Sulfuric Acid and Hydrochloric Acid Dew-point Corrosion-resistant Steel

S-TEN™

Technical Document

NIPPON STEEL & SUMITOMO METAL

Sulfuric Acid and Hydrochloric Acid Dew-point Corrosion-resistant Steel

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Features

◆ **S-TEN is a sulfuric acid and hydrochloric acid dew-point corrosion-resistant steel developed by NSSMC using proprietary technology.**

- S-TEN exhibits the best resistance to sulfuric acid and hydrochloric acid dew-point corrosion found in the flue-gas treatment equipment used with coal-fired boilers, waste incineration plants, etc. (This steel has the finest application record in the field of thermal power generation and waste incineration plants, according to surveys conducted by NSSMC)
- S-TEN exhibits the best resistance to sulfuric acid and hydrochloric acid dew-point corrosion found in hydrochloric acid pickling, industrial sulfuric acid and other tanks.
- S-TEN was awarded the Ichimura Industrial Award Achivement Award in 2007

◆ **S-TEN has strength, workability and weldability that are comparable to ordinary steel.**

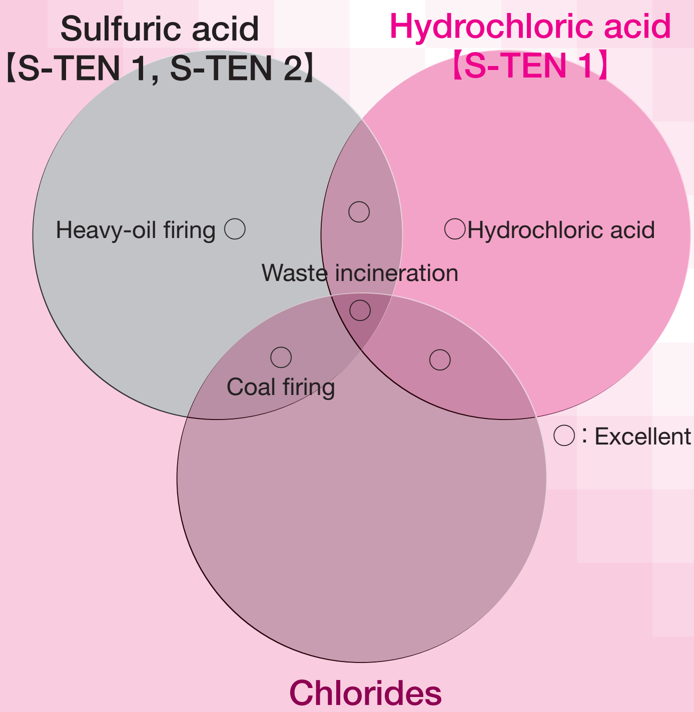
◆ **S-TEN is more economical than stainless steel.**

◆ **S-TEN offers a rich product line ranging from hot-rolled sheets (plates), cold-rolled sheets and pipe and tubes to welding materials.**

- Hot-rolled sheets (plates) conform to JIS G 3106 SM400A (S-TEN 1) and SM490A (S-TEN 2).

◆ **S-TEN products are easily available because they are constantly stocked by retailers.**

NSSMC:Nippon Steel & Sumitomo Metal Corporation



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1. Characteristics of S-TEN

Sulfuric Acid and Hydrochloric Acid Dew-point Corrosion

Recently, environmental issues are becoming pressing concerns. In parallel with this, construction of tall smokestacks, air preheaters, electrostatic precipitators and flue-gas desulfurizers and other treatment equipment has shown great strides.

Meanwhile, the mainstay industrial fuel has shifted from conventional coal to heavy oil, which poses a large problem of corrosion at the low-temperature section of flue-gas treatment equipment (in particular, air preheaters, flues and smokestacks) due to sulfur oxides.

The low-temperature section corrosion is the corrosion caused by high-temperature, highly-concentrated sulfuric acid, called sulfuric acid dew-point corrosion. This kind of corrosion differs from general atmospheric corrosion and causes heavy corrosion of not only ordinary steel but even stainless steel.

Further, because of the remarkable technological developments recently seen in dioxin countermeasures, flue-gas temperatures are increasingly being reduced from previous levels.

In conventional facilities where, formerly, only sulfuric acid dew-point corrosion occurred, there are now cases of hydrochloric acid dew-point corrosion that is caused by lower flue-gas temperatures resulting from remodeling with countermeasures against dioxins.

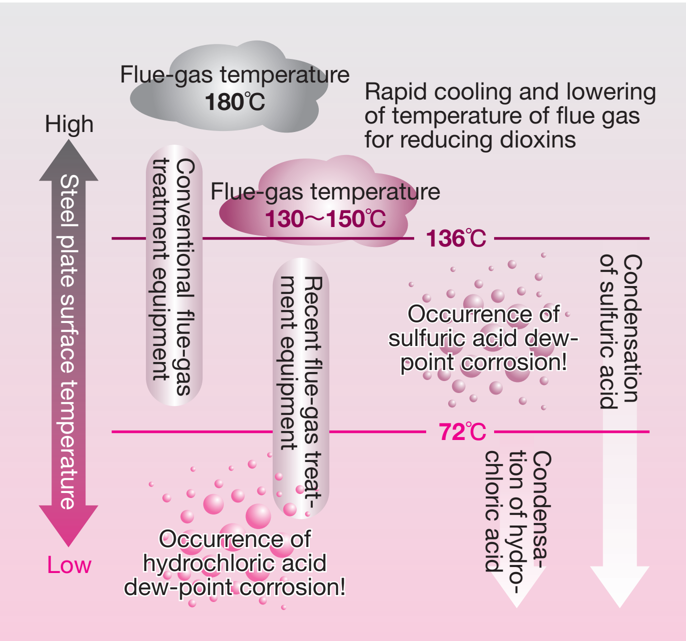
Developed to solve these problems is S-TEN — steel for welded structures, highly resistant to sulfuric acid and hydrochloric acid dew-point corrosion.

S-TEN 1 has effective resistance to both sulfuric acid dew point corrosion and hydrochloric acid dew point corrosion, while S-TEN 2 is effectively resistant to sulfuric acid dew point corrosion.

Grade	Sulfuric Acid Dew Point Corrosion Resistance	Hydrochloric Acid Dew Point Corrosion Resistance
S-TEN 1	○	○
S-TEN 2	○	—

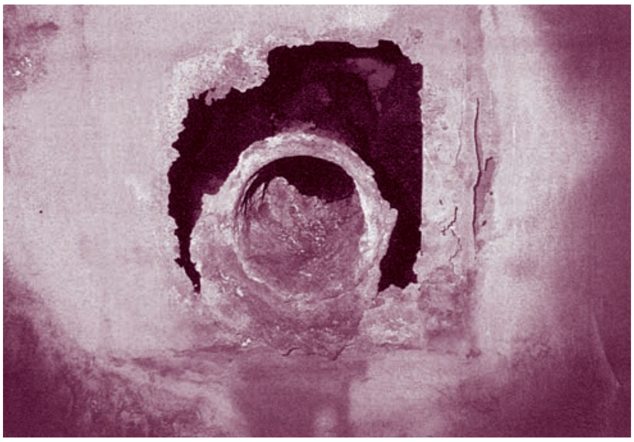
○: Excellent

Fig. 1.1 Waste Incineration Facility: Mechanism of Sulfuric Acid and Hydrochloric Acid Dew-point Corrosion Occurring in Flue-gas Treatment System



In the case of flue-gas composition (SO_3: 3 ppm, HCℓ: 300 ppm, H_2O: 30%)

Photo 1.1 Example of Hydrochloric Acid Dew-point Corrosion in Internal Cylinder of Stack



Sulfuric Acid Dew-point Corrosion

Because sulfur is contained in heavy oil used as fuel, combustion of heavy oil generates sulfur oxides (SO_x), an extremely small portion of which becomes SO_3.

Fig.1.2 shows the relation between the sulfur content of fuel and the amount of SO_2 generated, and Fig.1.3 the conversion rate from SO_2 to SO_3. When high-sulfur heavy oil containing about 3% sulfur is burnt, about 0.15% SO_2 is generated (Fig.1.2), about 2% or about 30 ppm of which becomes SO_3 (Fig.1.3).

When the flue gas temperature reaches the dew point or lower or the gas contacts the lower-temperature wall surface, SO_3 and H_2O in the gas combine to produce highly-concentrated sulfuric acid.

Fig.1.4 shows the relation between the SO_3 inclusion and the dew point in the case of 10% of H_2O concentration in the gas (normal heavy-oil combustion gas).

In the case of about 30 ppm of SO_3 inclusion, the dew point reaches 130～150℃, and at a temperature below this level sulfuric acid dew-point corrosion occurs.

Fig.1.5 shows the relation between the gas or wall surface temperature at the time of dew condensation and the sulfuric acid concentration. Sulfuric acid with a maximum concentration of 80% is produced.

Fig. 1.2 Relation between Sulfur Content and SO_2 Content in Combustion Gas[1)]

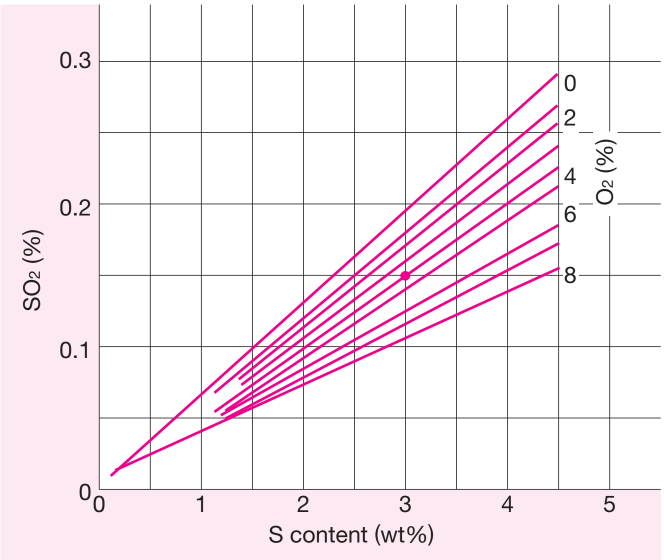
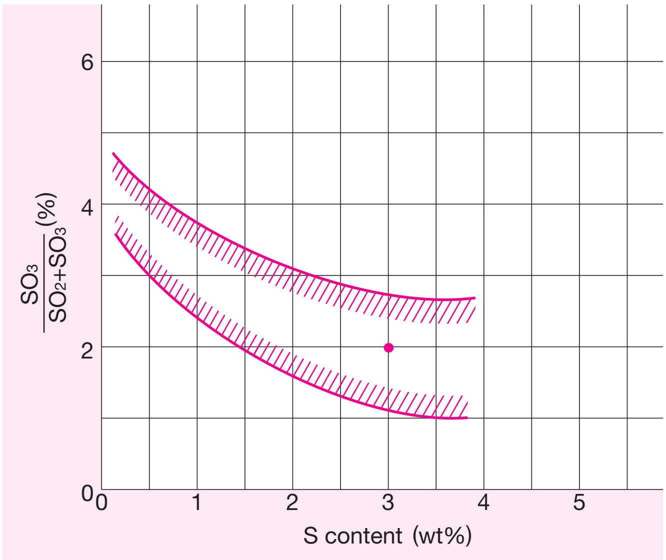


