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Development of High-Strength Stainless Steels (YUS 304N, YUS 170, and YUS 350) for High-Speed Ships

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Abstract:

Two austenitic stainless steels, YUS 304N and YUS 170, and a martensitic stainless steel, YUS 350, have been developed as new high-strength stainless steels for welded structures, including the hydrofoils of a large high-speed cargo ship called the Techno Super Liner (TSL). YUS 304N and YUS 170 excel in toughness and weldability and are strengthened by controlled rolling and accelerated cooling as well as by nitrogen solid-solution hardening. They have high strength and toughness and feature fatigue strength in salt solutions comparable to that in air. They also have satisfactory properties when welded using materials of similar metal. YUS 350 has excellent strength, improved toughness by the addition of nickel, reduced carbon content to ensure weldability, and additional niobium and molybdenum to prevent the deterioration of mechanical properties owing to stress-relief annealing. YUS 350 has sufficient strength and toughness in each of the base metals, the weld metal deposited by welding with materials of similar metal, and the weld metal deposited by electron-beam welding. These three new steels can be applied in various high-strength, corrosion-resistant welded structures in addition to high-speed cargo ships.

1. Introduction

Japan's Ministry of Transport is pushing ahead with the "modal shift" from highway transport to railroad and sea transport as an important policy for increasing efficiency. One associated project is the development of a large high-speed freight liner dubbed the Techno Super Liner (TSL)[1]. The TSL will be available in the hydrofoil type (TSL-F) and the air-cushioned type (TSL-A). High-strength stainless steels will be used in the hydrofoil of the TSL-F and the rudder of the TSL-A. The TSL is designed to cruise at 50 knots with a 1,000 ton cargo for 500 nautical miles[1]. Large hydrofoils for the TSL will be difficult to make from precipitation-hardening stainless steels used to fabricate the hydrofoils of conventional passenger hydrofoil ships. For

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example, these stainless steels must be aged after welding, which decreases the ease of fabrication for large members.

Two austenitic stainless steels, YUS 304N and YUS 170, and a martensitic stainless steel, YUS 350, have been developed as new high-strength stainless steels applicable to large welded structures. YUS 304N and YUS 170 are highly-weldable austenitic stainless steels strengthened by controlled rolling and accelerated cooling as well as by solid-solution hardening with nitrogen. YUS 350 is a high-strength martensitic stainless steel with its toughness improved by additional nickel and its weldability derived from reduced carbon content. These high-strength stainless steels can be used for welded structures in addition to high-speed ships. The development history and properties of the three new stainless steels are summarized here.

2. High-Strength Austenitic Stainless Steels YUS 304N and YUS 170

2.1 Optimization of chemical composition and thermomechanical processing conditions

Austenitic stainless steels have excellent toughness and weldability, but they have generally lower yield strength than martensitic stainless steels. The methods of strengthening austenitic stainless steels include grain refinement, solid-solution hardening, precipitation hardening, and work hardening. Strengthening by grain refinement makes use of working and recrystallization in transformation-free austenitic stainless steels, so that it is limited in applications where members for large cross sections are required. Precipitation hardening involves problems with fabricability, including aging heat treatment after welding. For solid-solution hardening, strengthening with interstitial solute elements is efficient[2]. The addition of nitrogen is the best strengthening method for austenitic stainless steels because nitrogen has especially high solubility in these steels[3]. Because austenitic stainless steels have a strong tendency toward work hardening, they can also be strengthened effectively by strain, which can be most efficiently introduced in the cold condition. When material strength increases, however, large-section members need a process that works the steel while inhibiting recovery in the high-temperature region where deformation resistance is low. It was thus decided to study the process whereby steel would be strengthened first by the addition of nitrogen and then by thermomechanical treatment.

2.1.1 Experimental materials and methods

The effects of chemical composition and thermomechanical process conditions on strengthening were investigated by high-temperature compression testing with samples melted in the laboratory. The content of nitrogen, a basic strengthener, ranged between 0.05% and 0.35%. The effects of niobium and molybdenum added to inhibit recovery after high-temperature working were also examined. The chemical compositions of the steel samples are given in **Table 1**. Each sample was vacuum melted and hot rolled to a 15-mm thick plate. Specimens were taken from the hot-rolled plates. In the high-temperature compression test, specimens were worked at 1,223 K and held at the same temperature for different times to simulate plate finish rolling at the mill, as shown in **Fig. 1**. They were then tested for hardness and examined microstructurally by optical and electron microscopy.

