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Technical Review

Eco-friendly Stainless Steel Sheets for Automobiles

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Abstract

As a core material that can contribute to the diversification of powertrains, fuels and combustion method, and ultimately to carbon neutrality, stainless steel will contribute to the next-generation automobiles by utilizing its diverse properties, such as corrosion resistance, heat resistance, formability, hydrogen embrittlement resistance, wear resistance, and high strength. This paper provides an overview of the application of unique stainless steel sheets and pipes, which are used particularly as environmental measures among the various parts of automobiles, and looks ahead to future changes in social conditions, diverse needs, and proposed solutions that can respond to further environmental measures.

1. Introduction

The use of stainless steel in automobiles began with decorative moldings. Its application expanded, primarily in exhaust system components, driven by stricter exhaust gas regulations and the need for weight reduction and improved fuel efficiency.[1–3] Additionally, including fuel system components, stainless steel usage per vehicle is 20–30 kg.[1–3] As a material used in various exhaust system components of ICE (Internal Combustion Engine) vehicles, HV (Hybrid Vehicle) vehicles, and PHV (Plug-in Hybrid Vehicle) vehicles, it significantly contributes to global environmental measures. Moreover, the automotive industry is said to be undergoing a "once-in-a-century transformation," with technological innovation advancing in new domains known as "CASE": "Connected," "Autonomous," "Shared," and "Electrification." Among these, "Electrification" is projected to see a significant increase in its share within various powertrains, as shown in **Fig. 1**, to achieve carbon neutrality by 2050 and mitigate global climate change.[4] On the other hand, it is predicted that the composition ratio of powertrains will vary greatly from country to country.[5] This is thought to be due to the impact of CO_2 emissions from battery production, in addition to infrastructure development and cruising range for BEVs (Battery Electric Vehicles) and FCVs (Fuel Cell Vehicles). Although strategies differ among Japanese automakers, the "Green Growth Strategy for Carbon Neutrality by 2050" states that "it is necessary to show diverse paths by optimally combining powertrains, energy, fuels, etc., without limiting ourselves to specific technologies".[6] In addition to biofuels and synthetic fuels (e-fuels) for ICE vehicles, engines that burn ammonia and hydrogen are also being developed, promoting diversification not only in powertrains but also in fuels and combustion methods.

Stainless steel is a material that can exhibit a wide range of properties by combining various elements and optimizing the manufacturing process. As shown in **Fig. 2**, stainless steel can be considered a key material that can contribute to the diversification of powertrains, fuels, and combustion methods, and ultimately to carbon neutrality, by utilizing its diverse properties. This report outlines the application of unique stainless steel sheets that contribute to environmental protection within various automotive component series, along with steel pipes made from these sheets. It also provides an outlook on solution proposals capable of responding to future societal changes, diverse needs, and further environmental measures.

2. Exhaust Components

Exhaust gases from the engine are collected in the exhaust manifold, purified by various environmental protection components, and

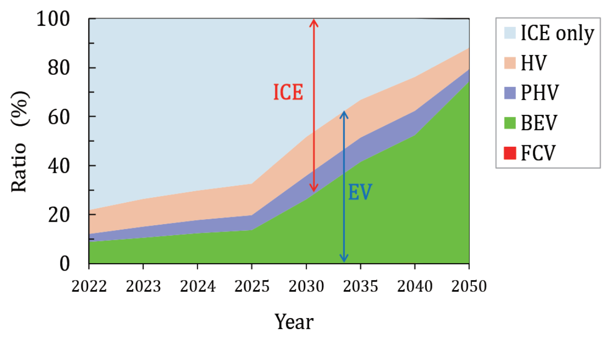

Fig. 1 Trend and forecasts of powertrain composition ratios in global passenger vehicle production[4]

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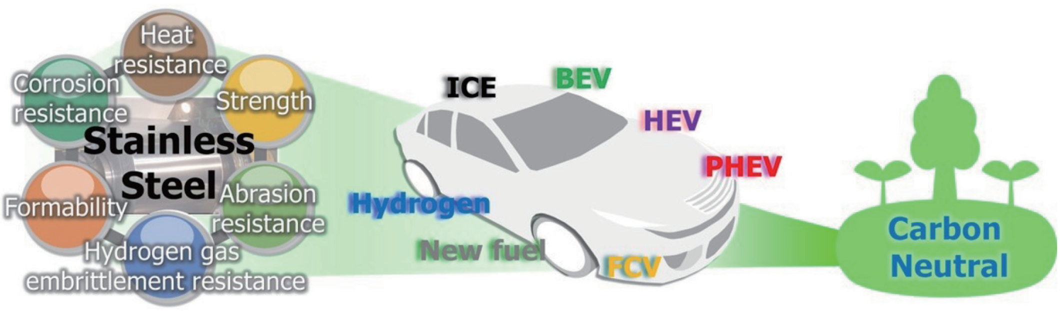


Fig. 2 Characteristics of stainless steel and its contribution to diversifying automobiles

then discharged through the muffler. The required material properties for these components are diverse. Components closer to the engine, known as the hot end, primarily require heat resistance, while components closer to the muffler, known as the cold end, primarily require corrosion resistance.

