

Present and Future Trends of Stainless Steel for Automotive Exhaust System

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Abstract

Stainless steel started to be used as material for decoration trims in automobile. However, in recent years, it is mostly used as material for the exhaust system. It is because that stainless steels with good performance of high temperature characteristics and high corrosion resistance meet the social needs for clean exhaust gases and reduced weight for better fuel economy. In this paper, the structure of automotive exhaust system and the materials used for the exhaust system are described. Then, the past change and future prospect of materials for the exhaust system of automobile are described and also those for exhaust system of motor bicycle in which stainless steel starts to be used recently are described.

1. Introduction

Stainless steel is used for a variety of automobile components by virtue of its excellent corrosion resistance, heat resistance and good appearance. Fig. 1¹⁾ shows the historical change of stainless steel consumption per unit of automobile; 20 to 30 kg or so of stainless steel is used at present for each car. The automotive use of stainless steel began with decorative trims and the like taking advantage of the good appearance of the material, but it is now used for many functional components as well. Its use for exhaust system components, among others, has increased remarkably, accounting now for more than a half of all the stainless steel use for an automobile.

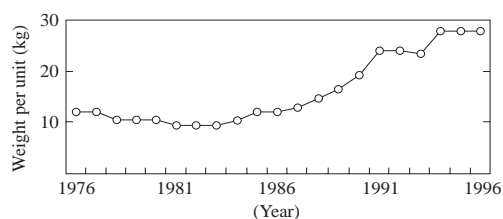


Fig. 1 Historical increase in use of stainless steel per unit of automobile

Tightening exhaust gas regulations and reducing fuel consumption by decreasing vehicle weight have come to be viewed as social requirements and to meet the requirements, carmakers have demanded materials having better and better corrosion and heat resistance for exhaust system components. Accordingly, the materials for the exhaust system components have changed from conventional cast metals and aluminized carbon steel sheets to stainless steels, and from general-purpose stainless steels to specialty stainless steels of higher performance.

The present paper describes the historical changes and future trends of the materials used for the exhaust system of an automobile, component by component. The trend of the same of a two-wheeled vehicle, the field of application where the use of stainless steel has expanded over the last years, is also described briefly.

2. Composition of Automotive Exhaust System and Materials

Fig. 2²⁾ shows the basic configuration of the exhaust system of an automobile. An automotive exhaust system consists of the following seven components from the engine side: an exhaust manifold, a front pipe, a flexible pipe, a catalytic converter, a center pipe, a main muffler, and a tail end pipe. Some models are equipped with more than one catalytic converters and/or a sub-muffler in addition

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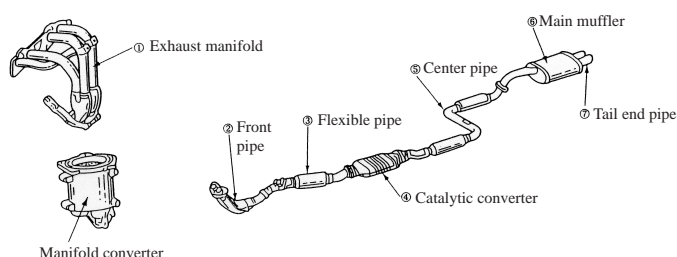


Fig. 2 Automotive exhaust system components

to the above.

Table 1³⁾ shows the service temperature and required characteristics of each exhaust system component and the materials currently used therefor. The principal properties required of the materials for the components in the high-temperature section near the engine (hot end) are high-temperatures strength, thermal fatigue properties, oxidation resistance and salt corrosion resistance at high temperatures, and the same required for the components away from the engine (cold end) is corrosion resistance to salt damage and exhaust gas condensate. Further, good appearance is required for the tail end pipe, which is exposed at the end of a car body, in addition to corrosion resistance. For each of these components, the kinds of stainless steel listed in Table 1 are used in consideration of the required properties and costs.

The functions and required properties of each of these components and the materials used therefore are described hereafter in detail.

2.1 Exhaust manifold

The exhaust manifold is a component to collect exhaust gas from each of the engine cylinders and direct it to the front pipe. Because it is directly fixed to the engine and the temperature of the exhaust gas is as high as 900°C or so, the properties required of it are excellent oxidation resistance, high-temperature strength and thermal fatigue properties. In addition, because it has a complicated shape, the material must have excellent formability.

The exhaust manifold of stainless steel is classified into two types according to the method of fabrication: one is that fabricated through press forming of steel sheets and welding; and the other is that fabricated through bending work of steel pipes and welding. The latter includes double pipe structures. Photo 1 shows an exhaust manifold of the steel pipe type.