2.1.2 Experimental results and discussion

The effects of the nitrogen content and holding time on the room-temperature hardness of specimens after 30% compressive working at 1,223 K are shown in **Fig. 2**. The post-compression hardness increases with higher nitrogen content and decreases with lower holding time. The decrease does not depend on the nitrogen content for the 18%Cr-9%Ni steel and cannot be checked by increasing the nitrogen content. The softening tendency is mild for the 0.35%N steel or steel with the highest nitrogen content. This is probably because of the effect of higher chromium and nickel contents that increase the solubility of nitrogen. For example, the I-S effect of chromium and nitrogen[4] is considered to delay recovery. **Fig. 3** shows the effect of the nitrogen content on the hardness of the 18%Cr-9%Ni steel immediately after working and after softening. The latter and the former can be practically considered the results of solid-solution hardening and the combination of solid-solution hardening and work hardening, respectively. The dependency of hardness on nitrogen content is greater immediately after working than after softening. This suggests work hardening depends on the nitrogen content to a greater degree than does solid-solution hardening, probably because increasing the nitrogen content changes the dislocation structure to planar arrays, as shown in **Photo 1**. Nitrogen provides efficient work hardening, but it lacks resistance to softening during holding. Other elements must be added to inhibit recovery and recrystallization.

Table 1 Chemical compositions of steels (mass%)

Steel	C	Si	Mn	P	S	Ni	Cr	N	Balance
SUS 304	0.02	0.5	1.0	0.025	0.001	9.0	18.0	0.05-0.25	Nb:0-0.2
SUS 170	0.02	0.5	1.0	0.028	0.001	13.5	24.5	0.35	Mo:0-1.5

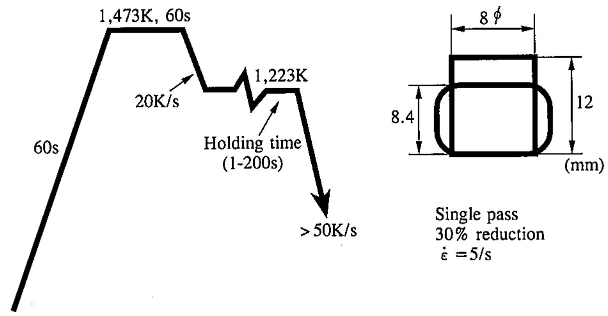


Fig. 1 High-temperature compression test conditions

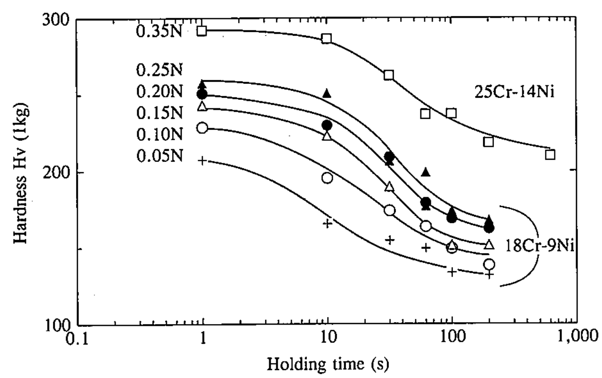


Fig. 2 Effects of holding time and nitrogen content on hardness after compressive working

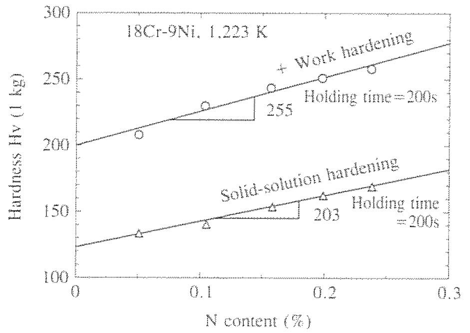
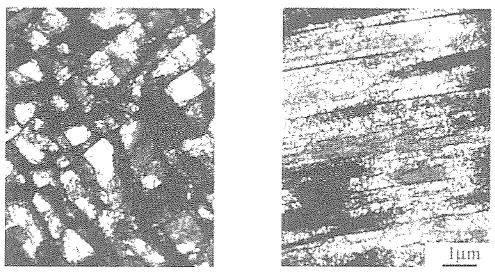


Fig. 3 Effect of nitrogen content on hardness after compressive working and after holding for 200 seconds



(a) 0.05%N (b) 0.25%N

Photo 1 Effect of nitrogen content on dislocation structure after compressive working