Fig. 1.3 Relation between Sulfur Content in Fuel and SO_2 to SO_3 Conversion Rate[1)]



1) H. Kuroda et al. : The Thermal Power, 16 (1965), 537. Thermal and Nuclear Power Engineering Society

Fig. 1.4 Relation between SO_3 Content in Combustion Gas and Dew Point[2)]

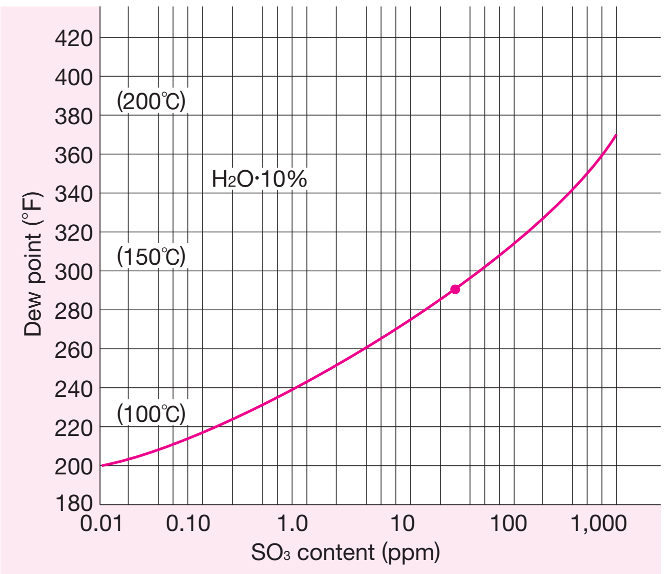
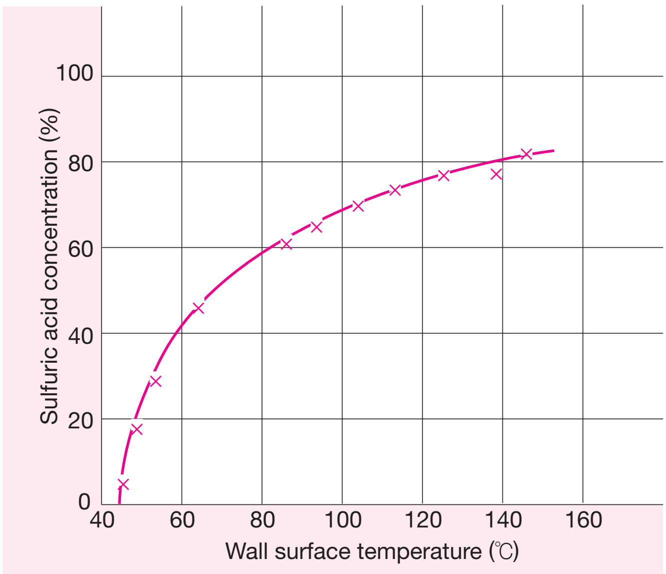


Fig. 1.5 Relation between Wall Surface Temperature and Sulfuric Acid Concentration[3)]



2) J.T. Reese et al. : Transactions of the ASME, Journal of Engineering for Power, 229, April 1965

3) H.D. Taylor : Trans. Faraday Soc., 47. 1114 (1951)

Advantages of S-TEN

Ordinary or stainless steel cannot be used in applications in which sulfuric acid dew-point corrosion is a governing factor. Neither can weathering steels such as COR-TEN™ provide satisfactory performance in these applications.

The material appropriate for these applications is S-TEN.

Fig.1.6 shows the results of sulfuric acid immersion tests conducted under the conditions of temperature and concentration obtained from Fig.1.5.

Extremely severe corrosion occurs under the conditions of 70℃ and 50% H_2SO_4. However, under such conditions, S-TEN exhibits corrosion resistance about five times greater than both ordinary steel and COR-TEN and about 10 times that of stainless steel. It is in such severe application environments that S-TEN shows the best performance.

In this way, corrosion caused by high-temperature, highly concentrated sulfuric acid differs from common atmospheric corrosion. Not only ordinary steel but stainless steel, as well, is heavily corroded in environments of high-temperature, highly concentrated sulfuric acid (in some cases, exceeding a corrosion rate of 5 mm/year).

Fig.1.7 shows the clear differences in corrosion resistance demonstrated by ordinary steel, COR-TEN, and S-TEN during long-term tests conducted in actual 60% H_2SO_4 or higher environments at 80℃ with sufficient oxygen to produce sulfuric acid dew-point corrosion.

Table 1.1 Chemical Composition of Test Specimens

Grade (equivalent)	Chemical composition (%)									
	C	Si	Mn	P	S	Cu	Ni	Cr	Sb	Others
SUS 410 (13%Cr) (equivalent)	0.10	0.38	0.46	0.019	0.012	0.12	0.19	12.53	—	—
SUS 430 (18%Cr) (equivalent)	0.07	0.51	0.34	0.040	0.006	0.11	0.27	17.29	—	—
SUS 304 (18Cr-8Ni) (equivalent)	0.08	0.58	1.42	0.029	0.008	0.20	9.21	18.56	—	—
SUS 316 (18Cr-12Ni-2Mo) (equivalent)	0.08	0.68	1.62	0.030	0.008	0.24	11.72	17.05	—	Mo:2.20
Mild Steel	0.16	0.03	0.23	0.008	0.013	0.08	—	—	—	—
S-TEN 1	**0.03**	**0.28**	**0.91**	**0.011**	**0.009**	**0.27**	**—**	**—**	**0.10**	**—**
S-TEN 2	**0.10**	**0.21**	**0.75**	**0.014**	**0.012**	**0.36**	**—**	**0.63**	**—**	**Ti:0.04**
COR-TEN A	0.09	0.46	0.38	0.110	0.017	0.32	0.30	0.52	—	—

Fig. 1.6 Sulfuric Acid Immersion Test Results under the Atmosphere-solution Equilibrium State of Sulfuric Acid and Hydrogen

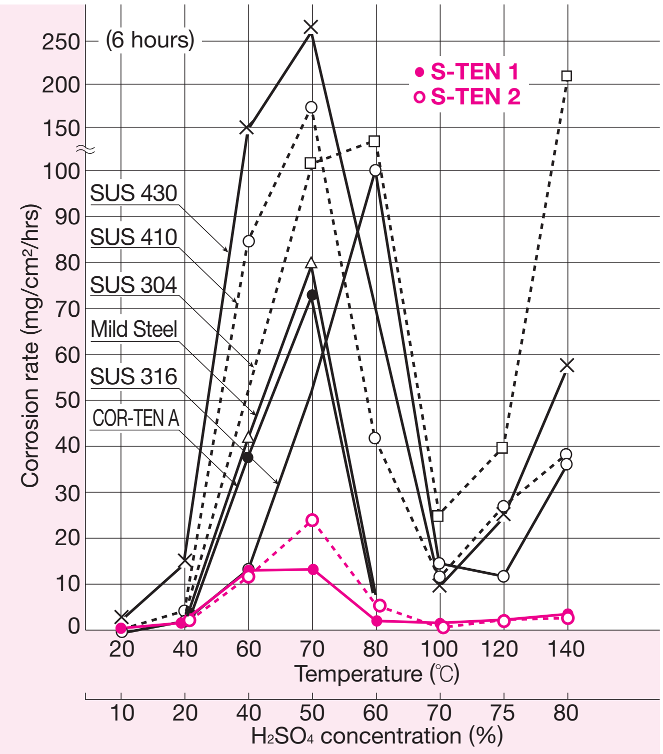
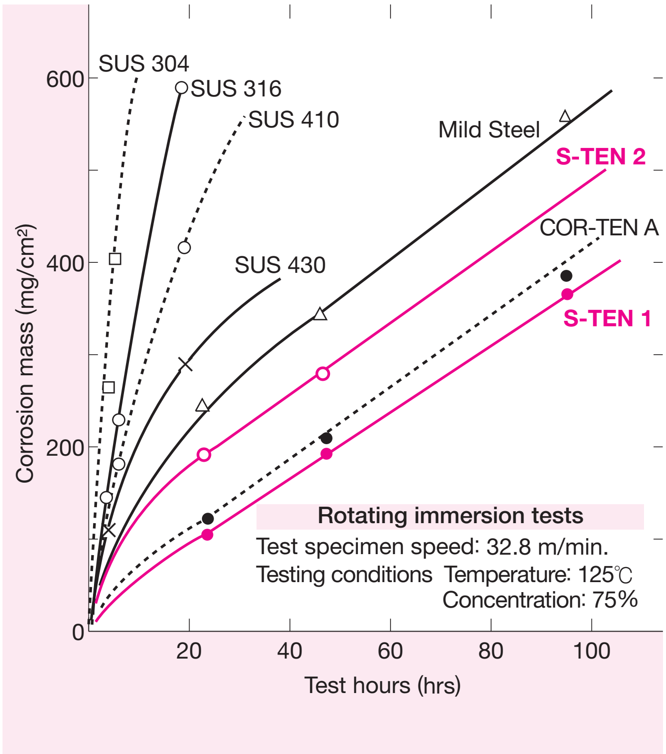