Either austenitic or ferritic stainless steel is used for an exhaust manifold. Austenitic stainless steel is excellent in high-temperature



Photo 1 Exhaust manifold

strength, but since its oxidation scale peels off easily, it is inferior to ferritic stainless steel in oxidation resistance. The grades of austenitic stainless steel used for exhaust manifolds include SUS 304 (18Cr-8Ni), SUS XM15J1 (18Cr-13Ni-4Si) and so on. Ferritic stainless steel, on the other hand, is excellent in oxidation resistance, but it is inferior to austenitic stainless steel in high-temperature strength. Nevertheless, because the thermal expansion coefficient of ferritic stainless steel is small, it is better than austenitic stainless steel in thermal fatigue properties. The grades of ferritic stainless steel used for exhaust manifolds include SUH 409L (11Cr-Ti-LC), SUS430J1L (18Cr-0.5Cu-Nb-LC,N) and so on. As a result of the recent tightening of exhaust gas regulations, the temperature of exhaust gas is rising to somewhere around 950°C, and, in such a case, steels of the SUS 444 (19Cr-2Mo) series are used. Steels of the SUS 429 (15Cr) series with low Cr contents are also used as low-cost materials.

In the case of the double pipe structure, the inner pipe is often made of austenitic stainless steel and the outer pipe ferritic stainless steel.

2.2 Front pipe

The front pipe is situated between the exhaust manifold and the flexible pipe. In this section, it is necessary to minimize heat radiation and thus prevent the cooling of the exhaust gas so as to prevent the catalytic activity of the downstream catalytic converter from lowering. It is also necessary to abate the noise. For these reasons, thin-wall double pipe structure is beginning to be employed for the front pipe, which has conventionally been of a single pipe. The steel grades used for this section are ferritic stainless steels such as SUH 409L,

Table 1 Exhaust system components and main materials

Reference number (see Fig. 2)	Exhaust manifold	Front pipe	Flexible pipe	Catalytic converter		Center pipe	Main muffler	Tail end pipe
				Shell	Catalyst carrier			
Service temperature	950-750	800-600			1,000-1,200	600-400	400-100	
Required properties	High-temperature strength Thermal fatigue life Oxidation resistance Workability	High-temperature strength Thermal fatigue life Oxidation resistance Workability	High-temperature strength High-temperature salt damage resistance Workability	High-temperature strength Thermal shock resistance	Oxidation resistance Thermal shock resistance	Salt damage resistance	Corrosion resistance at inner surface (condensate) Corrosion resistance at outer surface (salt damage)	
Current materials	SUH 409L SUS 430J1L SUS 429 SUS 444 SUS XM15J1	SUS 304 SUS X15J1	SUS 409L SUS 436J1L	SUS 21 20Cr-5Al Ceramics	SUH 409L	SUH 409L	SUH 409L	SUH 409L SUS 409L-A1 SUS 436 SUS 430J1L SUS 436J1L

SUS 436L (17Cr-1Mo-LC,N) and SUS 430J1L, and when the double pipe construction is employed, austenitic stainless steel is sometimes used for the inner pipe.

The trend from now is that ferritic stainless steel, which is economical and excellent in oxidation resistance and thermal fatigue properties, will remain the main material. To cope with the higher exhaust gas temperature and use of pipes of thinner wall thickness, steel grades having better high-temperature properties such as those of the SUS 429 class will be used.

2.3 Flexible pipe

The flexible pipe is provided between the exhaust manifold and the catalytic converter for the purpose of preventing the vibration of the engine from being transmitted to the rest of the exhaust system.

Photo 2 shows its appearance. It is composed of a bellows-shaped double pipe and an outer braid of stainless steel wire mesh that covers the double pipe. Good high-temperature fatigue properties are required of its material and because of the bellows shape, good workability is essential. In addition, since deicing salt is used in cold regions, resistance to high-temperature salt damage at the outer surface is also required.

SUS 304 is used at present as the main material. However, because of the use of deicing salt in cold regions, the resistance to high-temperature salt damage at the outer surface is required and for this reason, higher-performance SUS XM15J1, in which Si is added and the Ni content is increased, is also used. Recently, SUS 316L (18Cr-12Ni-2.5Mo-LC), which is more economical than SUS XM15J1 and better in inter-granular corrosion resistance than SUS 304, has also come to be used.

2.4 Catalytic converter (catalyst carrier and shell)

An exhaust gas purifying system called a catalytic converter is installed for mitigating the air pollution caused by automobile exhaust gas. It converts, among the pollutants in the exhaust gas, hydrocarbons and carbon monoxide into carbon dioxide and water, and nitrogen oxides (NO_x) into nitrogen and oxygen. The converter consists of a catalyst, a co-catalyst, wash-coat and a catalyst carrier.

