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Development of Ferritic Stainless Steel YUS 220M with High Corrosion Resistance for Architectural Use

Michio Nakata*1
Naoto Ono*1
Toshiro Nishimura*2
Toyohiko Kakihara*2
Kazuhiro Yanai*2
Shigenori Takahata*2

Abstract:

SUS 304 and SUS 316 have been traditionally used as building exterior materials, such as roofing and siding. Because they do not have high enough corrosion resistance for use in coastal regions, however, there has been increasing demand for stainless steels that can be employed at low cost in coastal regions. To meet this demand, a new ferritic stainless steel, designated as YUS 220M (22Cr-1.5Mo-Ti, Nb-L C, N) and characterized by high corrosion resistance, formability, and weld toughness, has been developed by minimizing the addition of chromium and molybdenum through the combined addition of titanium and niobium. YUS 220M is being increasingly used in roofing and siding applications.

1. Introduction

Stainless steels are being increasingly used as building materials where their aesthetic surface appearance as well as formability and corrosion resistance can be put to effective use. Traditionally, SUS 304 and SUS 316 have been employed in roofing and siding, but they are not fully resistant to corrosion in coastal areas. There has been mounting demand for low-cost architectural stainless steels that are more corrosion resistant than SUS 316.

One example of ferritic stainless steel used in the construction of a large public facility is a 22Cr steel, designated as YUS 220 by Nippon Steel, in the roofing of Makuhari Messe. When the YUS 220 roofing was investigated for subsequent change 6.5 years later, it exhibited some scattering of pits about 30-μm deep in its top surface and retained corrosion resistance equal or superior to that of SUS 316 in some structural members. Based on this finding, a study was made of ferritic stainless steels with higher corrosion resistance and glare resistance, which is another property in strong demand in recent years. The chemical composition and properties of the newly developed, highly corrosion-resistant architectural ferritic stainless steel YUS 220M are described below.

2. Design of Chemical Composition

2.1 Target of corrosion resistance

To design a chemical composition capable of inhibiting corrosion in seaside regions, the corrosion resistances of existing steels were investigated, and the target of corrosion resistance was established.

2.1.1 Experimental methods

Specimens 150mm wide by 200mm long were machined from four austenitic stainless steels and five ferritic stainless steels listed in **Table 1**, polished with #500 emery paper, and corrosion tested. The specimens were installed at a 30° incline five meters from a wharf occasionally splashed by seawater at Hikari Works on the Seto Inland Sea. They were exposed for two months.

*1 Technical Development Bureau
*2 Hikari Works

Table 1 Chemical compositions of steels (mass%)

steel	C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Ti	Nb	N	O
SUS 304	0.052	0.57	0.91	0.029	0.0042	9.11	17.95	0.13	0.13	0.004	0.003	0.0167	0.0040
SUS 316	0.018	0.57	0.82	0.025	0.0011	12.25	17.26	2.07	0.28	0.006	0.006	0.0268	0.0055
YUS 170	0.025	1.02	0.72	0.035	0.0016	13.50	24.69	0.80	0.15	0.004	0.002	0.3330	0.0038
YUS 270	0.012	0.55	0.57	0.017	0.0005	17.99	20.32	6.18	0.65	0.005	0.002	0.2240	0.0020
YUS 436S	0.007	0.15	0.15	0.024	0.0028	0.10	17.19	1.19	0.04	0.220	0.002	0.0080	0.0021
YUS 180	0.014	0.48	0.11	0.025	0.0006	0.33	19.49	0.01	0.42	0.005	0.400	0.0194	0.0112
YUS 190	0.005	0.22	0.15	0.021	0.0048	0.09	18.84	1.88	0.04	0.180	0.320	0.0101	0.0022
YUS 220	0.014	0.44	0.14	0.027	0.0037	0.13	21.52	0.82	0.44	0.005	0.370	0.0073	0.0106
YUS 250	0.007	0.40	0.14	0.020	0.0105	3.93	25.35	4.06	0.03	0.003	0.003	0.0201	0.0081

Their pitting potential was also measured in a 3.5% NaCl solution at 30°C as described in Japanese Industrial Standards (JIS) G 0577.