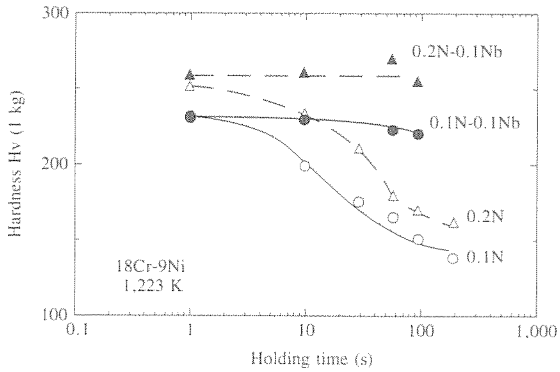


Fig. 4 Effect of niobium on softening behavior after compressive working

The addition of niobium and molybdenum was studied as one method for preventing softening after working. **Fig.** 4 shows the softening behavior of steels with 0.1% and 0.2% nitrogen additions and 0.1% niobium addition. The steels with niobium retain almost all of their hardness immediately after working when held for 100 seconds. This attests to the effectiveness of niobium additions in markedly preventing softening. This effect may be explained by the precipitation of fine NbN on dislocations, shown in **Photo** 2, that is thought to inhibit recovery. Molybdenum exhibits no effect of inhibiting softening when added in amounts up to 1.5% as shown in **Fig.** 5. However, molybdenum increases pitting corrosion resistance and is effective in seawater applications.

As previously mentioned, strengthening by thermomechanical treatment can be accomplished efficiently through solid-solution hardening with nitrogen and the promotion of work hardening. After the thermomechanical treatment, the addition of niobium is effective in preventing softening during high-temperature holding. Increasing the chromium content to boost the solubility of nitrogen and increasing nickel content are believed to be effective in inhibiting softening, although it is not as effective as the niobium addition.

2.2 Properties of YUS 304N and YUS 170

2.2.1 Properties of base metal

Based on the above-mentioned results of investigations of the effects of alloying elements, YUS 304N containing 0.18% nitrogen and YUS 170 containing 0.33% nitrogen were selected as a niobium steel and a high-chromium, high-nickel steel, respectively. From these steels 15-mm and 30-mm thick plates were made on an industrial scale. The chemical compositions and the controlled rolling and accelerated cooling conditions are given in **Table** 2. YUS 304N has 0.1% Nb added to the 8%Ni-18%Cr-

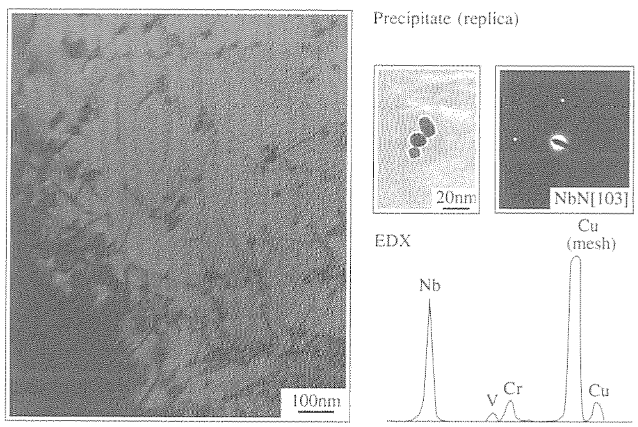


Photo 2 Electron microstructure after compressive working and 200-seconds holding (9%Ni-18%Cr-0.2%N-0.1%Nb)

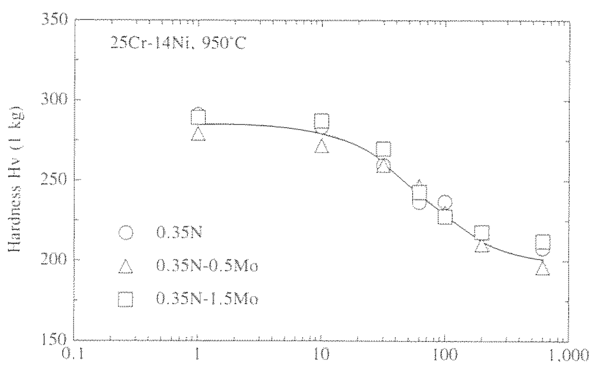


Fig. 5 Effect of molybdenum on softening behavior after compressive working

0.2%N compostion, and YUS 170 has 0.75% Mo added to the 13%Ni-24%Cr-0.33%N composition

The mechanical properties of the test plates are listed in **Table 3**. YUS 304N and YUS 170 exhibit high yield strengths of more than 600 MPa and 700 MPa, respectively, and have sufficient ductility as well. The Charpy absorbed energy at 0°C is high for the two steels. The absorbed energy value is somewhat lower for YUS 304N than for YUS 170, suggesting the effect of NbN precipitation.

Concerning the homogeneity believed to worsen with controlled rolling and accelerated cooling, as shown in **Fig. 6**, the hardness variations in the thickness direction are small for the two steels. In other words, YUS 304N and YUS 170 are homogeneous enough.