Since the catalytic converter is mounted immediately below the exhaust manifold or beneath the body floor, it must withstand severe service conditions of high temperature, vibration and so forth. Besides a ceramic carrier made of cordierite, a metal carrier made of ferritic stainless steel foils is used as the catalyst carrier. The reason why ferritic stainless steel foils are used is that they have good thermal shock properties and a small heat capacity. A metal catalyst carrier is composed of a honeycomb core of stainless steel foils and an outer shell of a stainless steel sheet. The honeycomb core is formed



Photo 2 Flexible pipe

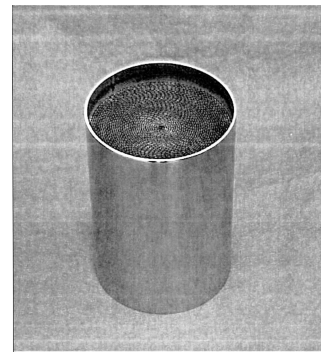


Photo 3 Catalytic converter with metal carrier

by winding a flat and a corrugated foil and bonding them together by brazing, welding or the like. The shell has to have good high-temperature strength, high-temperature salt damage resistance and workability. **Photo 3** shows a catalytic converter with a metal carrier.

Since excellent oxidation resistance is required of the foils, ferritic stainless steels of an Fe-Cr-Al system such as an Fe-20Cr-5Al alloy are used for them. Some steel grades are alloyed with small amounts of rare earth elements (REM) such as Hf, Sc, Y and Ce for enhancing the adhesion of oxide coating films. The trend is that further enhancement of oxidation resistance is required.

SUS 430 (17Cr) is mainly used for the outer shell of the catalytic converter, but ferritic stainless steels such as SUS 430J1L and the SUS 429 series, which have yet better high-temperature properties, have come to be used for the shell to cope with higher exhaust gas temperatures.

2.5 Center pipe

The center pipe connects the catalytic converter to the main muffler; in some models a sub-muffler is installed in the middle thereof. At this position, the temperature of the exhaust gas is comparatively low and consequently, the needs for high-temperature properties are not very demanding. On the other hand, the needs for corrosion resistance are demanding here: the resistance to the corrosion caused by the condensation of water vapor in the exhaust gas is required at the inner surface, and that to the salt damage caused by the deicing salt is required at the outer surface.

The center pipe was conventionally made of an aluminized carbon steel sheet, but use of stainless steel expanded rapidly as a countermeasure against the corrosion of the inner and outer surfaces. Stainless steels of the SUS 410 (13Cr), SUH 409L and SUS 430 series are used for the center pipe.

2.6 Main muffler

The main muffler, which is shown in **Photo 4**⁴⁾, absorbs and reduces the noise of the exhaust gas, and is composed of an outer shell,

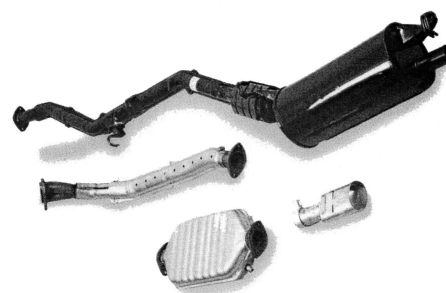


Photo 4 Main muffler

Table 2 Composition of exhaust gas condensate

Condensate	Cl ⁻ × 10 ⁻³	SO ₄ ²⁻ × 10 ⁻³	CO ₃ ²⁻ × 10 ⁻³	NO ₃ ⁻ × 10 ⁻³	NH ₄ ⁺ × 10 ⁻³	Fe ₃ ⁺ × 10 ⁻³	pH
	0.69	0.82	2.8	1.6	8	3.1	8.1
	2.80	2.6	9.8	1.6	54	2.5	8.4

Organic acids are also contained in small amounts.

inner plates, inner pipes, end plates and other components.

The main muffler is heated by the exhaust gas to about 400°C, at the highest, during a long-distance run and the condensation of water does not take place but in the case of a short-distance run, the temperature does not go up and condensation occurs inside it. The condensate contains NH₄⁺, CO₃²⁻, SO₄²⁻, Cl⁻, organic acids and so on, and these ions gradually condense as the starts and stops of the engine are repeated. Examples of the composition of the exhaust gas condensate are shown in **Table 2**⁵⁾. By the presence of the condensate, a very corrosive humid environment is formed inside a muffler. On the other hand, the outer surface of a muffler is exposed to a salt corrosion environment of the deicing salt.

Presently, SUS 436L is mainly used as the material for the main muffler, but use of the SUS 436J1L (17Cr-0.5Mo) series, in which the addition of Mo is reduced, is increasing for reasons of economy. An aluminized stainless steel sheet is sometimes used for the outer shell, end plates and the like because of its good appearance and corrosion resistance.