2.1.2 Experimental results

The two-month exposure test results are shown in relation to the pitting index (PI) in **Fig. 1**. **Fig. 2** shows the relationship between the maximum pit depth and pitting potential in the exposure test. As shown in **Fig. 1**, pitting corrosion can be prevented if the PI is 25 or more. As is evident from **Fig. 2**, the pitting potential is correlated with the pit depth measured in the exposure test. Because pitting corrosion can be prevented by setting the pitting potential (Vc' 100) at 800 mV vs SCE or more, the target of corrosion resistance was set at the pitting potential of 800 mV vs SCE.

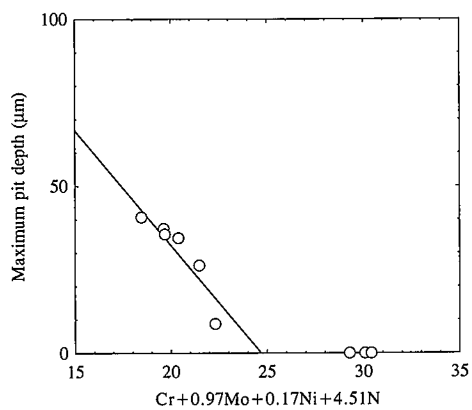

Fig. 1 Results of exposure test (five meters from wharf for two months)

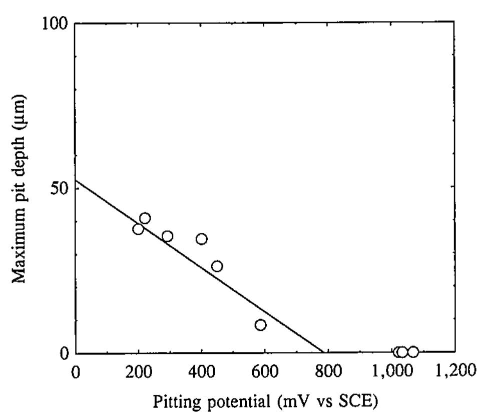

Fig. 2 Relationship between maximum pit depth and pitting potential in exposure test (pitting potential measured by JIS method)

2.2 Effects of chromium and molybdenum contents and stabilizing elements on corrosion resistance

Ferritic stainless steels invariably need the addition of titanium and niobium to impart toughness and weld metal corrosion resistance. When determining the chromium and molybdenum contents, the contribution of titanium and niobium as well as chromium and molybdenum to the corrosion resistance of the ferritic stainless steels was studied.

2.2.1 Experimental methods

The ferritic stainless steels YUS 180, YUS 220, and YUS 250 to which niobium was added separately, the ferritic stainless steels YUS 430D and YUS 436S to which titanium was added separately, and the ferritic stainless steel YUS 190 to which niobium and titanium were added in combination were selected for the experiment. They were supplemented by steels vacuum melted to clarify the effects of the stabilizing elements. Using these steels, the amounts of chromium and molybdenum required to achieve the critical pitting potential of 800 mV vs SCE were determined. Specimens were polished with #500 emery paper for the exposure test.

2.2.2 Experimental results

The relationship between the pitting potential (Vc' 100) measured by the JIS method and the pitting index is shown in **Fig. 3**.