2.1 Exhaust manifold

The exhaust gas temperature passing through the exhaust manifold directly beneath the engine is reported to be 700–950°C. While high-temperature strength, oxidation resistance, high-temperature fatigue resistance, formability, and weldability are primarily required, ferritic stainless steel, which has a lower thermal expansion coefficient than austenitic stainless steel, is often used.[7] Among these, NSSC™ FHZ (13Cr-1Si-0.4Nb)[8] is widely applied. For higher exhaust gas temperatures and thinner, lighter designs, the higher-grade steel NSSC 190EM (17Cr-1.8Mo-0.5Nb-0.1Ti)[9] is available. These grades primarily utilize solid solution strengthening from Nb and Mo to enhance high-temperature strength and thermal fatigue life. In contrast, NSSC 429NF (14Cr-1.2Cu-0.1Ti),[10–12] NSSC EM-C (17Cr-1.4Cu-0.5Nb-0.1Ti),[13] and NSSC 448EM-M (17Cr-1.2Cu-0.3Mo-0.5Nb-0.1Ti)[10, 14, 15] have been developed to meet demands for reduced alloy content, thin walls, and lightweighting. The Cu contained in these steels exists in a solid solution state at the product shipment stage. However, when components are heated by exhaust gases, the Cu precipitates as particles, exhibiting precipitation hardening. This unique technology involves the precipitation and coarsening of Cu,[16–18] the interaction with dislocations during high-temperature deformation,[19] morphological changes in Cu particles during thermal fatigue,[20] and effects on oxidation resistance in atmospheric and exhaust gas environments.[21, 22] Furthermore, development of NSSC EM-T (17Cr-1.5Cu-2Mo-1.3W-0.5Nb),[23] offering higher heat resistance than NSSC 190EM, has been completed, establishing a menu capable of handling even higher exhaust temperatures. The positioning of these heat-resistant ferritic stainless steels is shown in **Fig. 3**. Since exhaust gas temperatures and component restraint conditions vary by vehicle model and engine, steel grades are selected from this diverse lineup. While customer steel selection involves engine endurance testing, Nippon Steel Corporation contributes to reducing exhaust component design and development costs and shortening lead times. This is achieved by proposing optimal steel grades based on life prediction technology[24–26] derived from fundamental research on thermal fatigue damage, while also considering oxidation resistance and formability. Part shapes are complex, diverse, and relatively thick. To address the need for improved formability, we enhance deep drawing capability through manufacturing condition optimization[14, 15] and propose solutions utilizing FEM (Finite Element Method) simulation.[27]

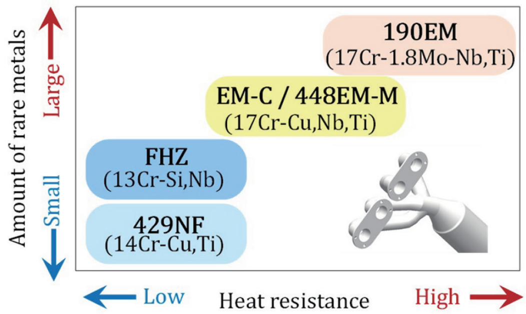


Fig. 3 Positioning of heat-resistant ferritic stainless steel for hot-end parts

Furthermore, in recent years, hydrogen engines and ammonia engines, which replace fossil fuels with hydrogen and ammonia, have been developed. Consequently, technological development for selecting suitable materials for combustion environments different from conventional ones is also progressing.