2.7 Tail end pipe

The tail end pipe is provided behind the main muffler as the final outlet of the exhaust gas and as such, it is exposed to eyes. For this reason, not only corrosion resistance but also good appearance is required of it. Since the exhaust gas is cool enough here, an aluminized carbon steel sheet is quite acceptable as its material, but high-purity ferritic stainless steels such as the SUS 409L, SUS 430 and SUS 436 series and the austenitic stainless steel SUS 304 are sometimes used for reasons of good appearance. When especially good appearance is required, a Cr-plated or hot-dip-aluminized stainless steel pipe is also used.

3. Nippon Steel's Stainless Steel Products for Automotive Exhaust System

Nippon Steel's stainless steel products that are used for the automotive exhaust system by JIS and the company's standards are listed in **Table 3**. The table shows the denominations, main chemical compositions, similar JIS steel grades, if any, and typical applications of the products. YUS 409D is a ferritic stainless steel applicable to the widest variety of purposes. YUS 432 and YUS 436S are ferritic stainless steels containing Mo and are used mainly for mufflers thanks to their excellent corrosion resistance. YUS 450-MS and YUS 190-EM are steels for high-temperature applications, characterized by a

combined addition of Nb and Ti, and are used mainly for exhaust manifolds. YUS 205M1 is used as the foil stock for the metal catalyst carriers. SUS 304 is the principal grade among the austenitic stainless steels for automotive exhaust system use, and YUS 731 is supplied as a steel grade having resistance to high-temperature salt damage.

There are many company standard products of ferritic stainless steel. This is because Nippon Steel has developed stainless steel products suitable for the exhaust system applications in consideration of the fact that ferritic stainless steel is more economical than austenitic stainless steel and for this reason, the former is more acceptable as an automotive material than the latter.

In addition to the above products, aluminized stainless steel products (NSA1 series such as NSA1YUS 409D, NSA1YUS 432, NSA1YUS 436S, etc.) having better corrosion resistance and appearance are also made available.

4. History and Future Trend of Materials for Automotive Exhaust System

4.1 Exhaust manifold

Nodular graphite cast iron or the like was used in the past for exhaust manifolds, but stainless steel has come to be used more and more to cope with improved engine performance and consequent higher exhaust gas temperature and meet the needs for reducing vehicle weight.

Either austenitic or ferritic stainless steel is used for an exhaust manifold. **Figs. 3 and 4**⁶⁾ show the high-temperature strength and oxidation resistance, respectively, of various stainless steels. As seen therein, austenitic stainless steel is excellent in high-temperature strength, but is inferior to ferritic stainless steel in oxidation resistance because its oxidation scale exfoliates easily. In contrast, fer-

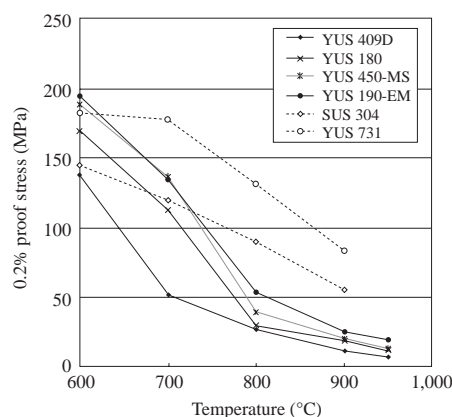


Fig. 3 Comparison of high-temperature strength of stainless steels

Table 3 Nippon Steel's stainless steel products for automotive exhaust system use

	Steel grade	Main alloying elements	Similar JIS steel grade	Typical applications
α	YUS 409D	11Cr-Ti	SUH 409L	Muffler, front pipe, center pipe
	YUS 432	18Cr-0.5Mo-Ti	SUS 436J1L	Muffler, front pipe
	YUS436S	18Cr-1.2Mo-Ti	SUS 436L	Muffler, front pipe
	YUS 450-MS	14Cr-0.5Mo-Ti-Nb	SUS 429	Exhaust manifold
	YUS 180	19Cr-Nb	SUS 430J1L	Exhaust manifold, front pipe, converter shell
	YUS 190-EM	19Cr-1.7Mo-Ti-Nb	SUS 444	Exhaust manifold
β	YUS 205M1	20Cr-5Al	-	Catalytic metal carrier
	SUS 304	18Cr-18Ni	-	Tail end pipe
	YUS 731	19Cr-13Ni-3Si-0.7Cu	SUS XM15J1	Inner pipe of double-pipe manifold, flexible pipe