Fig. 1.7 Corrosion Mass of Steel in H_2SO_4



Application Examples for S-TEN

Table 1.7 Examples of Applications of S-TEN

Equipment	Practical application examples				Precautions in use
	Application	Grade		Approximate plate thickness (mm)	
		S-TEN 1	S-TEN 2		
Dry-type electrostatic precipitator	Casing, duct, collecting electrode	○	○	1.2～8	The temperature of casings and ducts is 20～70℃ lower than that of flue gas, depending on the heat insulation conditions. It is estimated that the temperature of the collecting electrode and the gas is the same. In cases when dust accumulates, the absorbed H_2SO_4 is difficult to evaporate and leads to cases of more than expected corrosion. As a result, it is necessary to prevent dust accumulation.
Wet-type electrostatic precipitator	Casing, duct, collecting electrode	○	○	3.2～12	In cases when the flow of scrubber water is constant against a wall surface, the corrosion mass increases (by 0.1 mm/yr on one side). Further, in cases when the scrubber water in such a situation has a low pH value, the corrosion mass will increase abruptly, thereby making it necessary to avoid the use of S-TEN.
Gas cooler	Casing, duct	○	○	4.5～9	The temperature of casings and ducts is 20～70℃ lower than that of flue gas, depending on the heat insulation conditions. The mist droplet becomes large due to the deterioration of nozzle holes and does not evaporate to reach the casing, under which there are cases when unexpected corrosion occurs, and thus it is necessary to control the deterioration of nozzle holes.
	Ash discharge blade	—	○	12～20	S-TEN 2 is most suitable for use as the material for the blades that discharge the ash accumulated in the bottom section of gas cooler. The stress-induced corrosion cracking attributable to the chlorides contained in the ash can be prevented from occurring.
Air preheater	Ljungström-type basket case, element	○	○	0.6～6	Because of repeated fluctuations in wall surface temperature, dew-point corrosion from high to low temperatures occurs repeatedly, and the application advantage of S-TEN is exhibited to the high degree.
	Tube	○	—	0.6～3.5	The tubes are constantly in the dew-point state, and accordingly, S-TEN is highly effective. S-TEN 1 tube is most suitable for such application.
Flue	Duct, expansion	○	○	4.5～9	S-TEN of the no coating specifications or the acid resistant-coating specifications is suitable. When the temperature of the flue gas itself drops below the dew point, drainage accumulates in the flue bottom, frequently causing unexpectedly severe corrosion, and thus it is recommended to provide appropriate measures to carry out sufficient drainage and to prevent lowering of steel plate temperatures by means of external heat insulation.
Stack	Internal cylinder	○	—	6～12	
Flue-gas desulfurizer	Flue-gas cylinder, after-burner duct	○	○	3.2～6	In the ducts leading to and from gas coolers and absorption towers, low pH solutions occasionally adhere to wall surfaces due to sulfuric acid mist, and therefore it is necessary to fully investigate drainage conditions.
Hydrochloric acid pickling tank	Tank	○	—	9～20	The use for hydrochloric acid pickling tank in coating is suitable. S-TEN tanks have a high scratch resistance during use, and these tanks after use can be treated as the general recyclable steel material.

Precaution in the Use of S-TEN

1) S-TEN are a group of low-alloy corrosion-resistant steels. It should be noted that despite dew point corrosion being inhibited in them, there still occurs rust formation and progress of corrosion also.
2) S-TEN, as shown in Fig. 1.6, are effective in inhibiting sulfuric acid dew point corrosion, as compared with other steel grades, but, as can be seen from their performance at 60°C and 70°C in this figure, there are temperature regions in which steels' absolute corrosion weight losses become greater than those in the other temperature regions.
3) Careful note must be taken of the fact that S-TEN also tend to be more greatly susceptible to high-temperature corrosion and low-concentration sulfuric acid corrosion, than to corrosion occurring in the gas-liquid equilibrium state, as shown in Fig. 1.10.
4) Results of the corrosion test made at very thin concentrations of pH2 to 4 of sulfuric acid are shown in Table 1.8. As against corrosion by such weakly acidic or neutral liquid, stainless steels are most resistant, with very little corrosion weight loss. At concentrations of pH3 and over, there is no significant difference between ordinary steels and S-TEN.

Fig. 1.10 Corrosion behaviors of S-TEN in non-equilibrium regions

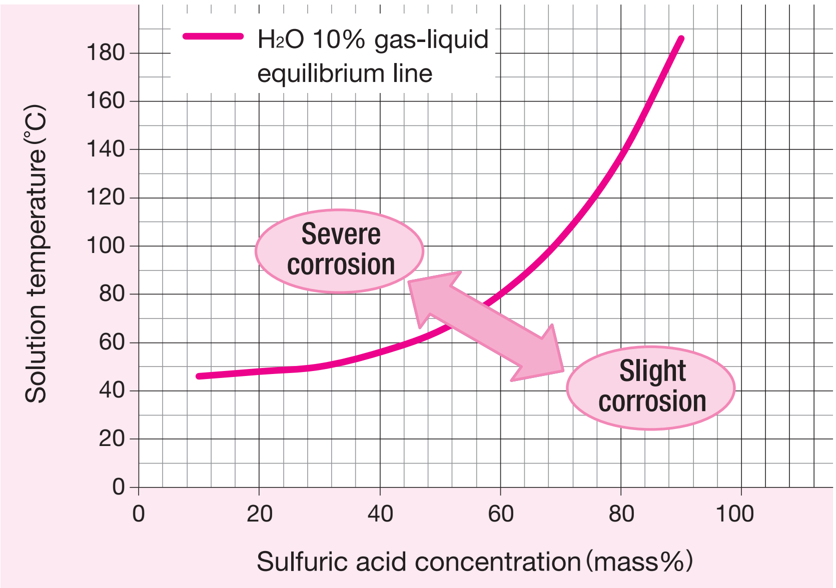


Table 1.8 Results of corrosion tests in the weakly acidic area (pH2 to 4)

Grade	Corrosion rate (mg/cm²/hrs)			Testing conditions
	pH2	pH3	pH4	
S-TEN 1	**1.6**	**2.0**	**0.36**	Test temperature: 30℃ Relative speed of specimen and solution: 1.8 m/sec Test time: 72 hrs
S-TEN 2	**2.8**	**2.2**	**0.38**	
Mild Steel	8.2	2.5	0.36	
SUS 304	<0.001	<0.001	<0.001	
SUS 316	<0.001	<0.001	<0.001	
SUS 410	0.51	<0.001	<0.001	
SUS 430	0.001	<0.001	<0.001	

2. Specifications and Available Sizes of S-TEN

Specifications of S-TEN

① Grade Designation

Table 2.1

Grade	Product	Thickness [diameter] (mm)	
S-TEN 1	Cold-rolled sheet	0.6≦t≦2.3	
	Hot-rolled sheet and plate 1)	1.6≦t≦20.2	
	ERW pipe and tube 2)	Outside dia.: 19.0～114.3	Wall thickness: 2.0～8.9
	Seamless pipe and tube 2)	Outside dia.: 31.8～426	Wall thickness: 3.0～50
	Large-diameter pipe	Outside dia.: 400～2,500	Wall thickness: 6.0～20
S-TEN 2	Cold-rolled sheet	0.6≦t≦2.3	
	Hot-rolled sheet and plate 1)	1.6≦t≦25.4	
	Bar and bar-in-coil	t≦38	

Notes 1) Hot-rolled sheets and plates (all plates; specification required for sheet) conform to JIS G 3106 (S-TEN 1: SM400A; S-TEN 2: SM490A). JIS is inscribed on the steel product inspection sheet when specified.
2) ERW pipe and tubes are registered in the technical standards for thermal power generation facilities (METI KA-STB380J2, KA-STPT380J2), ASME Code Case 2494 and ASTM A423.

② Chemical Composition

Table 2.2

Grade	Chemical composition (%)								
	C	Si	Mn	P	S	Cu	Cr	Ti	Sb
S-TEN 1	≦0.14	≦0.55	≦1.60 1)	≦0.025	≦0.025	0.25～0.50	—	—	≦0.15
S-TEN 2	≦0.14	0.15～0.55	≦1.60	≦0.035	≦0.035	0.25～0.50	0.50～1.00	≦0.15	—

Notes 1) 2.5×[C]≦Mn
2) Alloying elements other than those shown in the table may added as occasion demands

③ Mechanical Properties

Table 2.3 Cold-rolled Sheets and Bars

Grade	Thickness (mm)	Yield point (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)	Test specimen (JIS)
S-TEN 1	—	235≦	400≦	23≦	No. 5
S-TEN 2	—	325≦	440≦	22≦	No. 5 1)

Note 1) Bars: No. 2 for the diameters 25 mm or less; No. 14A for the diameters more than 25 mm

Table 2.4 Hot-rolled Sheets and Plates, and Spiral Welded Pipe

Grade	Thickness (mm)	Yield point (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)	Test specimen (JIS)
S-TEN 1	≦5	245≦	400～510	23≦	No. 5
	≦16			23≦	No. 5
				18≦	No. 1A 1)
	≦20.2	235≦		23≦	No. 5
				22≦	No. 1A 1)
S-TEN 2	≦5	325≦	490～610	22≦	No. 5
	≦16			22≦	No. 5
				17≦	No. 1A 1)
	≦25.4	315≦		22≦	No. 5
				21≦	No. 1A 1)

Note 1) Applied in the case of production as JIS G 3106 (applied in all production of plates)

Table 2.5 ERW Pipes and Tubes, Seamless Pipes and Tubes

Grade	Thickness (mm)	Yield point (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)	Test specimen (JIS)
S-TEN 1	—	230≦	380≦	35≦ 1)	No. 11 or 12
				30≦	No. 4 (pipe axis direction)

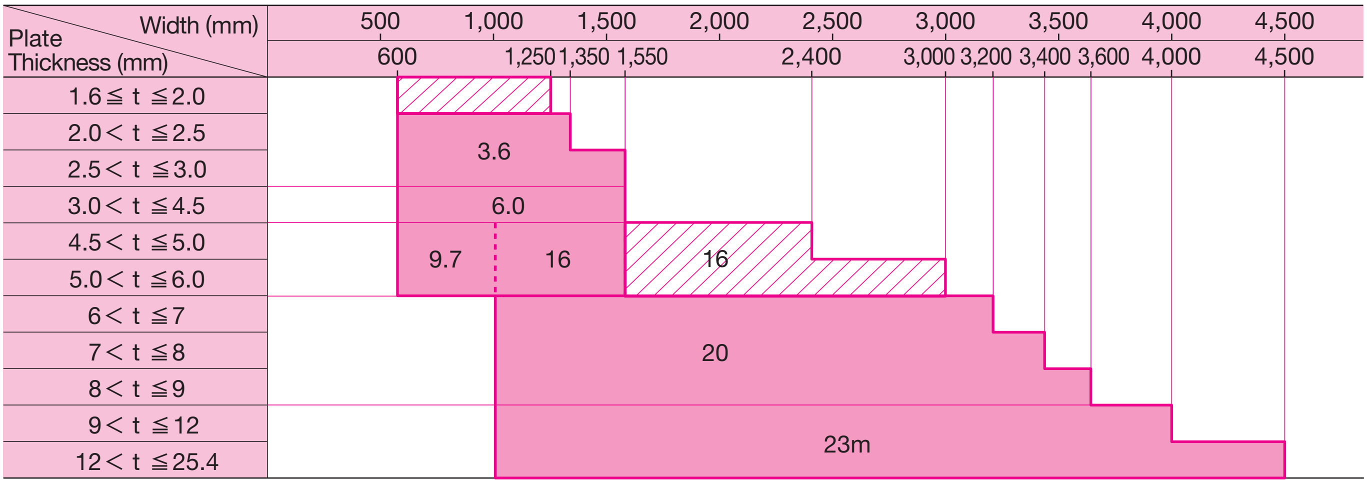
Note 1) Minimum elongation values for No.12 test piece (pipe axis direction) taken from pipes under 8mm in wall thickness