The fatigue properties of YUS 304N and YUS 170, expected to become important for hydrofoils, were evaluated in air and in a 3.5% sodium chloride (NaCl) solution at 25°C. Specimens were round, 8 mm or 10 mm in diameter and 40 mm long in the parallel section. They were axially fatigue tested at a stress ratio of 0.1 on a 10-ton servohyraulic testing machine. The frequency was 10 Hz in the air test and 0.5 Hz in the 3.5% NaCl solution test. In the corrosion fatigue test, the parallel section of each specimen was immersed in the 3.5% NaCl solution, and the solution was circulated between an immersion tank and a storage tank (open to the atmosphere). **Fig. 7** summarizes the fatigue strength data from a series of fatigue tests in relation to the 0.2% offset yield strength. The fatigue strength correlates with the 0.2% offset yield strength and increases in both the air and the 3.5% NaCl solution with increasing yield strength. The fatigue strength in the 3.5% NaCl solution is lower than in air, but the difference is very small. The corrosion fatigue strength is clearly improved by the yield strength increase. Corrosion phenomena such as pitting corrosion were not observed in any of the corrosion fatigue test specimens of YUS 304N and YUS 170, and clear-cut striations are observed in their fracture surfaces. These fracture surface forms are the same as observed in the air test and suggest that the two steels are least susceptible to the corrosion environment studied here.

2.2.2 Properties of welds

Butt joints were made in 30-mm plates of YUS 170 by TIG welding and shielded metal arc welding. The chemical composition and mechanical properties of the YUS 170 steel are listed in **Tables 2** and **3**, respectively. The steel plates had their edges prepared parallel to the rolling direction and were TIG and shielded metal arc welded under the conditions shown in **Table 4**. Tension and fatigue test specimens were machined from the midthickness portion of each welded joint at right angles to the weld line. The tensile and fatigue test specimens were both round 10 mm in diameter in the reduced section. They were fatigue test-

Table 2 Chemical compositions and manufacturing conditions of trial-made steels at mill

mass (%)

Steel	C	Si	Mn	P	S	Ni	Cr	N	Balance
SUS 304N	0.06	0.65	0.88	0.028	0.001	7.82	19.28	0.18	Nb:0.10
SUS 170	0.02	1.04	0.63	0.029	0.001	12.92	24.42	0.33	Mo:0.75

Plate thickness: 15 and 30 mm, Finish rolling temperature: 1,210-1,220 K, Final reduction: 20-30%, Cooling rate: > 20 K/s

Table 3 Mechanical properties of trial-made steels at mill

Steel	Plate thickness (mm)	0.2% offset yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Charpy absorbed energy $_vE_0$ (J)
YUS 304N	15	657	858	38	–
	30	627	836	43	190
YUS 170	15	847	1,026	26	–
	30	759	957	33	280

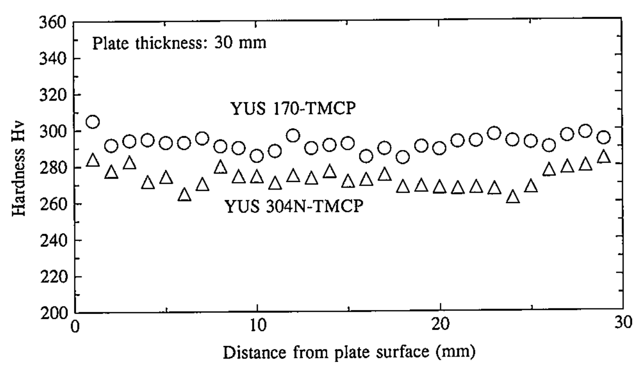


Fig. 6 Hardness distribution of trial-made steels at mill in thickness direction

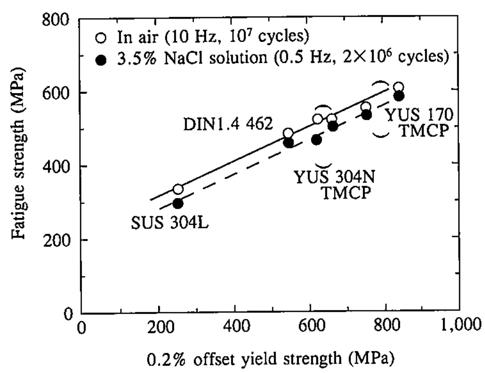
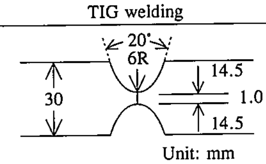
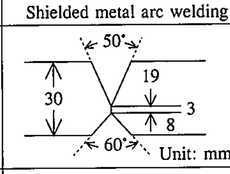