2.2 Turbochargers

Turbochargers are currently installed primarily for downsizing purposes. Austenitic cast steel and Ni-based alloys are often used for multiple components such as housings, wastegate valves, and nozzle plates/mounts. In recent years, there has been a trend toward sheet metal construction for thin-walled, lightweight designs and improved turbo performance. In addition to oxidation resistance and creep characteristics, NSSC LHT and 305B, based on SUSXM15J1 (19Cr-13Ni-3Si) with excellent high-temperature sliding properties, have been adopted for the nozzle plate mount, an internal component of the VG (Variable Geometry) turbo.[28] The silicon added to this steel forms a layered oxide film through external oxidation, which suppresses adhesive wear during sliding with the vanes, enabling the omission of surface treatments such as chromium plating. Furthermore, SUS310S (25Cr-20Ni) is applied to the backplate, which requires heat resistance, machinability, and surface smoothness as a partition plate between the turbine and the nozzle plate. Sheet metal fabrication using austenitic stainless steel plates is progressing. Furthermore, utilizing new findings on high-temperature strengthening through nitrogen addition,[29–31] NSSC 701 (24Cr-12Ni-2Si-0.6Mo-0.1C-0.2N) with even higher heat resistance has also been developed. As shown in **Fig. 4**, NSSC 701 exhibits high high-temperature strength, as well as excellent oxidation resistance, high-temperature fatigue resistance, creep characteristics, and high-temperature sliding properties.[32]

2.3 EGR cooler

The EGR (Exhaust Gas Recirculation) system is a device that recirculates a portion of the exhaust gas to the intake side to improve fuel efficiency. The EGR cooler is a component that suppresses NOx generation, reduces engine losses, and prevents knocking by cooling the exhaust gas. Primarily from a cost reduction perspective, the materials have shifted from conventional austenitic stainless steels like SUS304 and SUS316 to NSSC 442M3, NSSC 180 (19Cr-0.4Cu-0.4Nb), and NSSC 444M1 (19Cr-2Mo-0.4Nb) ferritic stainless steel plates with superior condensation corrosion resistance, as shown in **Fig. 5**. The internal structure of EGR coolers is complex to enhance heat exchange efficiency, and poor joints lead to water leaks, demanding high brazing performance. Furthermore, the spreadability of brazing filler metal in the heat exchange section has been examined from the perspective of surface energy, and excellent brazing properties have been achieved by controlling trace amounts of Al and Ti.[33] Additionally, deep drawability and hole expansion properties are required for the case and cone sections, making the application of high-r-value ferritic stainless steel sheets effective through manufacturing process optimization.

2.4 Flexible tubes

Flexible tubes are components that mitigate thermal distortion and control vibration in exhaust system parts. When deicing salt is used in winter, high-temperature salt corrosion becomes an issue, where deicing salt adheres to the heated outer surface of the flexible tube and causes corrosion. In response, fundamental research has been conducted on reactions with chlorides and the effects of alloying elements such as Si and Mo.[34, 35] NSSC 307FX (17Cr-13Ni-3Si-1.5Mo),[36] which offers higher corrosion resistance and superior weldability compared to existing SUS316L (17Cr-12Ni-2Mo) and SUSXM15J1 (19Cr-13Ni-3Si), has been put into practical use. It accommodates thin-walled, lightweight designs and higher exhaust gas temperatures.

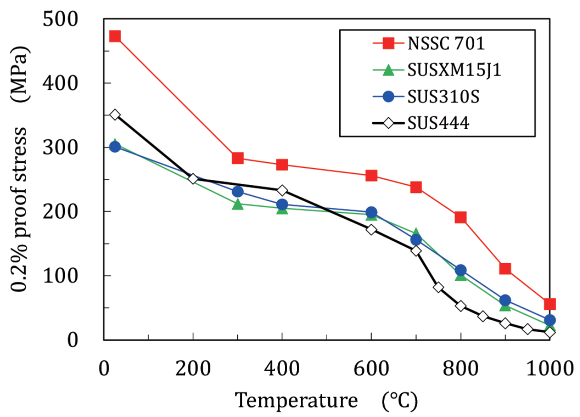


Fig. 4 Comparison of high-temperature strength between NSSC 701 and other stainless steel sheets[32]