Elongation value by thickness division						
1＜t≦2mm	2＜t≦3mm	3＜t≦4mm	4＜t≦5mm	5＜t≦6mm	6＜t≦7mm	7＜t＜8mm
26	28	29	30	32	34	35

(Unit : %)

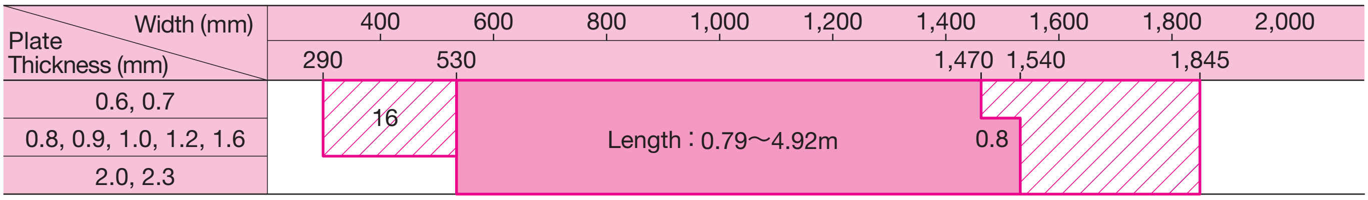
Available Sizes for S-TEN

①Hot-rolled Sheets and Plates (S-TEN 1, S-TEN 2)



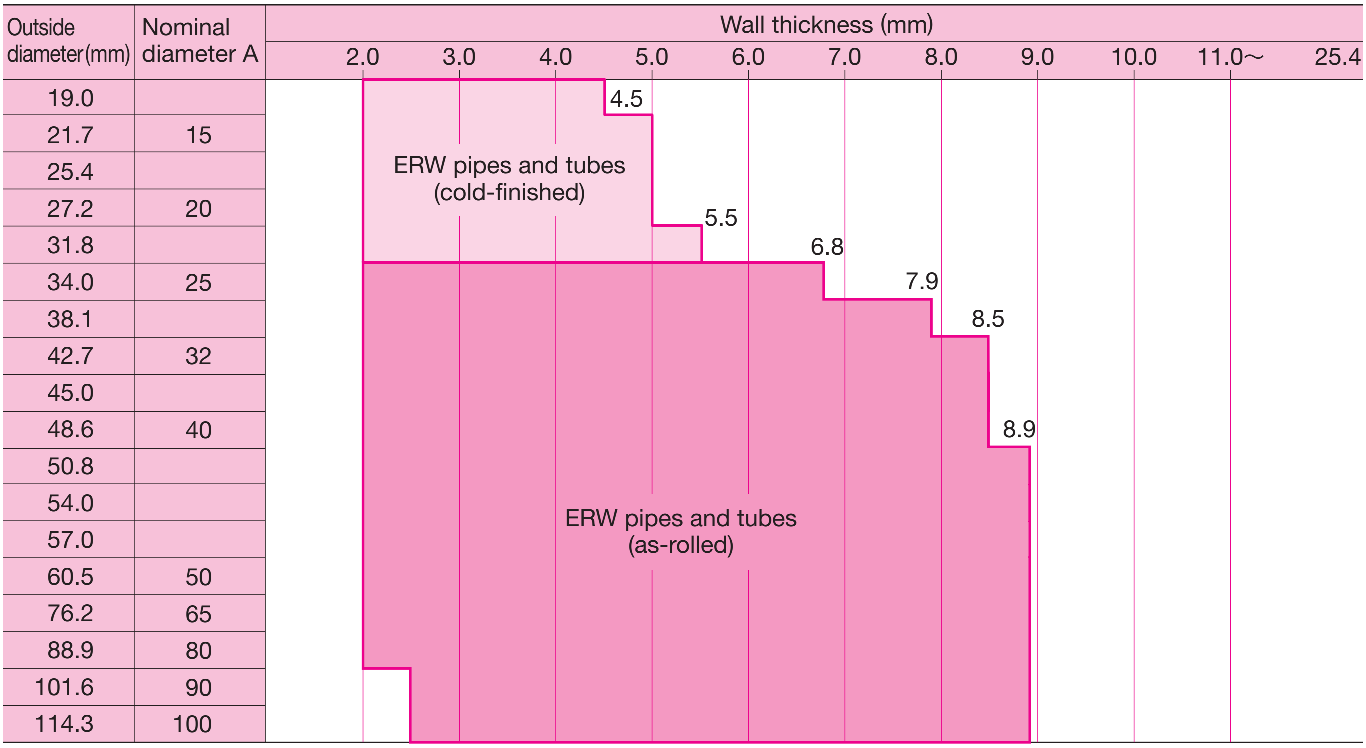
Notes 1) Figures in the table show the maximum length.
2) Minimum length: 3 m for the thicknesses 6 mm or more; 1.5 m for the thicknesses less than 6 mm
3) [hatched box] For this size range and the plate thicknesses up to 50 mm, please consult us in advance.

②Cold-rolled Sheets (S-TEN 1, S-TEN 2)



Note) [hatched box] For this size range, please consult us in advance.

③ERW Pipes and Tubes (S-TEN 1)

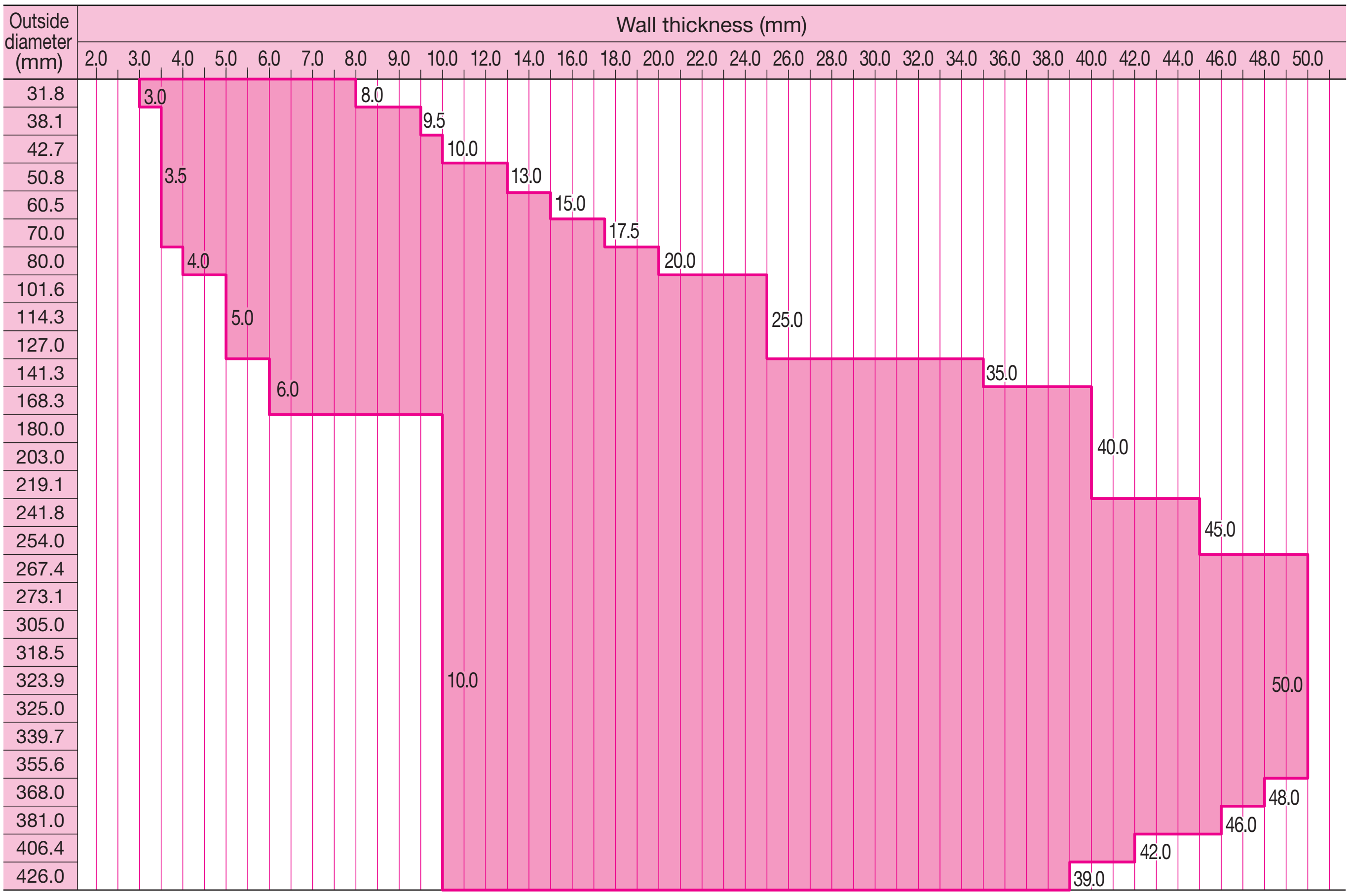


Note) The following sizes are subject to negotiation. Available products are SAW pipe (BR or SP). Outside diameter (nominal diameter A): 138.9–125, 165.2–150, 216.3–200, 267.4–250, 318.5–300, 355.6–350, 406.4–400; maximum outside diameter: 2,500 mm

2. Specifications and Available Sizes of S-TEN

Available Sizes for S-TEN

④Seamless Pipes and Tubes (S-TEN 1)



3.Characteristic Properties of S-TEN (Examples)

Chemical Composition and Mechanical Properties

① Chemical Composition

Table 3.1 Chemical Composition (Example)

Grade	Product	Chemical composition (%)							
		C	Si	Mn	P	S	Cu	Cr	Others
S-TEN 1	Cold-rolled sheet	0.04	0.30	0.91	0.015	0.010	0.30	—	Sb : 0.10
	Hot-rolled medium plate	0.04	0.30	0.91	0.015	0.010	0.30	—	Sb : 0.10
	Plate	0.04	0.28	1.00	0.012	0.012	0.28	—	Sb : 0.09
	ERW pipe and tube	0.04	0.20	1.00	0.011	0.010	0.27	—	Sb : 0.10
	Seamless pipe and tube	0.03	0.25	1.12	0.006	0.014	0.29	—	Sb : 0.12
S-TEN 2	Cold-rolled sheet	0.09	0.24	0.76	0.017	0.013	0.32	0.68	Ti : 0.03
	Hot-rolled medium plate	0.12	0.26	0.76	0.016	0.007	0.28	0.70	Ti : 0.03
	Plate	0.14	0.22	0.75	0.018	0.012	0.34	0.65	Ti : 0.03