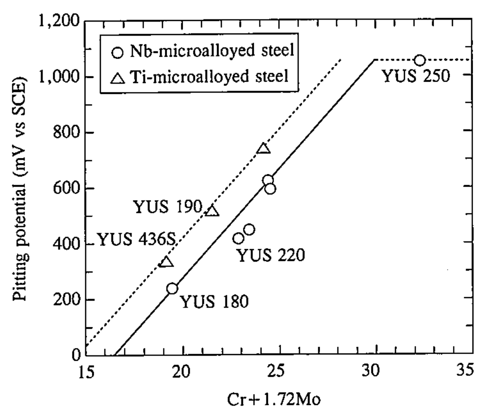

Fig. 3 Relationship between pitting index and pitting potential in ferritic stainless steels

The pitting potentials of the ferritic stainless steels was arranged by Cr + 1.7Mo, and the addition of titanium separately or in combination with titanium produced pitting potentials about 100 mV higher than possible with the addition of niobium alone. Findings with YUS 430D (17Cr-0.4Ti) and YUS 190 (19Cr-2Mo-0.15Ti-0.25Nb) show that this effect of titanium occurs because titanium inhibits the dissolution of nonmetallic inclusions that may serve as sites for initiating corrosion and titanium is concentrated as oxide in the passive film to improve the corrosion resistance of the matrix itself[1]. Titanium is markedly effective for the pitting potential when its content is 0.18% or more and does not change in effectiveness when its content is 0.4%. The optimum titanium content is thus about 0.2%.

YUS 190, applied as a material for electric calorifiers, was the first ferritic stainless steel to have titanium and niobium added in combination. This combined addition is designed to make the most of the elements' corrosion resistance and to offset the disadvantages of one element by the advantages of the other. For example, titanium improves the ductility of welds, but degrades toughness and causes surface flaws when added in excessive amounts. Niobium, on the other hand, is an element required to ensure the toughness of high-chromium and high-molybdenum steels. At the same time, niobium ties up carbon and nitrogen and makes up for (Ti + Nb)/(C + N) ≥ 16 necessary for preventing sensitization[2]. The combined addition of titanium and niobium was selected for these reasons. The pitting index required to achieve the critical pitting potential of 800 mV vs SCE with the combined addition of titanium and niobium is 24.5 as Cr + 1.72Mo, and the necessary molybdenum content at 22%Cr is 1.5%.

2.3 Effect of molybdenum content on corrosion resistance and formability of 22Cr steel

The molybdenum content in the range of 0.8% to 2.0% was investigated for its effect on low-carbon and low-nitrogen 22%Cr steel with the addition of 0.2%Ti and 0.3%Nb.

2.3.1 Experimental methods

Each steel sample was vacuum melted, cast into a 45-kg ingot, hot rolled, cold rolled to one-mm thick strip, annealed, and pickled. Because the PI was about two with 0.8%Mo and 2%Mo, a modified salt spray test was conducted by adding 0.2% H_2O_2 to 0.5%NaCl and 5% NaCl solutions to accelerate corrosion[3]. Cross-sectional Vickers hardness was measured as an index of formability.

2.3.2 Experimental results

The results of 24-hour modified salt spray test with the two NaCl solutions are shown by corrosion ranks in **Fig. 4**. The corrosion rank A indicates the absence of corrosion. As can be seen from **Fig. 4**, the molybdenum content required to prevent corrosion in the 5% NaCl solution is 1.5% or more. The effect of the molybdenum content on hardness is shown in **Fig. 5**. The hardness increases with increasing molybdenum content. Given the corrosion resistance noted above, the molybdenum content was set at 1.5%.

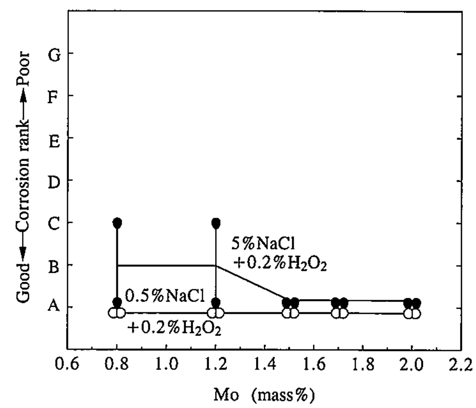

Fig. 4 Results of modified salt spray test (22Cr-0.2Ti-0.3Nb base composition, 35°C, 24-hour spray)