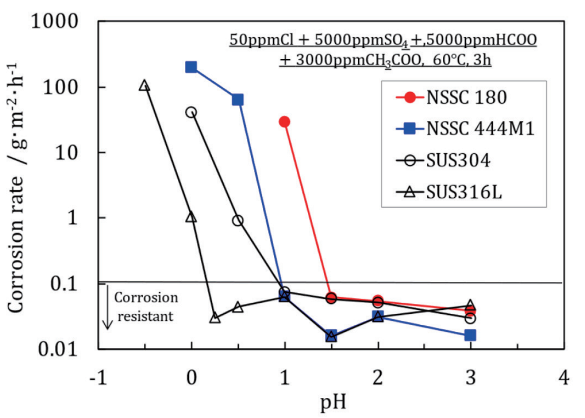


Fig. 5 Condensation corrosion resistance of stainless steels

2.5 Catalytic converter

Catalytic converter is an environmentally compliant component that neutralizes CO, NOx, and HC contained in exhaust gases by contacting them with a catalyst. This consists of a honeycomb-shaped catalyst support inserted inside a shell made of ferritic stainless steel plate. The shell requires heat resistance, so heat-resistant ferritic stainless steel sheet used for exhaust manifolds is employed. Catalyst supports for precious metal catalysts include ceramic and metal supports; ceramic supports are mainstream for four-wheeled vehicles, while metal supports are mainstream for two-wheeled vehicles. Metal carriers use high-Al-added ferritic stainless steel plates NSSC 205M1 (20Cr-5Al-REM),[37] NSSC 21M (18Cr-2Al-0.5Si-0.2Ti),[38] and NSSC NCA-1 (18Cr-3Al-0.2Ti).

2.6 Urea SCR

Urea SCR (Selective Catalytic Reduction) systems purify exhaust gases by decomposing NOx into nitrogen and water. They are installed in trucks, buses, general vehicles, construction equipment, and other vehicles equipped with diesel engines. It neutralizes hydrocarbons and carbon monoxide emitted by the diesel engine using an oxidation catalyst. Simultaneously, urea water is injected at high temperatures and passed through an SCR catalyst. Here, the hydrolyzed NH_3 reacts chemically with NOx, converting them into harmless N_2 and H_2O for release into the atmosphere. NSSC 439 (17Cr-0.2Ti) and NSSC 436S (17Cr-1Mo-0.2Ti) are used. However, in areas prone to corrosion damage from urea water spray, the more corrosion-resistant NSSC 447M1 (30Cr-2Mo-0.2Nb-0.2Ti) may be applied.

3. Fuel Components

3.1 Fuel filler pipes

Due to emissions regulations such as LEV II and P-ZEV in North America, fuel system components like fuel tanks and fuel filler pipes are regulated not only for durability but also for fuel permeability to prevent fuel leakage into the atmosphere. For resin materials, achieving zero fuel permeability poses challenges such as high manufacturing costs due to layering and environmental recyclability issues, making iron-based materials effective. Ferritic stainless steel does not exhibit stress corrosion cracking but requires consideration of crevice corrosion progression. Consequently, fuel filler pipes made from NSSC 436S (17Cr-1Mo-0.2Ti) with cationic electrodeposition coating are adopted.[39, 40] Furthermore, since the expanded section of the fuel filler pipe is formed by integral expansion to more than twice the diameter of the base pipe, excellent expandability is required for TIG (Tungsten Inert Gas), ERW, and laser-welded pipes. In contrast, applying high formability material enables 2D expansion and forming into complex shapes. This high formability ferritic stainless steel achieves a highly uniform and sharply developed {111} grain structure in the thickness direction through opti-

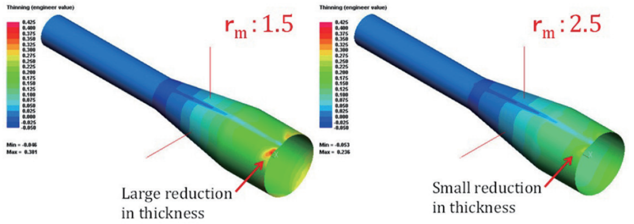


Fig. 6 Effect of r-value on expandability of pipe

mized composition and integrated manufacturing conditions, resulting in an extremely high average r-value.[41] **Figure 6** shows an example of FEM analysis demonstrating the effect of average r-value on the expandability of TIG tubes. The application of this high formability ferritic stainless steel enables improved forming freedom and one-piece forming of steel tubes.

3.2 Biofuels

Biofuels are already used as alternatives to fossil fuels, including bioethanol (a mixture of ethanol and gasoline) and biodiesel (a mixture of fatty acid methyl esters and light oil). The corrosion resistance of stainless steel against various biofuels has been evaluated. Even under the most severe conditions, NSSC 436S (17Cr-1Mo-0.2Ti) and NSSC 190M (19Cr-2Mo-0.2Nb-0.1Ti) have been reported to exhibit excellent corrosion resistance.[42]