Fig. 7 Relationship between fatigue strength and 0.2% offset yield strength in air and NaCl solution

Table 4 Weld groove shapes and welding conditions

	TIG welding	Shielded metal arc welding
Groove shape		
Welding conditions	Electrode: Nittetsu 170 Current: 260 A Voltage: 11 V Welding speed: 9-10 cm/min Number of passes: 8 top passes and 8 bottom passes Interpass temperature: 100°C Preheating: No	Electrode: Nittetsu 170 Current: 140 A Voltage: 23 V Welding speed: 11-12 cm/min Number of passes: 12 top passes and 9 bottom passes Interpass temperature: 100°C Preheating: No

ed in the air and a 3.5% NaCl solution under the same conditions as described for the base-metal specimens.

The hardness distributions of TIG-welded specimens in different portions are shown in **Fig. 8**. At 2 mm below the surface, the weld metal and the heat-affected zone (HAZ) are low in hardness. At 10 mm below the surface, the hardness distribution is almost uniform. At the midthickness, the weld metal is harder. The hardness distribution measurements show that softening from welding heat is only slightly visible in the surface layer alone and that the strength increase provided by the thermomechanical treatment process is retained after the welding operation.

The tensile test results of the welded joints are given in **Table 5**. Although the steel plates were believed to soften because of welding heat, all specimens fractured in the weld metal. Compared with the mechanical test results of the base-metal specimens, the yield strength and tensile strength of the welded joints are somewhat low, but the differences are small. The degree of softening from welding heat is thus shown to be small.

The fatigue test results of the TIG-welded joints in the air and in the 3.5% NaCl solution are shown in **Fig. 9**. The welded joints are have fewer cycles to failure and less fatigue strength than the base-metal specimens. At the low end of the cycle range, the number of cycles to failure is slightly lower in the 3.5% NaCl solution than in the air, but the fatigue strength of the welded joint specimens in the 3.5% NaCl solution differs little from that in the air. The fatigue strength of the TIG-welded joints is less than that of the shielded metal arc-welded joints. Pitting corrosion and other forms of corrosion are not observed in the parallel section surface of the fatigue test specimens in the 3.5% NaCl solution. The fracture surfaces of the fatigue test specimens in the 3.5% NaCl solution have striations and are not appreciably different from those of the fatigue test specimens in the air.

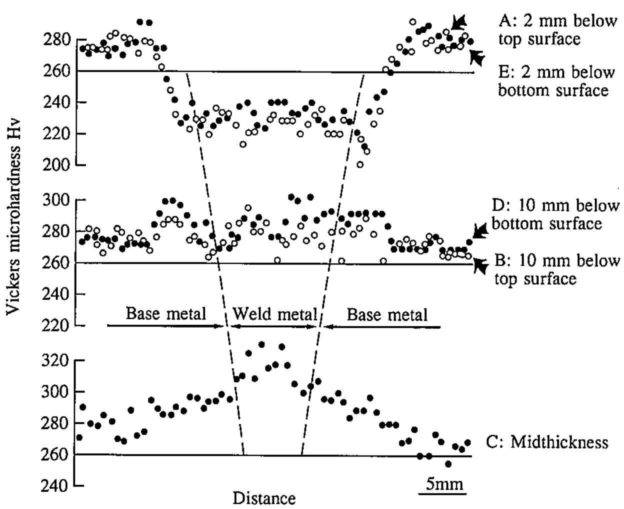


Fig. 8 Hardness distributions in welded joint

Table 5 Tensile test results of welded joints

Welding process	0.2% offset yield strength	Tensile strength	Elongation	Reduction in area	Fracture position
TIG	748MPa	927MPa	26%	52%	Weld metal
Shielded metal arc	693MPa	879MPa	18%	52%	Weld metal

