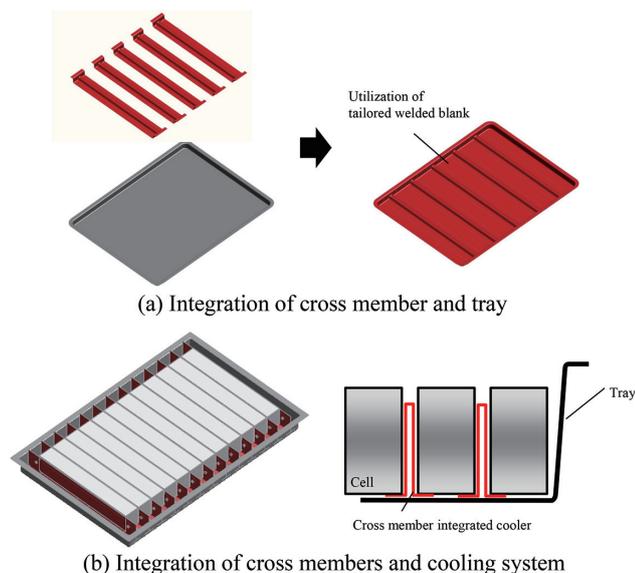


Fig. 17 Examples of integration of battery pack case components

um metal anode, which undergoes significant expansion and contraction during charge and discharge. Therefore, development of structures and mechanisms is necessary to achieve high levels of constraint. To maintain durability against applied pressure, each component will require materials with higher strength.

Consequently, there are high expectations for steel sheets that surpass the strength of 1470 MPa-class cold-formed high-tensile steel sheets and 2.0 GPa-class HS steel sheets, while also offering superior formability and corrosion resistance.

## 5. Conclusion

This paper introduced elemental technologies developed by Nippon Steel to achieve advanced functionality of battery pack. For concepts of the battery pack, two models were presented: one excelling in weight reduction by incorporating cross members made of 2.0 GPa HS steel sheets within the battery pack, and another excelling in cell installation efficiency and layout flexibility by placing cross members made of cold-formed ultra-high-strength steel sheets like GA1470 on the rear surface of the battery pack. For the electrocoat-free upper cover, the application of highly corrosion-resistant coated steel sheet SuperDyma™ and chemical conversion treatment demonstrated the potential to omit the electrocoating process and the lubrication/degreasing required during forming, thereby achieving high environmental performance and economic efficiency. For the integrated small-radius corner tray, a manufacturing method was developed enabling press forming of a single steel sheet with a small curvature radius at the ridge line and a wall angle closer to vertical. This demonstrated the potential for high cell installation efficiency and watertightness. For wave-shaped EA components, we developed high-performance collision energy absorption members by combining EA steel sheets with excellent energy absorption and

collision resistance properties with sectional design for buckling control, demonstrating potential for space savings and further collision safety improvements. For module cases, we discussed the suitability of high-strength EA steel sheets for weight reduction, space savings, and adding battery protection functions. For cell cases, the excellent heat resistance and fatigue properties of SUPERNICK-EL™ steel sheets demonstrated the potential for achieving high safety. Through the Nippon Steel Group's advanced technologies, and the total solutions utilizing them, we can provide effective solutions for various battery pack needs and technical challenges of battery packs, thereby realizing steel sheet battery packs that consider environmental friendliness, safety, and economy. We will continue to contribute to the sustainable development of the automotive industry.

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