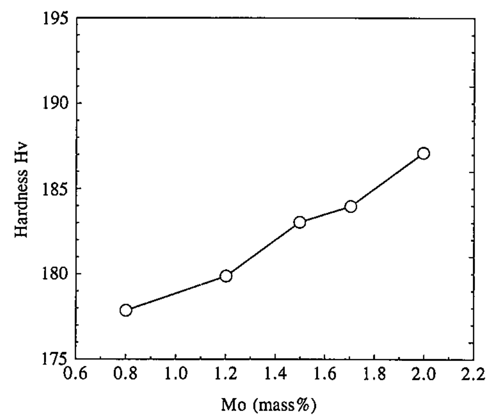

Fig. 5 Effect of molybdenum content on hardness (22Cr-0.2Ti-0.3Nb base composition)

3. Antiglare Surface Finish

Stainless steels are available with many types of surface finishes. The No. 2D finish is mainly used in the siding and roofing applications where glare resistance is of primary importance. In recent years, demand has grown for more glare-resistant surfaces. To meet this demand, YUS 220M with two types of antiglare surface finishes has been developed.

Glare resistance is sensorially expressed. A glossless and whitish surface is apparently preferred. An attempt was made to express this surface finish numerically. As a result, it was found that the surface finish can be represented by a coordinate system composed of gloss (GS45) measured with a gloss meter and color (L* value) measured with a color difference meter. Based on this finding, technology was established for producing a bright annealing (BA) dull finish mainly aimed at corrosion resistance by the combination of BA and dull rolling and an annealing-pickling (AP) dull finish mainly aimed at glare resistance by the combination of annealing, pickling, and dull rolling. The BA and AP dull finishes are compared with conventional surface finishes in **Fig. 6**.

4. Properties of YUS 220M

4.1 Chemical composition

The typical chemical composition of YUS 220M is given in **Table 2**. The base composition is 22Cr-1.5Mo. Titanium and niobium are added in combination as stabilizing elements. The silicon content is reduced to decrease hardness and increase toughness.

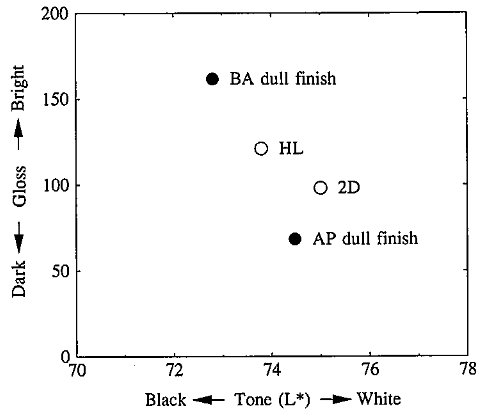

Fig. 6 Glare resistance of dull finish stainless steel sheets

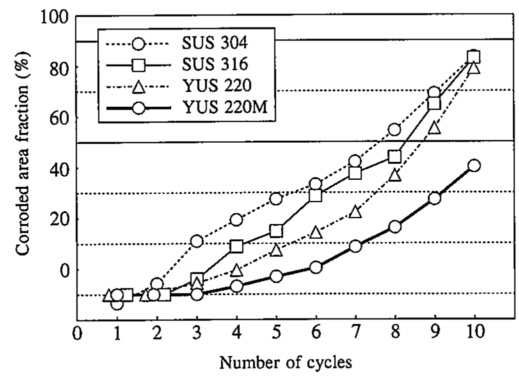

Fig. 7 Results of cyclic corrosion test with seawater [seawater spray (room temperature) → Dry (60°C, 15 minutes) → wet (50°C, 100%RH, 30 minutes)]

Table 2 Typical chemical composition of YUS 220M (mass%)