② Mechanical Properties

Table 3.2 Hot-rolled Sheets and Plates

Grade	Plate thickness (mm)	Tensile test		
		Yield point (N/mm²)	Tensile strength (N/mm²)	Elongation (%)
S-TEN 1	2.3	345	470	36
	6.0	383	458	38
	12.0	382	452	42
	16.0	368	441	47
S-TEN 2	2.3	440	540	33
	6.0	440	530	35
	9.0	420	520	39
	13.0	410	510	41

Test specimen: JIS No. 5

Table 3.3 Cold-rolled Sheets

Grade	Plate thickness (mm)	Tensile test		
		Yield point (N/mm²)	Tensile strength (N/mm²)	Elongation (%)
S-TEN 1	1.2	295	410	36
	1.6	305	440	36
S-TEN 2	0.8	380	490	32
	1.2	380	490	32

Table 3.4 ERW Pipes and Tubes

Grade	Outside diameter × Wall thickness (mm)	Tensile test		
		Yield point (N/mm²)	Tensile strength (N/mm²)	Elongation (%)
S-TEN 1	48.6 × 3.5	298	403	61
	89.1 × 5.0	293	418	41

Table 3.5 Seamless Pipes and Tubes

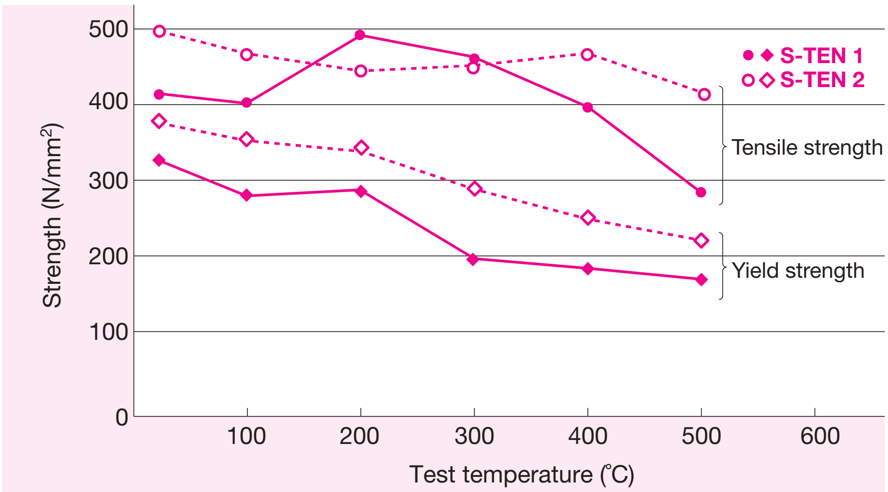
Grade	Outside diameter × Wall thickness (mm)	Tensile test		
		Yield point (N/mm²)	Tensile strength (N/mm²)	Elongation (%)
S-TEN 1	50.8 × 8.0	319	440	58
	219.1 × 15.1	300	414	56

High-temperature Characteristics

High-temperature Short-time Strength

Results of high-temperature tensile tests are shown in Fig. 3.1.

Fig. 3.1 High-temperature Tensile Test Results



Physical Properties

Physical properties are shown in Table 3.6. Specific heat, thermal conductivity and thermal expansion coefficient of S-TEN are similar to those of Mild Steel, SM400A, SM490C, etc.

Table 3.6 Physical Properties

Grade	Temperture (℃)	Young's modulus (GPa)	Specific heat (kJ/kg・K)	Thermal conductivity (W/m・K)	Thermal expansion coefficient 20℃~T (×10^{-6}/℃)
S-TEN 1	25	207.4	0.450	44.2	—
	100	203.7	—	—	12.8
	200	198.3	0.491	45.5	13.2
	300	192.0	—	—	13.6
	400	184.0	0.532	36.8	14.0
	500	—	—	—	—
S-TEN 2	25	211.0	0.456	45.1	—
	100	207.0	0.486	41.2	12.8
	200	202.0	0.520	40.8	13.1
	300	196.0	0.553	40.2	13.5
	400	188.0	0.590	37.7	13.8
	500	179.0	0.644	34.1	14.2

Measurement method — Young's modulus: Resonance method; Specific heat and thermal conductivity: Laser flash method; Thermal expansion coefficient: Measurement of thermal expansion

Corrosion Resistance

① Weather Resistance

S-TEN surpasses ordinary steel in weather resistance:
S-TEN 1: About 2 times (similar to Cu-containing steel)
S-TEN 2: 4~6 times (similar to COR-TEN 490)

Table 3.7 Chemical Composition of Test Specimens for Hydrochloric Acid Resistant and High-temperature Oxidation Tests (Figs. 3.2~3.5)

Grade	Chemical composition (%)								
	C	Si	Mn	P	S	Cu	Cr	Sb	Ti
S-TEN 1	0.03	0.26	0.90	0.011	0.010	0.27	—	0.09	—
S-TEN 2	0.09	0.24	0.69	0.009	0.014	0.29	0.54	—	0.03
Mild Steel	0.15	0.14	0.70	0.014	0.005	0.01	—	—	—

② Hydrochloric Acid Resistance

Corrosion caused by hydrochloric acid gas contained in the exhaust gas of garbage disposal incinerators has recently become a social problem. S-TEN 1 has greater resistance to hydrochloric acid corrosion than ordinary steel, and thus permits effective application in this field (for example, hydrochloric acid tanks for galvanizing). Figs. 3.2~3.5 show the results of tests pertaining to hydrochloric acid corrosion.

1) S-TEN 1 exhibits corrosion resistance 5~10 times that of ordinary steel.
2) In dilute hydrochloric acid (about 3% or less), the corrosion rate of S-TEN is higher than that of SUS, and thus the use of S-TEN in such environments is not recommended.
3) In hydrochloric acid with a concentration of 10% or more, S-TEN 1 exhibits high corrosion resistance.
4) As the temperature and concentration of hydrochloric acid increases, S-TEN 1 exhibits higher corrosion resistance.
5) Please pay attention to the fact that when alien substances are mixed in the acid, characteristic properties may vary in some cases.

Fig. 3.2 Relation between Hydrochloric Acid Concentration and Corrosion Rate

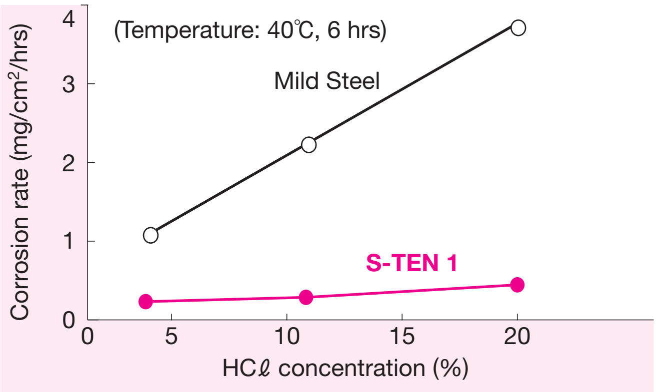


Fig. 3.3 Relation between Hydrochloric Acid Concentration and Corrosion Rate

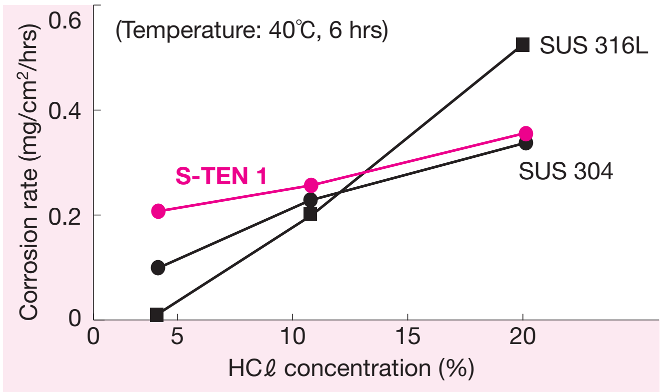


Fig. 3.4 Relation between Hydrochloric Acid Concentration and Corrosion Rate

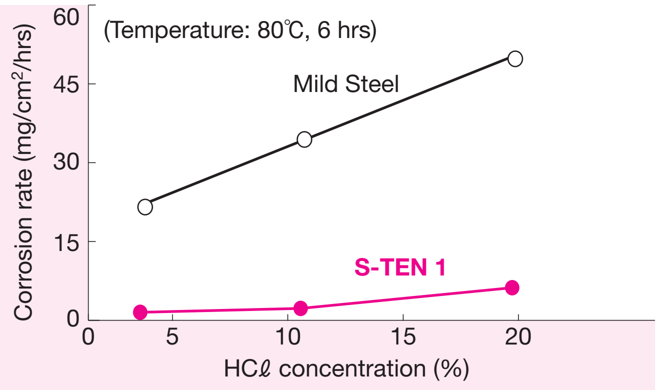
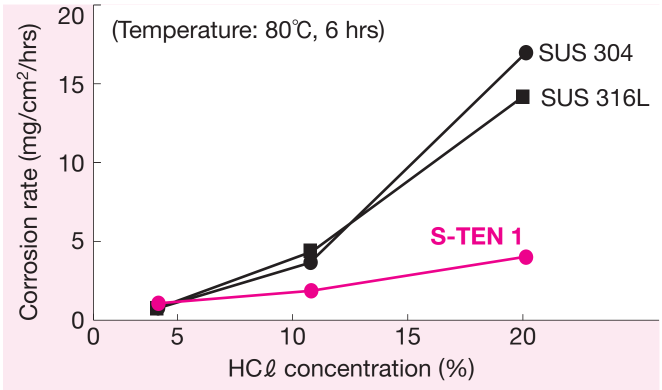
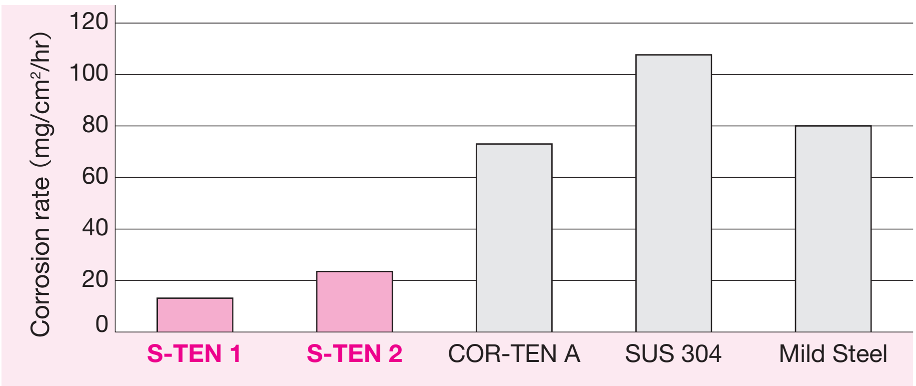