4. Electric Components

4.1 Battery case

The cases for vehicle-mounted lithium-ion batteries (LIB) used in EVs, etc., come in cylindrical, prismatic, and pouch types, with aluminum being the most common material. However, as shown in **Figs. 7** to **9**, stainless steel significantly outperforms aluminum in strength, Young's modulus, and high-cycle fatigue strength, offering superior rigidity, fatigue characteristics, and crash safety. Here, A3003 is aluminum alloyed with manganese, with A3003-O being annealed material and A3003-H being work-hardened material. For example, while stiffness is influenced by Young's modulus, plate thickness, and yield strength, switching to stainless steel enables a 30–64% reduction in wall thickness. This allows for increased electrolyte capacity, effectively boosting energy density. Furthermore, since aluminum has a melting point of approximately 600°C, a short circuit can trigger a chain reaction: electrolyte reacting with the negative electrode (80–90°C), separator meltdown (120°C), and positive electrode thermal decomposition (220–300°C). This rapidly exceeds aluminum's melting point, causing thermal runaway and leading to ignition.[43] Stainless steel possesses significantly higher high-temperature strength than aluminum and a melting point around 1 500°C, giving it an advantage in terms of fire spread during thermal runaway.[44] Thus, stainless steel contributes more to battery safety than aluminum, and NSSC 439 (17Cr-0.2Ti) is adopted for prismatic battery cases. **Figure 10** shows the effect of alloying elements on Fe dissolution in the electrolyte. The electrolyte used was 1M LiPF6, EC (ethylene carbonate) : DEC (diethyl carbonate) = 1 : 1 by volume, 1–5 mL, with 300 ppm H_2O added. Test temperatures were 25°C and 80°C. The corrosion resistance of the stainless steel improved with increasing Cr, Ni, and Mo additions, and the amount of Fe ions eluting into the electrolyte decreased. This indicates that steel grades can be selected according to electrolyte characteristics.[45]

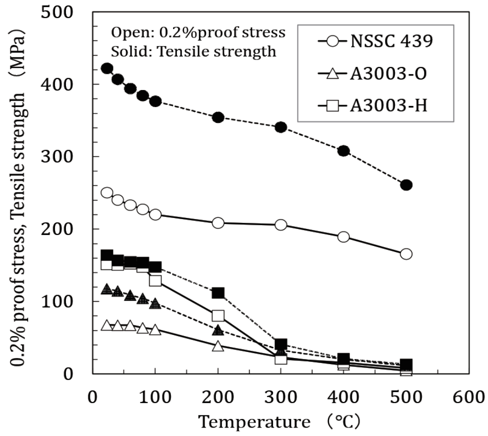


Fig. 7 Comparison of high-temperature strength between ferritic stainless steel (NSSC 439) and aluminum (A3003)

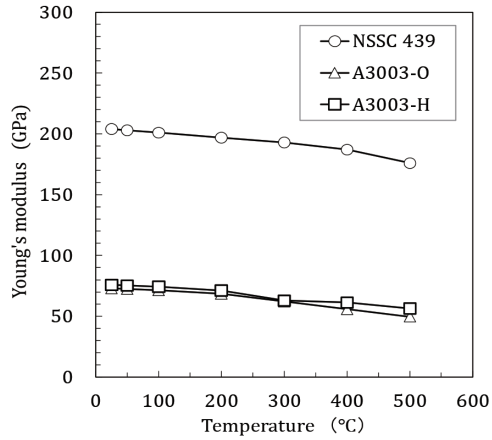


Fig. 8 Comparison of Young's modulus between ferritic stainless steel (NSSC 439) and aluminum (A3003)

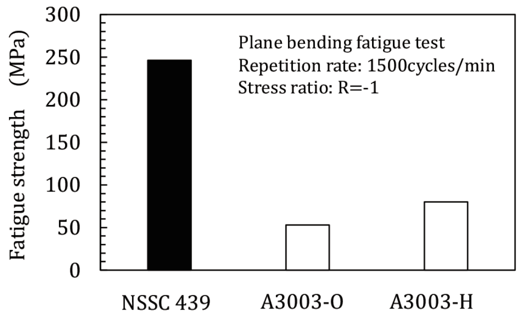


Fig. 9 Comparison of room temperature fatigue strength (10^7 cycles) between ferritic stainless steel (NSSC 439) and aluminum (A3003)

4.2 Current collectors

Stainless steel foil possesses outstanding properties not found in other metal foils, such as high corrosion resistance, strength, and a wide potential window. Applying it as a current collector, one of the battery's constituent materials, is expected to significantly enhance battery performance. Specifically, it enables the realization of high-capacity cathodes and anodes, as well as dramatically extended