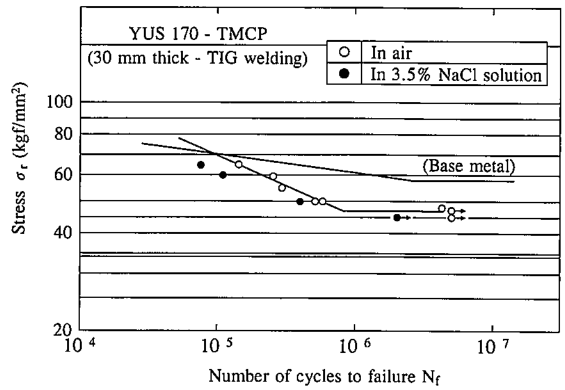


Fig. 9 Fatigue properties of welded joints in air and NaCl solution

3. High-Strength Martensitic Stainless Steel YUS 350

3.1 Optimization of chemical composition

Martensitic stainless steels can be strengthened easily, but they are generally poor in weldability and toughness. Their weldability (cold cracking sensitivity) can be improved by reducing their carbon and nitrogen contents[5], and their toughness can be improved by adding nickel. Because the formation of δ ferrite reduces the toughness of martensitic stainless steels, microstructural control must be important as well. Because martensitic stainless steels have higher notch sensitivity than austenitic stainless steels, their nonmetallic inclusion control is important. After martensitic stainless steels are welded, they are heat treated to relieve residual stresses to prevent their delayed fracturing. Measures are necessary to prevent the loss of strength and the deterioration of toughness because of this stress-relief (SR) heat treatment.

3.1.1 Experimental materials and methods

Low carbon and nitrogen contents were set as base compostion for use in welded structures. The contents of chromium and nickel, the main alloying elements, were studied. The addition of molybdenum and of niobium and titanium were investigated to provide corrosion resistance and to prevent temper softening, respectively. That is, the experimental materials had their carbon and nitrogen contents fixed at about 0.01% each and their chromium, nickel, molybdenum, niobium, and titanium contents were changed. The candidate chemical compositions of YUS 350 are given in **Table 6**. Samples were vacuum melted, hot rolled into 12-mm thick plates, and hardened by heating at 1,000°C for one hour and then air cooled. Temper characteristics were investigated by heating at 500°C to 800°C for one hour, followed by air cooling. Tensile test specimens (Japanese Industrial Standards (JIS) No. 14, 5 mm in diameter and 25 mm in gauge length) and Charpy impact test specimens (JIS No. 2, with a 2-mm V-notch)

Table 6 Chemical compositions of samples (mass%)

Cr	Ni	Mo	Nb	Ti
8.7-16.9	0.1-7.2	0-6.0	0-0.20	0-0.28

were machined from the midthickness of the 12-mm thick plates. Microstructures were observed with an optical microscope, hardness was measured, transformation temperature was measured with the Formaster, and the amount of retained austenite was determined by the vibrating sample magnet meter.

3.1.2 Experimental results and discussion

The microstructures of specimens quenched from 1,000°C were observed by optical microscopy and investigated by measuring transformation temperatures. The results are shown in **Fig. 10**. To obtain a complete martensite microstructure, the chromium equivalent must be 16% or less when the nickel equivalent is 6%. The results of mechanical tests confirmed that the 0.2% offset yield strength and tensile strength are at least 700 MPa and 900 MPa, respectively, in the martensite region and that nickel sharply increases the toughness and improves the fracture appearance transition temperature (FATT) to -50°C or less. In view of corrosion resistance, strength, and toughness, therefore, 15%Cr-5%Ni was selected as the basic chemical composition.

The base composition of 15%Cr-5%Ni is softened by tempering or reduced in hardness to about 80% of the as-quenched hardness when tempered at 600°C. A study was made of the method for preventing this softening tendency by adding niobium or titanium. Niobium was confirmed as effective in preventing softening and in providing the as-quenched hardness even after tempering at 600°C when it is added in an amount of 0.1%. Titanium is effective in preventing softening by tempering at up to 500°C, but it cannot prevent softening by tempering at 600°C. Niobium is effective in preventing temper softening in this way, but it markedly reduces toughness after tempering as shown in **Fig. 11**. The addition of molybdenum is effective against this problem. The effect of molybdenum on the toughness of niobium-containing steels after tempering is shown in **Fig. 12**. The addition of about 1% Mo helps these steels to recover their toughness.