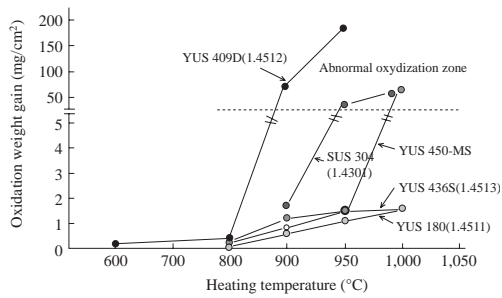


Fig. 4 Comparison of oxidation resistance of stainless steels

ritic stainless steel is excellent in oxidation resistance, but is inferior to austenitic stainless steel in high-temperature strength. However, as seen in Fig. 5, ferritic stainless steel, which has a small thermal expansion coefficient, is advantageous in terms of thermal fatigue properties. For this reason, ferritic stainless steel is mainly used for exhaust manifolds.

Fig. 6 shows the history of Nippon Steel's stainless steel products for exhaust manifold use. YUS 409D (11Cr-Ti) was used in the past as the material that withstands exhaust gas temperatures up to approximately 800°C. Then, to cope with higher exhaust gas temperatures as a result of tightened exhaust gas regulations, YUS 180 (19Cr-Nb) excellent in high-temperature properties began to be used. Later, YUS 450-MS (14Cr-0.5Mo-Nb-Ti) was developed through optimization of chemical composition for realizing good high-temperature properties and reducing costs. As a consequence to the tighter exhaust gas regulations enacted over the last years, the exhaust gas temperature rose further to as high as 950°C, and since conventional

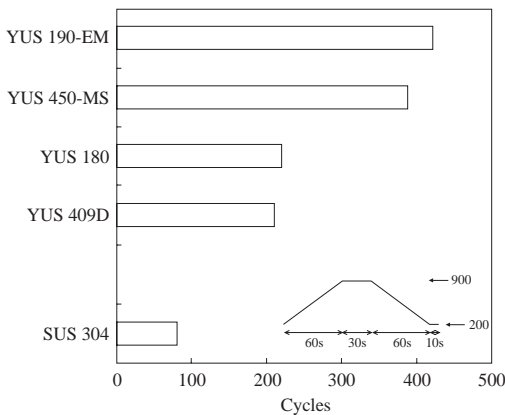


Fig. 5 Thermal fatigue properties of stainless steels (Constraint ratio : 100%)

materials could not withstand such a high service temperature, YUS 190-EM (19Cr-2Mo-Nb-Ti) was developed, in which the addition amounts of Cr and Nb were increased and Mo was added for enhancing oxidation resistance and high-temperature strength.

The characteristic of Nippon Steel's stainless steel products for exhaust manifold use (YUS 450-MS and YUS 190-EM) lies in the combined addition of Nb and Ti; this improves high-temperature properties, in particular, thermal fatigue properties.

Fig. 7⁷⁾ shows the influences of alloying elements over the 0.2% proof stress at 950°C of ferritic stainless steel. Nb, Mo, W and Ta are effective for enhancing the proof stress, and among these, Nb is particularly effective with an addition by a small amount. In addition, it has been made clear that solute Mo and Nb contribute to improving high-temperature strength^{7,8)}. However, since Nb precipitates in the form of carbide and/or a Laves phase during long use at high temperatures, the amount of solute Nb diminishes gradually, and so does high-temperature strength. The combined addition of Nb and Ti was studied for minimizing the fall of high-temperature strength resulting from the decrease in the amount of solute Nb. Fig. 8⁷⁾ is a graph showing the change of the 0.2% proof stress at 900°C

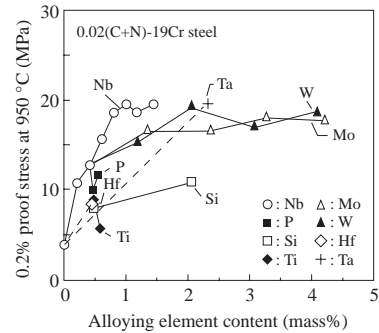


Fig. 7 Influences of alloying elements over high-temperature strength of ferritic stainless steel

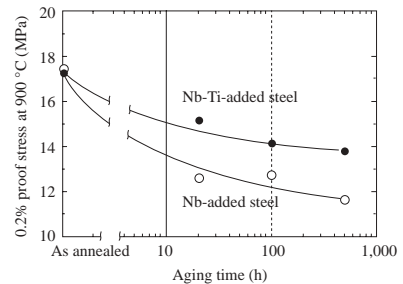


Fig. 8 Change of 0.2% proof stress at 900°C of Nb-added and Nb-Ti-added steels during aging at 900°C