Fig. 3.5 Relation between Hydrochloric Acid Concentration and Corrosion Rate



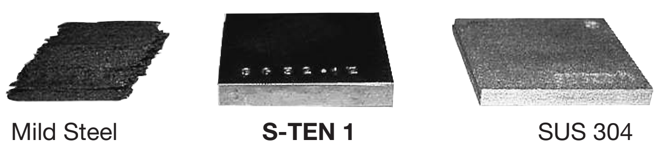
③ Sulfuric Acid Resistance

Fig 3.6 Sulfuric Acid Resistance of Various Steel Products (50%, 70℃, H_2SO_4)



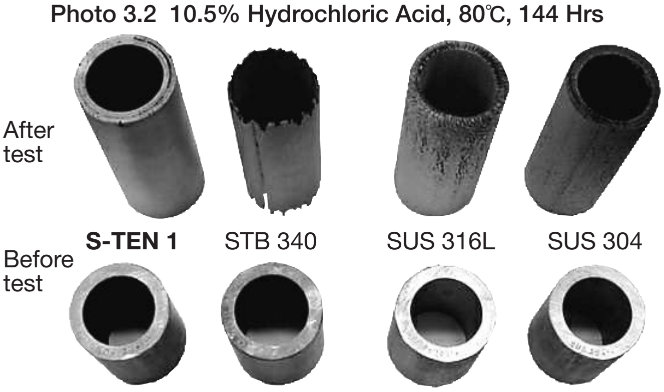
④ Appearance of Various Steel Products after Accelerated Corrosion Tests

Photo 3.1 10.5% Hydrochloric Acid, 60℃, 72 Hrs



(Initial size of test specimen : 4t×25×25 mm)

Photo 3.2 10.5% Hydrochloric Acid, 80℃, 144 Hrs



4. Welding of S-TEN

The carbon and manganese contents of S-TEN are kept low to secure high corrosion resistance. Therefore, S-TEN offers excellent weldability and can be welded under the same conditions as those for ordinary steel of the same strength level.

However, because sulfuric acid and hydrochloric acid dew-point corrosion resistance similar to that of the base metal is required for welds, it is necessary to use welding materials for exclusive use for S-TEN.

Welding Materials

As the welding material for exclusive use for S-TEN, Nippon Steel & Sumikin Welding Co., Ltd.* supplies the following products.

*Inquiry: Nippon Steel & Sumikin Welding Co., Ltd.
Shingu Bldg.,2-4-2 Toyo, Koto-ku,Tokyo 135-0016
Tel: +81-3-6388-9000 Fax: +81-3-6388-9160
www.welding.nssmc.com

① Welding Materials

Table 4.1

Grade	Kind of shielding material			
	Shielded metal arc welding (SMAW)	Gas shielded metal arc welding		Submerged arc welding (SAW)
		MAG welding (FCAW)	TIG welding (GTAW)	
S-TEN 1	NSSW ST-16M 1) ☆(JIS Z 3211 E4916-G)	NSSW SF-1ST ☆(JIS Z 3313 T49J0T1-1CA-UH5) (AWS S-36 E81T1-C1A0-G)	NSSW YT-1ST ☆(JIS Z 3313 T49J0TG-1GA-U)	NSSW Y-1ST × NSSW NB-1ST ☆(JIS Z 3183 S502-H)
S-TEN 2	NSSW ST-16Cr 1) ☆(JIS Z 3211 E5516-G)	NSSW FC-23ST ☆(JIS Z 3313 T49J0T1-1CA-U)	—	—
	NSSW ST-03Cr 2) ☆(JIS Z 3211-E4903-G)			

Notes 1) Low-hydrogen type 2) Lime titania type
Mark"☆" means that the product meets the classification requirements but that the JIS Mark system is not applicable to the classification.

② Chemical Composition and Mechanical Properties of Various Welding Materials (Example)

Table 4.2

Welding method	Brand	C	Si	Mn	P	S	Cu	Cr	Sb	YS (N/mm²)	TS (N/mm²)	EL (%)	vE0 (J)
SMAW	NSSW ST-16M	0.04	0.62	0.50	0.009	0.004	0.42	—	0.08	471	568	29	165
	NSSW ST-16Cr	0.05	0.50	0.48	0.012	0.006	0.20	0.73	—	481	550	27	203
	NSSW ST-03Cr	0.06	0.15	0.56	0.014	0.011	0.23	0.79	—	463	532	26	112
FCAW	NSSW SF-1ST	0.05	0.60	1.41	0.012	0.013	0.39	—	0.10	581	640	25	71
	NSSW FC-23ST	0.04	0.38	0.81	0.016	0.013	0.35	0.74	—	512	585	25	52
GTAW	NSSW YT-1ST	0.01	0.29	1.33	0.004	0.009	0.32	—	0.10	398	478	39	285
SAW	NSSW Y-1ST × NSSW NB-1ST	0.03	0.34	1.13	0.007	0.011	0.19	—	0.09	452	530	31	141

③ Welding Materials for Dissimilar Welding with Stainless Steels (Example)

Table 4.3

Welding method	Brand	C	Si	Mn	P	S	Cr	Ni	YS (N/mm²)	TS (N/mm²)	EL (%)	vE0 (J)
SMAW	NSSW 309·R	0.06	0.33	1.51	0.020	0.006	24.2	13.2	460	582	37	64
SAW	NSSW Y-309× NSSW BF-300M	0.06	0.45	1.64	0.020	0.010	24.0	13.5	375	558	38	89
FCAW	NSSW SF-309L	0.03	0.65	1.54	0.023	0.009	24.4	12.7	429	566	37	36
GMAW	NSSW YM-309	0.05	0.35	1.74	0.021	0.007	23.6	13.3	447	618	33	92
GTAW	NSSW YT-309	0.05	0.40	1.65	0.020	0.006	23.8	12.4	517	620	34	166

Welding Characteristics

Maximum hardness tests and y-groove weld cracking tests prescribed by JIS were performed to confirm the weldability of S-TEN. S-TEN 1 and 2 having the characteristics shown in Tables 4.4 and 4.5 were used as the test specimens.

Table 4.4 Chemical Composition of Test Specimens

Grade	Thickness (mm)	Chemical composition (%)								
		C	Si	Mn	P	S	Cu	Cr	Ti	Sb
S-TEN 1	16	0.04	0.28	1.00	0.012	0.012	0.28	—	—	0.09
S-TEN 2	16	0.09	0.21	0.74	0.023	0.010	0.35	0.70	0.02	—

Table 4.5 Mechanical Properties of Test Specimens

Grade	Thickness (mm)	Tensile test		
		Yield point (N/mm^2)	Tensile strength (N/mm^2)	Elongation (%)
S-TEN 1	16	368	441	47
S-TEN 2	16	380	500	43

Tensile test specimen: JIS No. 5

① Maximum Hardness Test

Table 4.6 shows the results of HAZ maximum hardness tests in accordance with JIS Z 3101 (Testing Method of Maximum Hardness in Weld Heat-Affected Zone).

Table 4.6 Maximum Hardness Test Results

Grade	Thickness (mm)	Initial temperature of specimen	Maximum hardness (Hv)
S-TEN 1	16	Room temperature	189
S-TEN 2	16	Room temperature	242

Welding conditions: Welding Electrodes 4 mm in dia.; current 170 A; voltage 24 V; speed 150 mm/min

② y-groove Cracking Test

To determine the crack sensitivity of welds, the test was conducted using the test specimens, shown in Fig. 4.1, in accordance with JIS Z 3158 (Method of y-Groove Cracking Test). The test results are shown in Table 4.7.

Fig. 4.1 Configuration of y-groove Weld Cracking Test Specimen

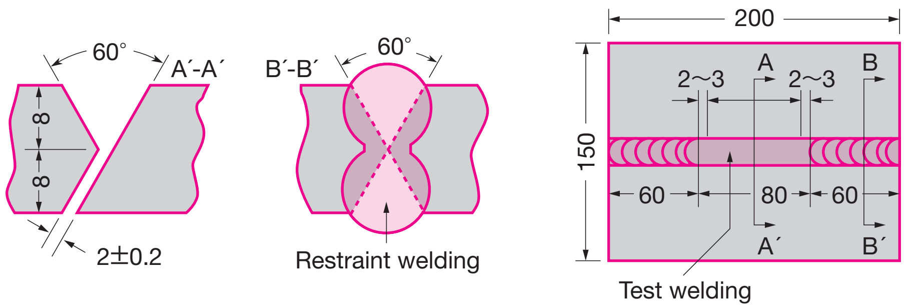


Table 4.7 y-groove Weld Cracking Test Results

Grade	Thickness (mm)	Initial temperature of specimen (℃)	Surface crack rate (%)				Section crack rate (%)				Root crack rate (%)			
			1	2	3	Average	1	2	3	Average	1	2	3	Average
S-TEN 1	16	0	0	0	0	0	0	0	0	0	0	0	0	0
		25	0	0	0	0	0	0	0	0	0	0	0	0
S-TEN 2	16	0	0	0	0	0	0	0	0	0	0	0	0	0
		25	0	0	0	0	0	0	0	0	0	0	0	0

Welding conditions: Welding Electrodes 4 mm in dia.; current 170 A; voltage 24 V; speed 150 mm/min

Sulfuric Acid and Hydrochloric Acid Resistance of Welded Joints

Sulfuric acid and hydrochloric acid immersion test of welded joints was conducted to determine the sulfuric acid resistance of welded joints, the results of which are shown below.

The test results indicate that the welded joints made using welding rods for exclusive use for S-TEN exhibit corrosion resistance similar to that of the base metal. But in the case of using welding rods for use for mild steel, the results clearly indicate that the welded joints only are severely corroded.

① Example of S-TEN 1

Immersion tests were conducted using the test specimen, consisting of both base metal and weld metal, shown in Fig. 4.2 and under the conditions shown in Photo 4.1. Cross sections of the corroded specimen are shown in Photo 4.1.