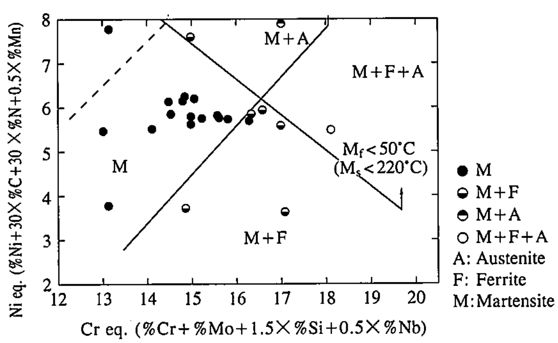


Fig. 10 Microstructures after quenched from 1,000°C

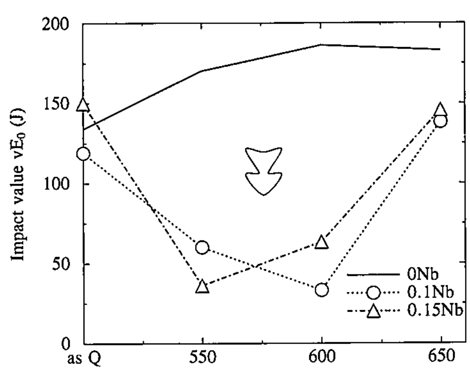


Fig. 11 Effect of niobium on toughness after tempering

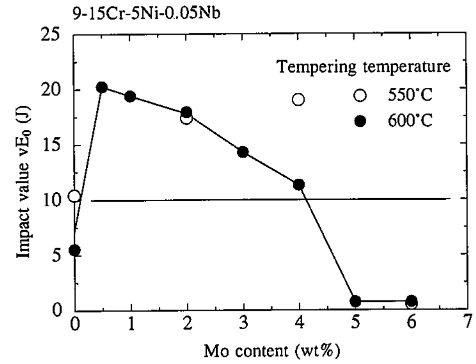


Fig. 12 Effect of molybdenum on toughness after tempering of niobium-containing steels

Table 7 Candidate chemical composition of martensitic stainless steel for welded structures (mass%)

Steel	C	Si	Mn	P	S	Ni	Cr	Mo	Nb
YUS 350	0.01	0.3	0.5	0.015	0.002	5.4	13.2	1.0	0.1
JIS F6NM	<0.5	<0.6	0.5-1.0	<0.03	<0.03	24.5	3.5-5.5	0.5-1.0	—

Based on the results of investigations into the effects of alloying elements discussed above, the chemical composition shown in **Table 7**, or chromium-nickel steel with molybdenum and niobium additions, was selected as that for a high-strength martensitic stainless steel for welded structures.

3.2 Properties of YUS 350

3.2.1 Properties of base metal

The YUS 350 steel of the chemical composition given in **Table 7** was melted in a 50-ton electric-arc furnace and worked to 20-mm and 200-mm thick plates by the combination of vacuum oxygen decarburization (VOD) refining and plate rolling. In the refining stage, calcium was added to reduce the size of nonmetallic inclusions. The mechanical properties of product plates after quenching and tempering are shown in **Table 8**. The 20-mm thick plates have a 0.2% offset yield strength of more than 900 MPa, a total elongation of more than 20%, and a Charpy impact value of more than 250 J/cm² at 0°C. The anisotropy of these properties is also small. The 200-mm thick plates have similar mechanical properties in the direction (L) parallel with the rolling direction and in the direction (T) perpendicular to the rolling direction. In the through-thickness direction (Z), the strength is similar to that of the 20-mm thick plates, but the total elongation and toughness are somewhat lower than those of the 20-mm thick plates. Because their Charpy impact value is more than 100 J/cm² at 0°C, however, the 200-mm thick plates are ductile and tough enough for practical purposes.

The results of the axial fatigue tests of the 20-mm thick plates in the air are shown in **Fig. 13**. The fatigue strength is comparable to that of SUS 630, and the fatigue strength of vacuum-melted steels on a laboratory scale is reproduced.

Table 8 Mechanical properties of mill plates of YUS 350

Plate thickness (mm)	Heat treatment	Direction	Position	0.2% offset yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Reduction in area (%)	20 °C impact value (J/cm²)	0°C impact value (J/cm²)
20	950°C, 1 h Air cooling + 520°C, 1 h Air cooling	L	1/4t	908	1,031	22	71	278	270
			1/2t	—	—	—	—	276	269
		T	1/4t	917	1,039	23	72	271	281
			1/2t	—	—	—	—	268	275
200	950°C, 5 h Air cooling + 530°C, 5 h Air cooling	L	1/4t	935	1,036	20	62	250	261
			1/2t	927	1.036	20	56	270	264
		T	1/4t	938	1.032	20	61	274	273
			1/2t	917	1.023	20	55	255	255
		Z	Full thickness	925	1.021	16	41	—	—
			1/4t	—	—	—	—	132	106
			1/2t	—	—	—	—	150	125