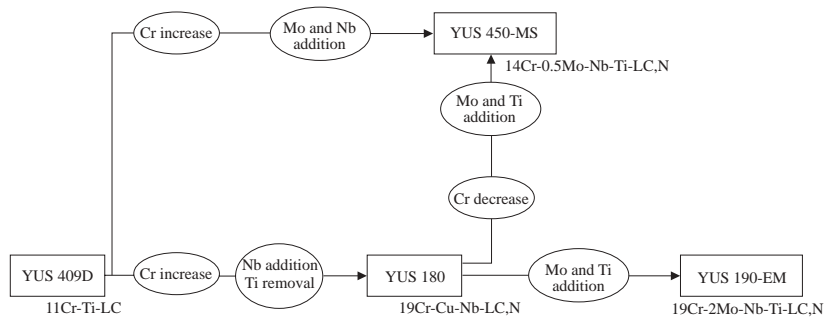


Fig. 6 History of Nippon Steel's stainless steels for exhaust manifold

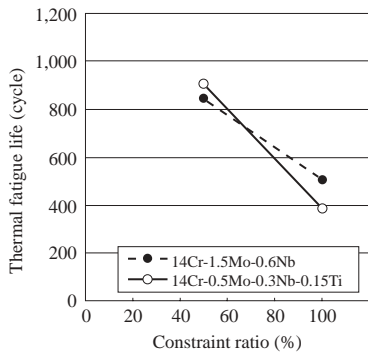


Fig. 9 Thermal fatigue properties of Nb-added and Nb-Ti-added 14Cr steels (repetitive heating and cooling from/to 200 and 900°C)

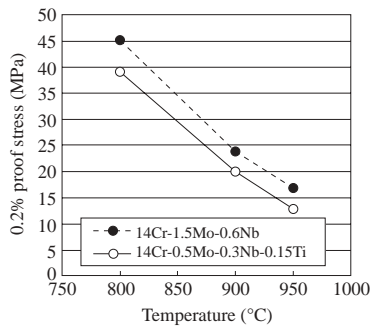


Fig. 10 High-temperature strength of Nb-added and Nb-Ti-added 14Cr steels

of steel containing Nb and Ti and another containing Nb but not Ti during aging at 900°C. It is clear in the graph that the fall of high-temperature strength during aging is smaller in the Nb-Ti-added steel. This is because the precipitation of coarse Nb carbide (M_6C) is inhibited by the addition of Ti^{7,8)}.

Fig. 9⁹⁾ shows the results of thermal fatigue tests of two kinds of 14Cr steel having the high-temperature strength shown in Fig. 10⁹⁾, one containing Nb and the other containing Nb and Ti, under different constrain ratio. Here, the constrain ratio means how much of free thermal expansion is restricted: a constrain ratio of 100% means that a test piece is completely restricted so as not to allow any thermal expansion to occur. Under a constrain ratio of 100%, the thermal fatigue life of the steel containing Nb and Ti is shorter than that of the steel containing Nb but not Ti owing partly to its lower high-temperature strength. However, under a constrain ratio of 50%, the increase in the thermal fatigue life of the former is larger than that of

the latter. The reason for this is presumed as follows: the thermal fatigue life of a material is generally longer under a lower constrain ratio, and thus the material is exposed to high temperatures for a longer period of time; then, with the steel containing Nb and Ti, the precipitation of Nb in the form of carbide is inhibited by the Ti addition; and the fall in the strengthening capacity of Nb at high temperatures is decreased.

The exhaust system components of a real automobile are subjected to repetitive thermal loads while restricted by adjacent components and thus, thermal fatigue properties are essential for their materials. However, since a constrain ratio of 100% restriction is unrealistic, the better thermal fatigue properties of the steel containing Nb and Ti under a low constrain ratio are very effective in actual applications.

The exhaust gas temperature will tend to rise in the future and as a consequence, steel materials having better high-temperature strength and thermal fatigue properties will be required. In addition, because of the complicated shape of an exhaust manifold, better formability will also be pursued.

4.2 Main muffler

Fig. 11 shows comparisons of different stainless steel products in terms of condensate corrosion resistance. It is seen here that pitting corrosion occurs easily under the conditions where chlorides are present. The addition of Cr and Mo is effective for suppressing the occurrence of pitting corrosion in such an environment and Nippon Steel have proceeded with material development in view of this fact.