Fig. 4.2 Configuration of Sulfuric Acid Immersion Test Specimen

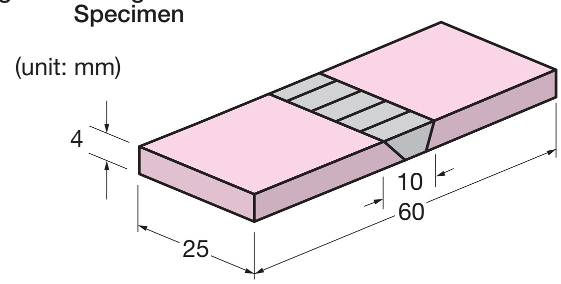
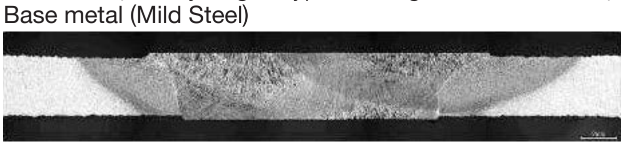


Photo 4.1 Corrosion Conditions of S-TEN 1 Weld Joint

Hydrochloric acid : 10.5% hydrochloric acid × 80℃ × Immersion for 24 hrs

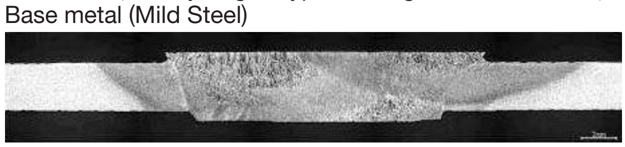
NSSW-16 (Low hydrogen-type welding rod for mild steel) × Base metal (Mild Steel)



NSSW ST-16M (Welding rod for exclusive use for S-TEN) × Base metal (S-TEN 1)

Sulfuric acid : 50% sulfuric acid×70℃×Immersion for 24 hrs

NSSW-16 (Low hydrogen-type welding rod for mild steel) × Base metal (Mild Steel)



NSSW ST-16M (Welding rod for exclusive use for S-TEN) × Base metal (S-TEN 1)

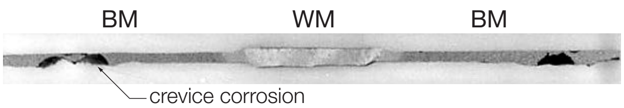
② Field Test Results

Immersion condition : 17.5% hydrochloric acid, 32℃, fully immersed
Immersion period : 4 months

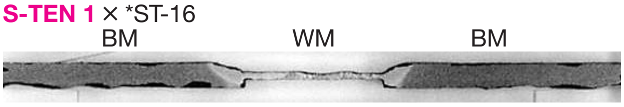
Photo 4.2 Cross Sections of Joint Specimens Immersed in Hydrochloric Acid Pickling Tank for 4 Months

Base metal × Weld metal

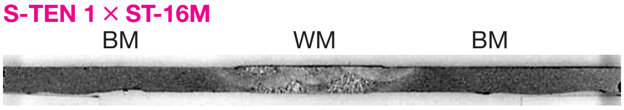
Mild Steel × NSSW-16



S-TEN 1 × *ST-16

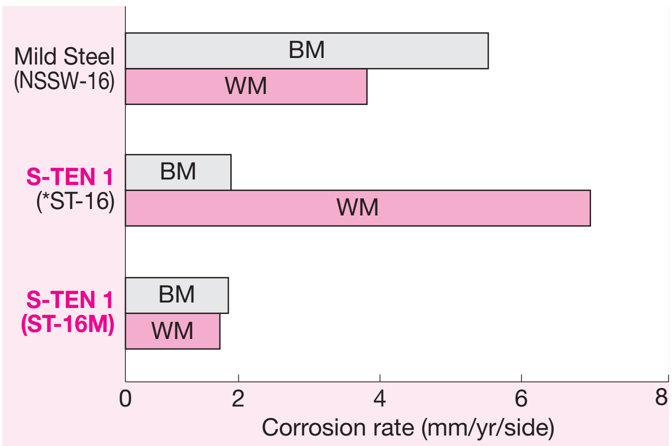


S-TEN 1 × ST-16M



BM : Base metal : WM : Weld metal *ST-16 : Brand name of conventional weld material for S-TEN (production discontinuation)

Fig. 4.3 Test Results for Weld Joint Test Specimens Immersed in Hydrochloric Acid Pickling Tank



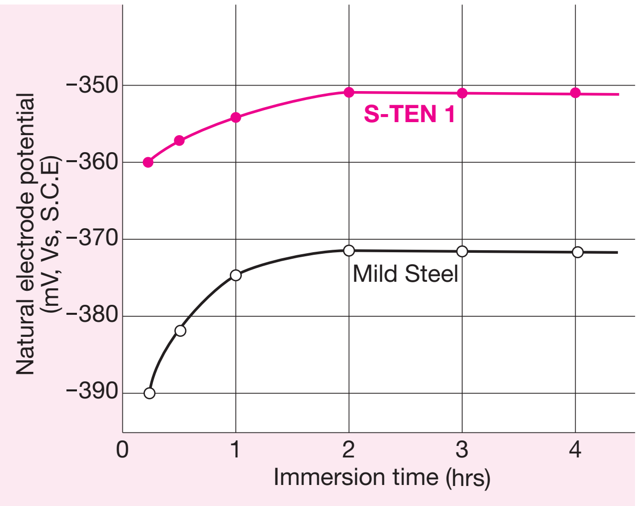
BM : Base metal : WM : Weld metal *ST-16 : Brand name of conventional weld material for S-TEN (production discontinuation)

Galvanic Corrosion in Corrosive Atmosphere

Galvanic corrosion is caused by the difference in electrical potential between different metals.

S-TEN 1 and Mild Steel show the trend of natural electrode potential in a 40% sulfuric acid solution at 60℃, as shown in Fig. 4.4. In other words, S-TEN 1 shows 20 mV higher potential than Mild Steel. Therefore, joining of Mild Steel with S-TEN 1 would make Mild Steel a cathode and the corrosion of S-TEN 1 (anodic dissolution) would be accelerated. It has been confirmed, however, that such slight difference in potential is practically insignificant, as introduced below.

Fig. 4.4 Natural Electrode Potentials of S-TEN 1 and Mild Steel in 40% Sulfuric Acid (60˚C)



Property Qualification Test Results

S-TEN 1

The following property qualification tests were conducted in the laboratory. In preparing test specimens, it was thought that corrosion of Mild Steel would be accelerated when the area of Mild Steel was less than that of S-TEN 1. Taking this into account, the test specimens were prepared so that the ratio of the area of Mild Steel to S-TEN 1 became 1:1 and 1:10 for butt-welded joints.

The tests were conducted by immersing the specimens in 40%-concentrated sulfuric acid at 55℃ for 5 hours. As a result, as shown in Figs. 4.5 and 4.6, it was found that the corrosion of specimens was nearly the same as that of S-TEN itself and that, in such sulfuric-acid corrosive environment, contact of different metals with an electrical potential difference of approximately 20 mV can be disregarded.

Fig. 4.5 Corrosion Mass of S-TEN 1 / Different Material Weld Joint

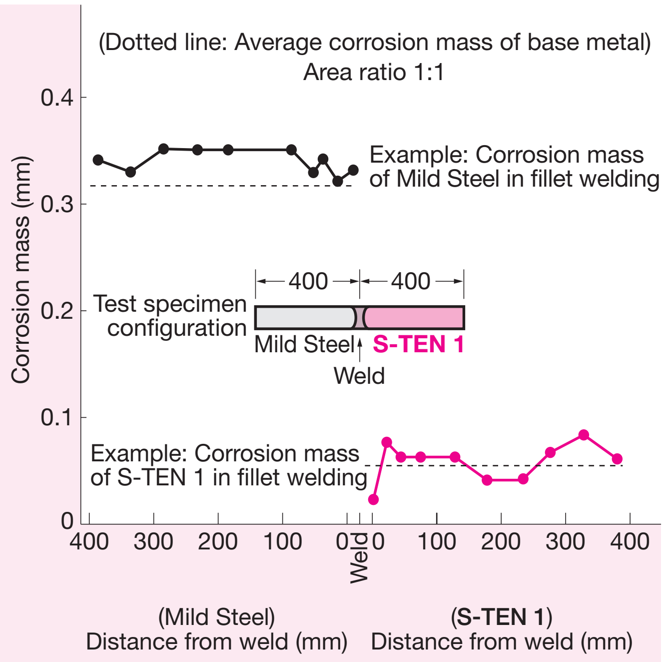
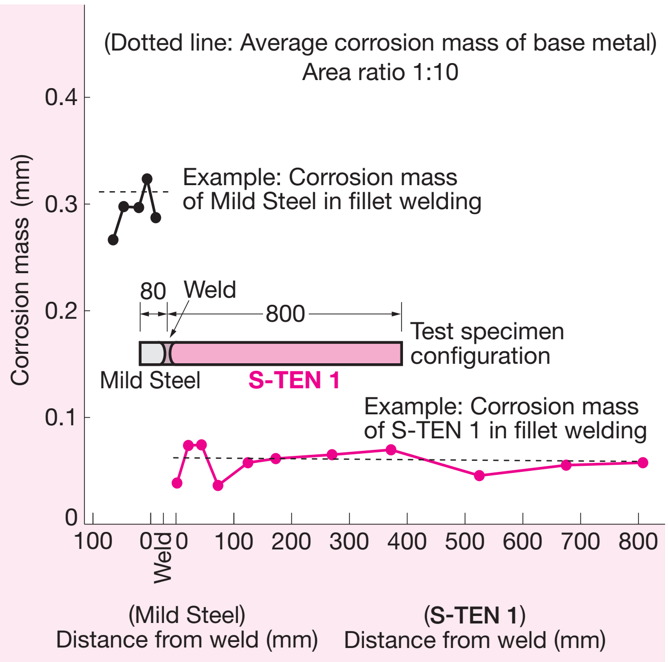
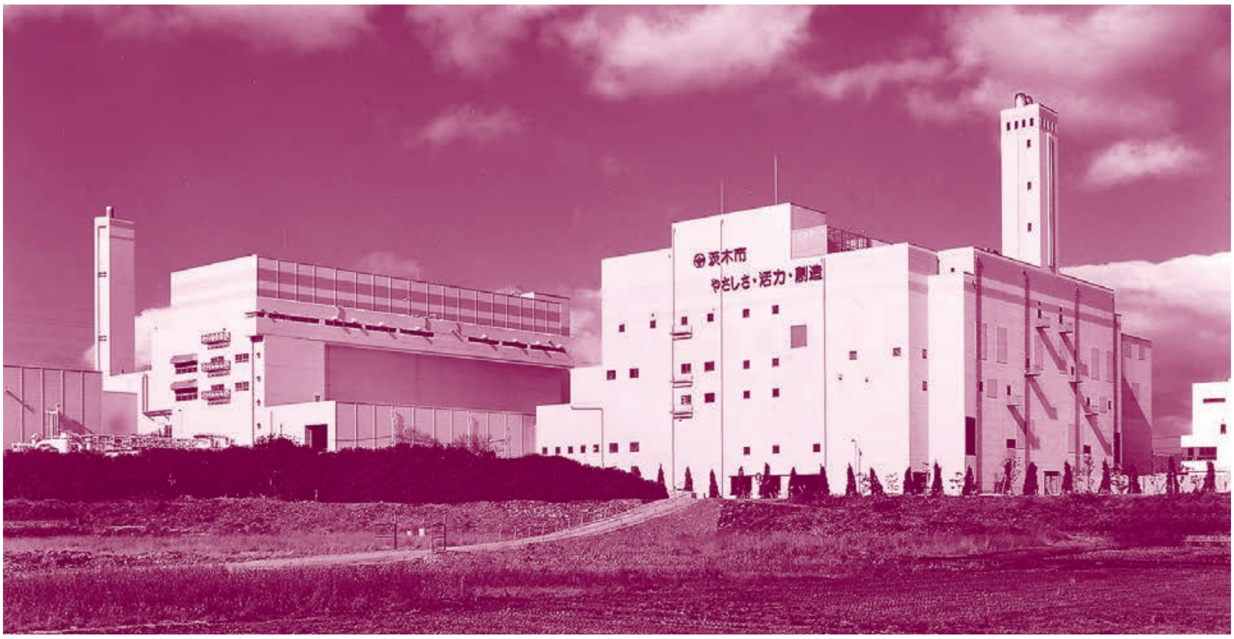