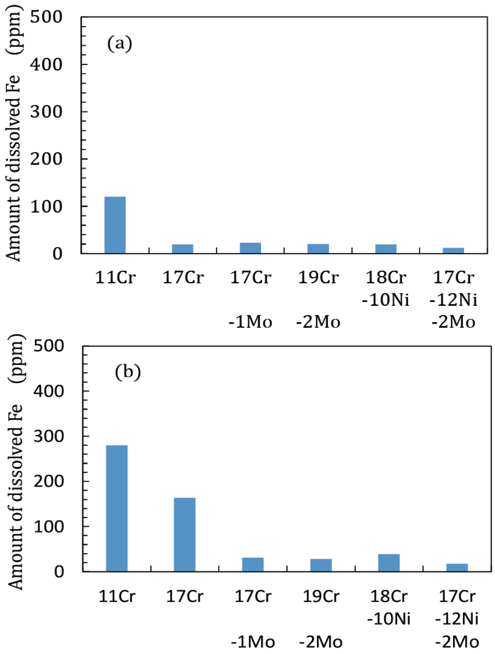


Fig. 10 Effect of alloying elements on amount of Fe dissolved after immersion test in electrolyte for 500 hours (a) at 25°C and (b) at 80°C[45)]

lifespans. Furthermore, various stainless steels have been reported to exhibit excellent corrosion resistance in all-solid-state LIBs, which are being actively researched from the perspectives of high energy density and safety.[46)]

4.3 Motor

EVs drive the motor using electricity supplied from the battery, transmitting power directly to the wheels. While motor types include permanent magnet synchronous motors, wound field synchronous motors, and induction motors, end plates are used on both sides of the rotor, typically made of SUS304 or aluminum. The primary functions of end plates are noise and vibration reduction, rotor core retention, and prevention of magnetic flux leakage. The application of high-strength and non-magnetic materials enables thinner, lighter designs and improved motor efficiency. Additionally, precision machinability, such as punchability, is sometimes required during component manufacturing. To address various needs, non-magnetic austenitic stainless steel sheets, as shown in **Fig. 11**, have been developed.

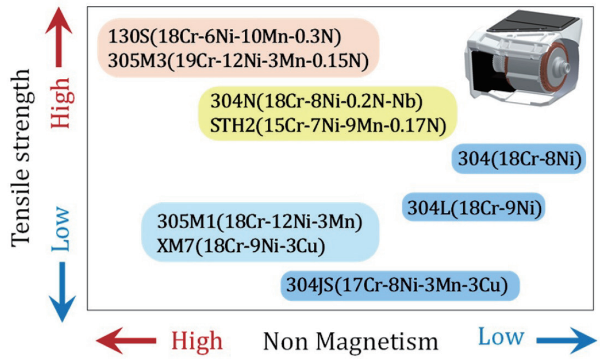


Fig. 11 Positioning of non-magnetic austenitic stainless steels for motor parts

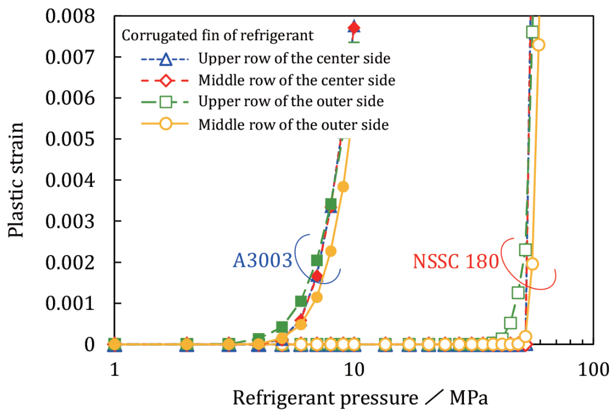


Fig. 12 Effect of refrigerant pressure on plastic strain of corrugated fins made of ferritic stainless steel (NSSC 180) and aluminum (A3003)[47)]

5. Thermal Management Components

5.1 Exhaust heat recoverer

An exhaust heat recovery system is a thermal management component that recovers and utilizes heat from engine exhaust gases. It is installed to reduce warm-up time and improve fuel efficiency. Although its internal exhaust and cooling passages are complex, corrosion-resistant materials like NSSC 436S (17Cr-1Mo-0.2Ti) and NSSC 190M (19Cr-2Mo-0.2Nb-0.1Ti) are used, enabling optimized thermal design and progress toward miniaturization and weight reduction.