Fig. 12 shows the history of Nippon Steel's stainless steel products for main muffler use. As the material of a main muffler, which

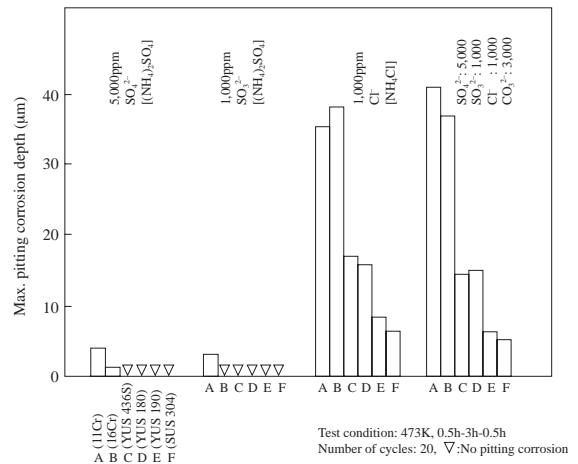


Fig. 11 Condensate corrosion resistance of stainless steels

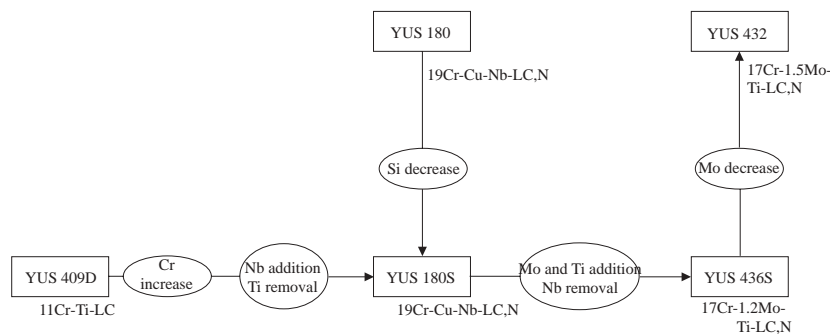


Fig. 12 History of Nippon Steel's stainless steels for muffler

is exposed to severely corrosive environments at the inner and outer surfaces, steel sheets of hot-dip-aluminized carbon steel, SUS 410L and YUS 409D were used in the past, but they came to be replaced by stainless steel sheets having yet higher corrosion resistance. The early substitute materials included high-Cr YUS 180 excellent in corrosion resistance and YUS 180S the workability of which was improved by reducing the Si content.

Later, as the techniques of evaluating the corrosion environment of real mufflers advanced, various test and evaluation methods for stainless steel were proposed based on the advancement. Nippon Steel proposed the partial immersion thermal cycle test method (hereinafter referred to as the NSC test method). Fig. 13⁵⁾ schematically illustrates the NSC test method, and Table 4⁵⁾ shows the composition of the simulative exhaust gas condensate used for the test. With this method, it became possible to evaluate the corrosion resistance of muffler materials under a condition similar to the actual service environment. It was made clear through tests by the method that the addition of Cr and Mo was effective for suppressing local corrosion of stainless steel in exhaust gas condensate and based on the finding, YUS 436S (17Cr-1.2Mo-Ti) was developed. This product is characterized by the following: the incidence and propagation of pitting corrosion, which determines the service life of a muffler, is suppressed by the addition of Cr and Mo by respective optimum amounts; and Ti, rather than Nb, is used for forming carbonitride to stabilize C and N, and as a result, it can be produced through the highly efficient production processes of ordinary carbon steels, namely cold rolling on a tandem cold mill, continuous annealing and pickling.

Fig. 14⁵⁾ shows the Mo-dependency of the pitting corrosion depth of 17Cr steels obtained through the NSC test method, and Fig. 15⁵⁾ the pitting corrosion depths of commercial stainless steel products obtained also through the NSC test method. YUS436S is now widely used for various automotive exhaust system components.

Over the last few years the corrosion environment of real mufflers, which was assumed to be severer than what was the actual situation, has been reviewed in view of the needs for reducing costs and as a consequence, use of more economical materials has expanded. YUS 432 (17Cr-0.5Mo-Ti) having a reduced content of Mo has come to be used as one of such new products.

Aluminizing is sometimes applied to the outer shell and end plates of a muffler for improving appearance and corrosion resistance; NSAIYUS 409D, NSAIYUS 436S and NSAIYUS 432, which are

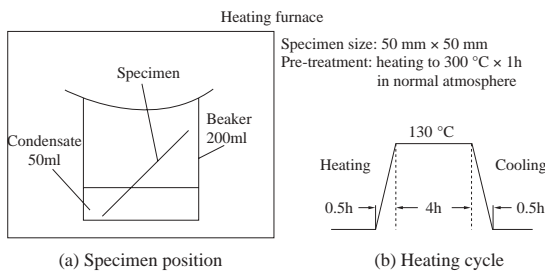


Fig. 13 Schematic diagram of NSC test method

Table 4 Composition of simulative condensate used for NSC test method

pH	Cl ⁻	SO ₄ ²⁻	CO ₃ ²⁻	NO ₃ ⁻	NH ₄ ⁺	HCOOH
8.5	50	100	500	-	220	-

pH is adjusted with NH₄OH.