	C	Si	Mn	P	S	Ni	Cr	Mo	Ti	Nb	N
Representative value	0.006	0.10	0.13	0.026	0.0015	0.12	22.29	1.63	0.18	0.30	0.0106

Table 3 Physical properties of YUS 220M

Property	YUS 220M	YUS 220	SUS 304	SUS 316
Density (g/cm³)	7.75	7.75	7.93	7.98
Coefficient of thermal expansion (10^{-6}/°C)	10.4	10.0	17.3	16.0
Thermal conductivity (cal/cm/°C/s)	0.050	0.047	0.039	0.033
Specific heat (cal/g/°C)	0.11	0.10	0.12	0.12
Electrical resistivity (μΩ-cm)	55	68	72	74
Young's modulus ($\times 10^5$ N/mm²)	2.12	2.00	1.93	1.93

Table.4 Mechanical properties of YUS 220M

Property	YUS 220M	YUS 220	SUS 304	SUS 316
0.2% offset yield strength (N/mm²)	389	373	284	280
Tensile strength (N/mm²)	522	530	696	650
Elongation (%)	28	28	50	50
Hardness Hv	180	175	161	170

4.2 Physical properties

The physical properties of YUS 220M are compared with those of three conventional steels in **Table 3**. YUS 220M has a small coefficient of thermal expansion as compared with austenitic stainless steels such as SUS 304 and is suited as long-size roofing material.

4.3 Mechanical properties

The typical mechanical properties of YUS 220M are listed in **Table 4**. YUS 220M is higher in 0.2% offset yield strength and lower in elongation than SUS 304 and SUS 316, but it is equivalent to YUS 220 (22Cr-0.8Mo-Nb) in 0.2% offset yield strength and elongation although its molybdenum content is about two times higher.

4.4 Corrosion resistance

The results of the cyclic corrosion test with seawater are shown in **Fig. 7**. YUS 220M has corrosion resistance superior to that of SUS 316. The hydrochloric acid corrosion resistance of YUS 220M is shown in comparison with three other stainless steels in **Fig. 8**. YUS 220 retains hydrochloric acid corrosion resistance to higher concentrations than do the other stainless steels.

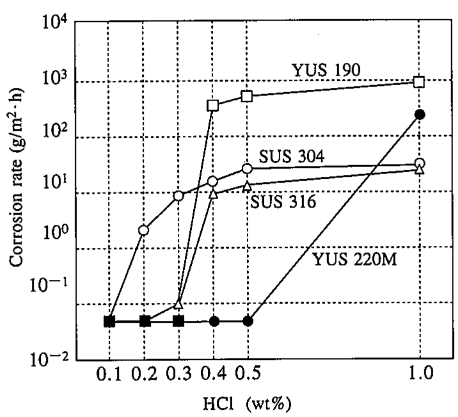

Fig. 8 Hydrochloric acid corrosion resistance (immersion in boiling hydrochloric acid for one to six hours)

4.5 Weldability and welds properties

Two 0.4-mm thick steel sheets were seam welded, and the peel strength of the seam-welded specimens was measured. The results are shown in **Fig. 9**. YUS 220M can be seam welded with good results at a current slightly above that of SUS 304. The higher welding current provides a superior strength than that of SUS 304.

TIG-welded specimens of YUS 220M were bent through 180° over a bent radius equivalent to one sheet thickness without cracking in the weld metal. The weld metal has a Charpy impact energy value of 5 kgf-m/cm² at -40°C as shown in **Fig. 10**.

5. Examples of Applications

YUS 220M has been or is being applied in the roof and wall panels of such buildings as the Aomori Wholesale Market, Narashino Pool, Tokyo International Exhibition Hall, Tokyo Telecom Center, Nakano Sakaue Redevelopment Building, and Osaka Dome. An example is shown in **Photo 1**.