5.2 Heat exchangers and coolers

One challenge for EVs is extending battery life. Since heat generated during use, especially during rapid charging, reduces battery life, thermal management components such as heat exchangers and coolers are increasingly being installed. Aluminum, with its excellent thermal conductivity, is primarily used for these components. However, for heat transfer in the thickness direction, as in laminated plate heat exchangers and coolers, it has been confirmed that thin materials with a thickness of 0.5 mm or less, such as, exhibit heat exchange performance equivalent to aluminum.[47)] Furthermore, as mentioned earlier, ferritic stainless steel plates offer higher strength than aluminum. Calculations show that the pressure resistance of laminated plate heat exchangers can be approximately ten times higher, as illustrated in **Fig. 12**. Therefore, stainless steel plates hold promising potential for meeting future demands for higher internal pressures within components, as well as thinner walls and smaller sizes, tailored to specific refrigerants and cooling capacities.[47)]

6. Hydrogen Components

6.1 For high-pressure hydrogen gas

Various initiatives are underway to build a hydrogen energy society using hydrogen as an energy carrier. High-pressure hydrogen gas has become the mainstream hydrogen storage method for fuel cell vehicles (FCVs) that use hydrogen as fuel. Austenitic steel is less susceptible to hydrogen gas environment embrittlement than martensitic or ferritic steel. Therefore, the application of austenitic stainless steel is expected not only for high-pressure hydrogen gas

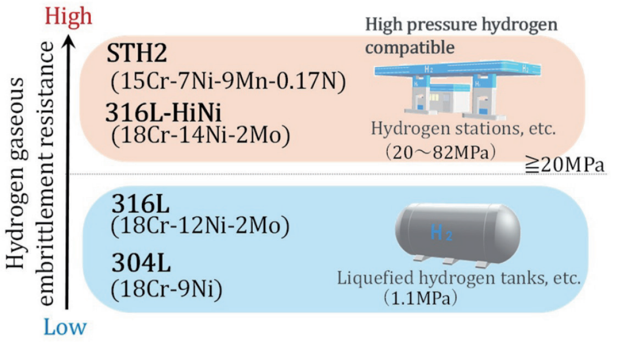


Fig. 13 Hydrogen gas embrittlement resistant austenitic stainless steels

containers but also for various valves, including piping, fittings, and pressure regulating valves that form the hydrogen gas pathway from the container to the fuel cell. Furthermore, its application is anticipated in various components at hydrogen stations supplying high-pressure hydrogen gas to vehicles, from accumulators to dispensers. As shown in **Fig. 13**, Nippon Steel has developed SUS316L (316L-HiNi, Ni equivalent >28.5) with enhanced Ni equivalent (Ni+0.72Cr+0.88Mo+1.11Mn-0.27Si+0.53Cu+12.93C+7.55N), an indicator of austenite stability, to satisfy exemplary standards for high-pressure hydrogen gas environments. In addition, NSSC STH™2 (15Cr-7Ni-9Mn-0.17N, Ni equivalent>30.2), which has achieved excellent price stability by reducing the amount Cr, Ni, and Mo added by 40% compared to SUS316L, has been strengthened by adding N, and is commercially available in plate and sheet.[48–51] These diffusion bonding materials and TIG welding materials have also been confirmed to exhibit excellent hydrogen embrittlement resistance, with minimal reduction in ductility under high-pressure hydrogen gas. They are expected to be applied to welded structural components in FCVs and hydrogen stations.

6.2 Separators and bipolar plates

FCVs generate electricity using PEFCs (Polymer Electrolyte Fuel Cells), with the FC stack responsible for power generation. This stack consists of stacked flat cells. Austenitic stainless steel sheets, which are cheaper than carbon and offer superior formability, are gaining attention as separator materials for these stacks. Separators operate in an environment where sulfate ions and fluoride ions leach from the electrolyte membrane, and chloride ions also contaminate. Additionally, the cathode potential rises to approximately 0.6 to 1V. The low-Ni, low-Mo development steel 218N (21Cr-8Ni-0.15N) exhibits superior resistance to metal leaching compared to SUS304 and SUS316L in an environment simulating the PEFC environment. It is a resource-saving material with excellent cost performance.[52)]

7. Braking Components

7.1 Motorcycle brake discs

Motorcycle brake discs require appropriate hardness (approximately 32–38 HRC) to suppress wear and squeal caused by friction with pads, resistance to softening due to braking heat, and corrosion resistance for aesthetic purposes. Martensitic stainless steel sheets NSSC 410DE (11Cr-0.03C-0.04N-1Mn) and NSSC 410M4 (12Cr-0.06C-0.01N-0.8Mn) are used as materials for brake discs. These steels can achieve the required hardness after quenching by appropriately adjusting the carbon and nitrogen content, thereby eliminating the need for subsequent tempering.