All constituents added as ammonium salts.

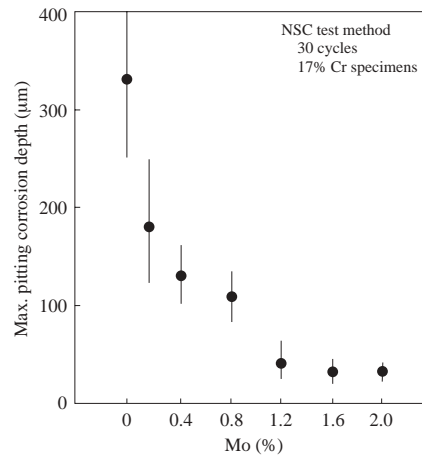


Fig. 14 Pitting corrosion depth of Cr-Mo-added steels by NSC test method

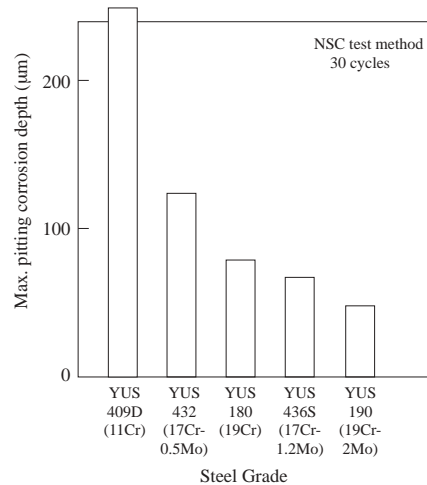


Fig. 15 Pitting corrosion depth of commercial stainless steel products by NSC test method

the aluminized versions of YUS 409D, YUS 436S and YUS 432, respectively, are used in these cases.

5. Exhaust System of Two-wheeled Vehicle

The exhaust system of a two-wheeled vehicle is composed, mainly, of an exhaust pipe and a muffler. What is peculiar to the exhaust system of a two-wheeled vehicle compared with that of a four-wheeled one is that the entire system is exposed to eyes and good appearance has to be ensured besides the essential functions.

Before the revision of the exhaust gas regulations in 1998, Cr-plated or painted carbon steel sheets were used for the exhaust system components of two-wheeled vehicles marketed in Japan. As a measure to cope with the tightened exhaust gas regulations enacted in October 1998, however, the catalytic converter began to be used for a two-wheeled vehicle as well. Accordingly, the exhaust gas temperature at the muffler was raised from 500 to 900°C because of the catalytic activities, and the application of stainless steels not only to the muffler but also to the whole exhaust system including the exhaust pipe rapidly expanded.

Basically, the same stainless steels used for the exhaust system of a four-wheeled vehicle are used also for a two-wheeled vehicle. In some models, however, the catalyst is held by the exhaust pipe

and in such a case, the corrosion resistance of stainless steels of an Fe-Cr system becomes insufficient. The following countermeasure is taken depending on the case: an undercoating layer is formed between a stainless steel pipe of YUS 436S and a catalyst layer for preventing the deterioration of the catalyst resulting from the diffusion of Fe and Cr; or SUH 21 (18Cr-3Al) having good oxidation resistance is used for the exhaust pipe. In the latter case, however, fabricating an exhaust system using SUH 21 is not easy because the steel grade is not very good in workability and weldability. Recently, Nippon Steel developed a new steel grade YUS 21M (18Cr-2Al-0.5Si) having substantially the same oxidation resistance as that of SUH21 and workability significantly better. The new product performed well at user trials and began to be used commercially.

The regulations related to the exhaust gas of a two-wheeled vehicle will be tightened not only in Japan but also in other countries, and thus, the use of stainless steels for the exhaust system of a two-wheeled vehicle is expected to expand. On the other hand, titanium emerged as a new and tough competitor of stainless steel, as it came to be used lately for the exhaust system of a two-wheeled vehicle for reasons of lighter weight and good appearance.

6. Conclusions

Overviews of stainless steel applications to the exhaust systems of four-wheeled and two-wheeled vehicles have been given above in

relation to each of the components. It will yet be some time before a fuel cell automobile, which is viewed as the most promising of next-generation automobiles, becomes popular, and the present internal combustion engine vehicles will prevail for years to come. Accordingly, reduction of environmental loads by purifying the automobile exhaust gas and improving fuel economy through vehicle weight reduction will continue being the social vocation of carmakers. For this end, material suppliers will be requested to supply materials having better and better characteristics. The application of stainless steel to the exhaust system of four-wheeled vehicle has covered nearly all its components, and materials of higher performance and lower costs will be required. The application of stainless steel to the exhaust system of a two-wheeled vehicle, on the other hand, is yet to expand.

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