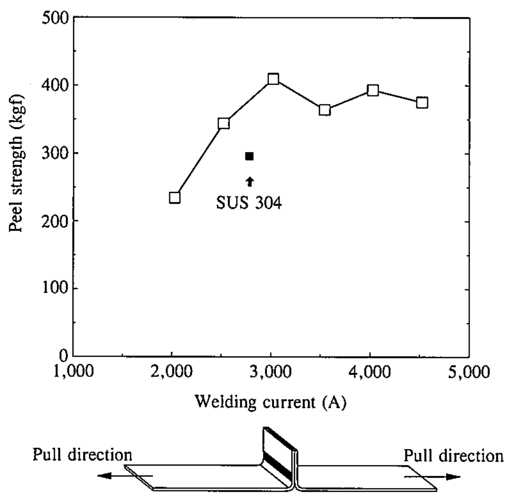

Fig. 9 Peel strength of seam-welded specimens

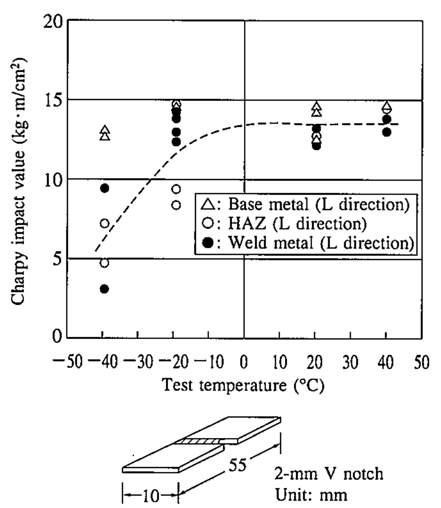

Fig. 10 Toughness of TIG-welded specimens (1.2-mm thick, JIS No. 4)

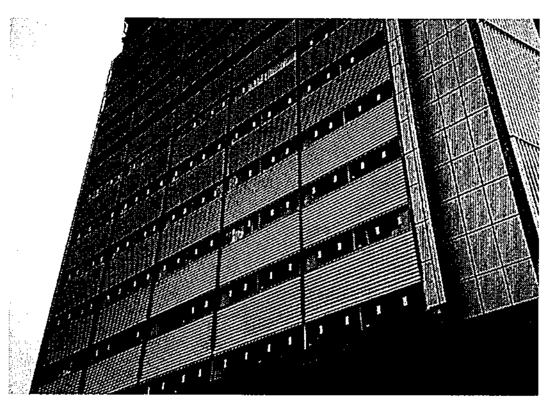

Photo 1 Wall panels of YUS 220M in Nakano Sakaue Sunbright Twin Building in Tokyo

6. Conclusions

YUS 220M (22Cr-1.5Mo-Ti-Nb) has been developed as a new ferritic stainless steel having corrosion resistance superior to that of SUS 316 and featuring high formability and seam weldability. The chemical composition and other properties of the new stainless steel for building exterior use are summarized as follows:

1)Given the increase in cost and the decrease in formability from the increase in chromium and molybdenum contents, titanium is added to improve corrosion resistance, and niobium is also added to prevent sensitization owing to welding and to improve toughness.

2)At 22%Cr, the molybdenum content is set at 1.5% to provide sufficient corrosion resistance and formability. YUS 220M has corrosion resistance superior to that of SUS 316.

3)It was found that glare resistance can be indicated by the combination of gloss (GS45) and color difference (L*). Based on this finding, the dull finish grade of YUS 220M has been developed by combining annealing and pickling with dull rolling.

4)YUS 220M can be seam welded, can be bent in TIG welds without cracking, and can be applied in welded roofing.

5)YUS 220M is finding increasing usage in roofing and siding applications.

References

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2) Onoyama, M. et al.: Tetsu-to-Hagané. 63 (5), 641 (1977)
3) Nakata, M. et al.: Proceedings of 28th Joint Symposium on Corrosion Science and Technology. 1981, Japan Society of Corrosion Engineering, p. 18