7.2 Four-wheel brake discs

Currently, cast iron is used for automotive brake discs, but rust formation poses an aesthetic issue. Furthermore, especially after rust develops, wear particles from the brake disc and pads are released into the atmosphere as brake dust, creating significant environmental impact. The Euro 7 environmental regulations in Europe have introduced restrictions on brake dust, and it is highly likely that similar regulations or standards for brake dust will be incorporated in Japan as well. High-strength steels like NSSC 410DE and SUS420J2 (13Cr-0.4C), which offer excellent wear resistance and corrosion resistance, are promising materials for such environmental countermeasures. **Figure 14** shows the appearance of NSSC 410DE and cast iron (FC150) after a salt spray test (SST test, 3 hours) and after a brake test (JASO C406) following the salt spray test.[53)] NSSC 410DE showed no rust formation, whereas cast iron exhibited significant rusting. Friction and wear with the pads during the brake test caused rust particles to scatter. **Figure 15** shows the relationship between salt spray test duration and the amount of brake dust generated during the subsequent brake test.[53)] Cast iron rusts progressively as the salt spray test time increases, and the amount of brake dust released into the atmosphere due to wear also increases. NSSC 410DE does not rust under these test conditions, resulting in minimal changes in wear and, consequently, less brake dust compared to cast iron. Based on the relationship between rust formation due to actual atmospheric exposure and brake dust volume, it has been es-

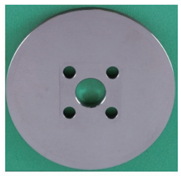
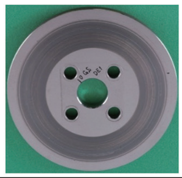
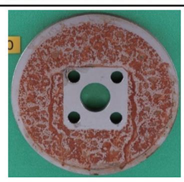
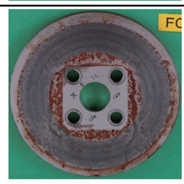
Material	After SST	After brake test
11Cr martensitic stainless steel NSSC 410DE		
FC 150 cast iron		

Fig. 14 Appearances of NSSC 410DE and cast iron after salt spray test (3 hr) and after brake test (JASO C406)[53)]

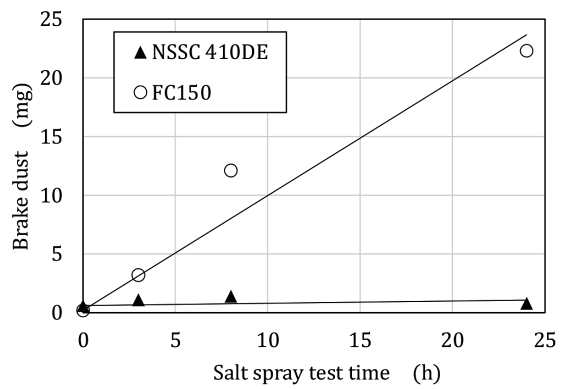


Fig. 15 Amount of brake dust when NSSC 410DE and cast iron were subjected to a salt spray test followed by a brake test[53)]

timated that using stainless steel discs can reduce annual brake dust volume by approximately 13%.[53] Moving forward, applying stainless steel plates to automotive brake discs is effective from both environmental and aesthetic perspectives.

8. Structural Components

Leveraging stainless steel's high corrosion resistance and high strength-high ductility properties, overseas reports document its application in impact-absorbing components and outer panels.[54, 55] Nippon Steel also offers a wide range of high-strength stainless steel plates.[56] The representative high-strength austenitic stainless steel SUS301 (17Cr-7Ni) series material used in railway vehicles, etc., exhibits an excellent strength-ductility balance due to transformation-induced plasticity (TRIP) during deformation. Furthermore, it is possible to produce different strength grades by optimizing manufacturing conditions. Furthermore, among ferrite-austenite duplex stainless steels, NSSC 2120 (21C-2Ni-3Mn-1Cu-0.17N) and NSSC 2351 (23Cr-5Ni-1Mo-0.17N) are lean duplex stainless steels utilizing nitrogen to reduce nickel content, serving as high corrosion resistance and high strength materials capable of meeting requirements such as paint omission.[57–59] Furthermore, ferrite-martensite duplex stainless steels like NSSC 431DP2 (16Cr-2Ni), precipitation-hardening stainless steels such as NSSC HT1770 (14Cr-7Ni-1.5Si-0.7Cu-Ti) and NSSC HT2000 (14Cr-8Ni-3Si-2Mo), a diverse range of steel grades is available through steel composition and microstructure control, enabling tailored material proposals to meet specific needs.[56]

9. Conclusion

This paper outlined stainless steel sheets and steel pipes made from them, which contribute to global environmental measures while responding to the diversification of automotive powertrains, fuels, and combustion methods, categorized by parts. Various options exist for achieving carbon neutrality in the future, and amid ongoing daily evolution, stainless steel contributes to "multiple pathways" by leveraging its diverse properties, serving as a material that further enriches our lives.

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