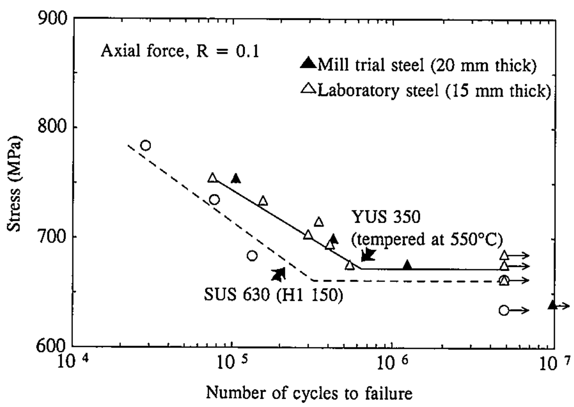


Fig. 13 Fatigue strength of YUS 350 in air

3.2.2 Properties of weld metal

(1)TIG welding

A chemical composition with the carbon and nitrogen contents made higher than those of the base metal to provide desired strength and with retained austenite introduced to reduce the yield ratio was developed as a TIG welding material for YUS 350. Using the new welding material, 20-mm plates of YUS 350 were TIG welded, and the mechanical properties of welded joints were investigated. The tensile test results of the weld metals and welded joints are given in **Table 9**. Irrespective of whether the weld metal is given postweld heat treatment, the metal is stronger than the base metal and equivalent to the base metal in total elongation. Each welded joint failed in the base metal, attesting to the soundness of the weld metal. The Charpy impact test results of weld portions are shown in **Table 10**. The Charpy absorbed energy of the weld zones is slightly lower than that of the base metal, but it is above 200 J from the weld metal to the heat-affected zone (HAZ). In other words, the welded joints are sufficiently tough.

The cold cracking sensitivity of welded joints of YUS 350 made by using the new welding material was evaluated by the Y-groove weld cracking test. YUS 350 was welded with and without preheating at 50°C. After 48 hours, the welded joints were machined and examined for cracks. Neither welded joint showed no cracks, and this confirmed that YUS 350 has extremely good cold cracking resistance.

(2)Electron-beam welding

YUS 350 steel plates, 20 mm thick, were demagnetized and electron-beam welded under the conditions shown in **Table 11**. The tensile and Charpy impact properties of the electron-beam welded metals are given in **Table 12**. The 0.2% offset yield strength and tensile strength of the as-welded weld metals are lower than those of the base metal, but the stress-relieved weld metal has 0.2% offset yield strength and tensile strength equivalent to those of the base metal. The stress-relieved weld metal varies in the Charpy impact absorbed energy value to a slightly greater extent than the as-welded weld metal. The impact value is high enough at more than 100 J.

Table 9 Tensile test results of TIG-welded joints of YUS 350

	Postweld heat treatment	0.2% offset yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Reduction in area (%)	Fracture position
Weld metal	No	1,034	1,093	24	74	—
	530°C, 1 h	1,083	1,085	26	75	—
Welded joint	No	963	1,036	20	76	Base metal
	530°C, 1 h	999	1,040	20	77	Base metal

Table 10 0°C Charpy absorbed energy of TIG-welded joints of YUS 350

(J)

Postweld heat treatment	Weld metal			Bond			HAZ (1mm)			HAZ (3mm)		
No	218,	206,	231	243,	248,	229	235,	231,	232	242,	231,	235
530°C, 1h	221,	210,	213	244,	251,	245	242,	247,	242	239,	239,	251

Table 12 Mechanical properties of electron-beam weld metals

Postweld heat treatment	0.2% offset yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Reduction in area (%)	0°C absorbed energy (J)
No	821	950	20	70	132, 144, 145
530°C, 1h	908	1,017	24	67	137, 147, 104

Table 11 Electron-beam welding conditions

Welding output	150 kV, 150 mA
Welding speed	50 cm/min
Frequency	1,000 Hz
Deflection	-5° in X direction
Working distance	700 mm
Focal length	470 mm
Total number of passes	11
Cooling	Furnace cooling (5 min to 350°C)

4. Conclusions

The austenitic stainless steels YUS 304N and YUS 170 and the martensitic stainless steel YUS 350 have been developed as high-strength stainless steels for use in the hydrofoils and the rudder of a large high-speed cargo ship called the Super Techno Liner (STL) under development in a Ministry of Transport project.

YUS 304N and YUS 170 are austenitic stainless steels with excellent toughness and weldability that are strengthened by solid-solution hardening with nitrogen as well as by the application of controlled rolling and accelerated cooling. Each steel features high levels of strength and toughness, and each has fatigue strength in a sodium chloride (NaCl) solution comparable to that in the air. YUS 304N and YUS 170 exhibit satisfactory properties when TIG welded by using a welding material of similar metal.

YUS 350 is a martensitic stainless steel with excellent strength that has toughness improved by the addition of nickel. The carbon content is reduced to obtain desired weldability, and niobium and molybdenum are added to prevent the deterioration of mechanical properties during postweld heat treatment. YUS 350 exhibits sufficient strength and toughness in the base metal, in the weld metal deposited by using a welding material of matching compostion, and in the weld metal deposited by electron-beam welding. YUS 350 is satisfactorily applicable to welded structures.

Originally developed for use in the underwater parts of large high-speed cargo ships, YUS 304N, YUS 170, and YUS 350 can be employed as high-strength, corrosion-resistant materials in many other welded structures.

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