Fig. 4.6 Corrosion Mass of S-TEN 1 / Different Material Weld Joint



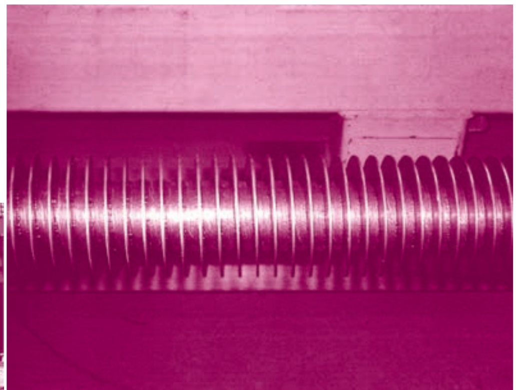
5. Application Examples

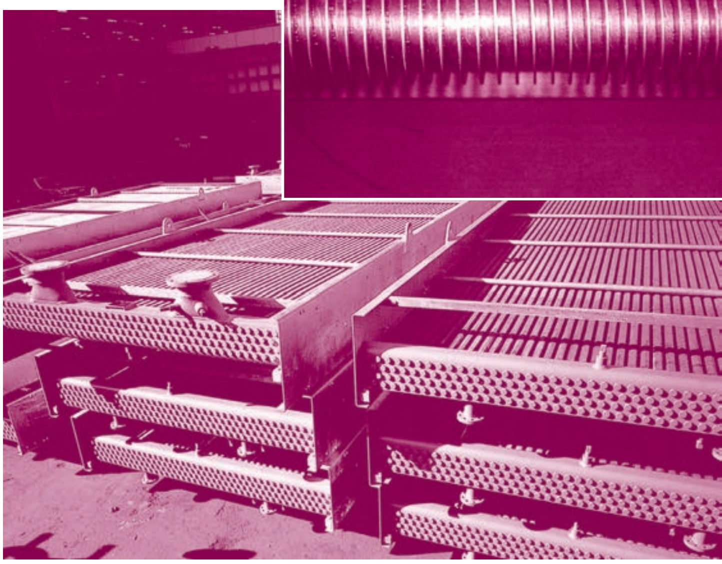


Waste melting furnace

Economizer and air preheater of thermal power plant

Fin tubes





Tubes for air fin cooler

6. Reference

Unit Conversion Table

℃	℉
20	68
40	104
60	140
80	176
100	212
120	248
140	284
160	320
180	356
200	392
300	572
400	752
500	932

F = 9/5 × C + 32

N/mm^2	ksi
100	689
200	1379
250	1724
300	2068
350	2413
400	2758
450	3103
460	3172
470	3241
480	3309
490	3378
500	3447
510	3516
520	3585
530	3654
540	3723
550	3792
560	3861
570	3930
580	3999
590	4068
600	4137
610	4206
620	4275
630	4344
640	4413

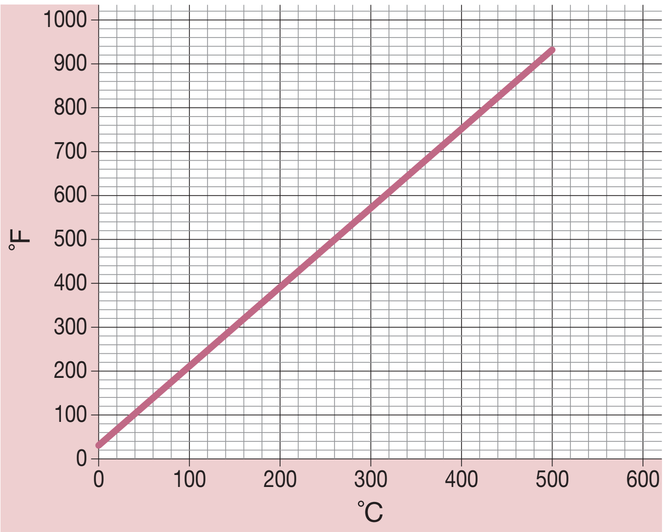
1 ksi = 0.145038 N/mm^2

mm	mil	inch	ft
0.1	3.94	0.003937008	
0.2	7.87	0.007874016	
0.3	11.81	0.011811024	
0.4	15.75	0.015748031	
0.5	19.69	0.019685039	
1	39.37	0.039370	
2	78.74	0.078740	
3	118.11	0.118110	
4	157.48	0.157480	
5	196.85	0.196850	
10	393.70	0.393701	
20	787.40	0.787402	
30		1.181102	
40		1.574803	0.13123
50		1.968504	0.16404
100		3.937008	0.32808
200		7.874016	0.65617
300		11.81102	0.98425
400		15.74803	1.31234
500		19.68504	1.64041995
1000		39.37008	3.2808399
2000		78.74016	6.56167979
3000			9.84251969
4000			13.1234
5000			16.4041995
6000			19.6850

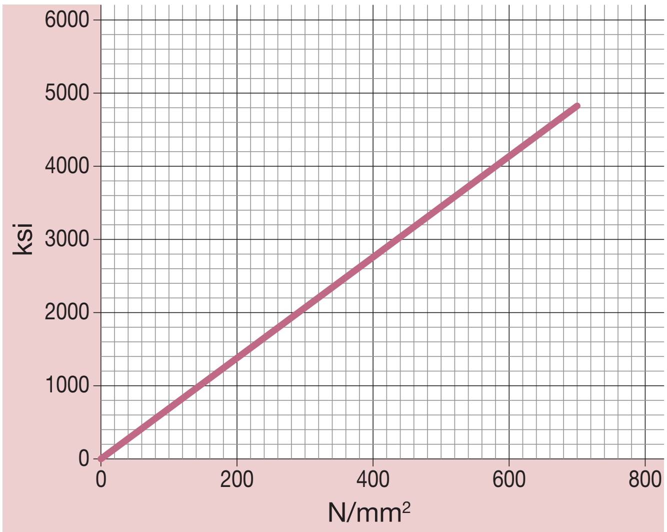
1 mil = 0.0254 mm　1 inch = 25.4 mm　1 ft = 304.8 mm

Unit Conversion Charts

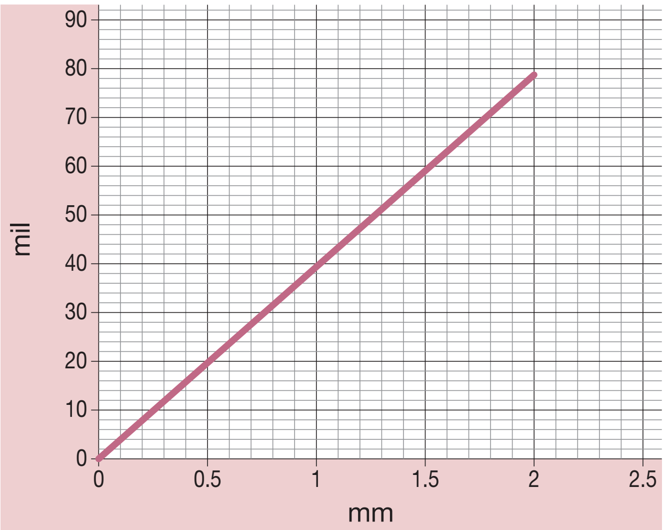
Temperature (˚C vs ˚F)



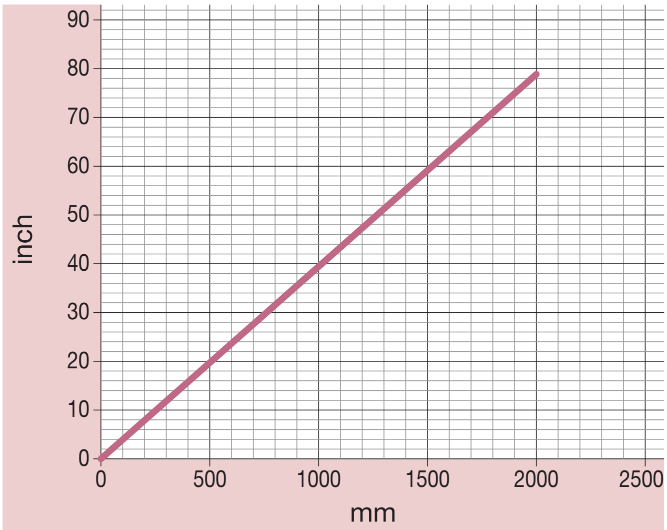
Stress (N/mm² vs ksi)



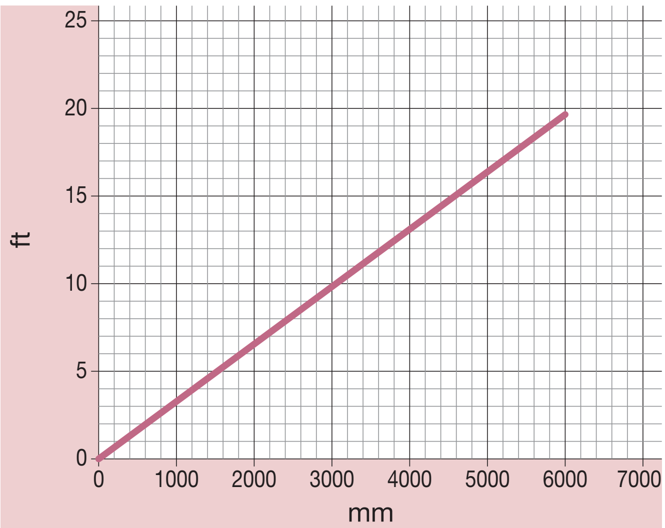
Length (mm vs mil)



Length (mm vs inch)



Length (mm vs ft)



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