Coastal Weathering Steel

Nippon Steel Corporation

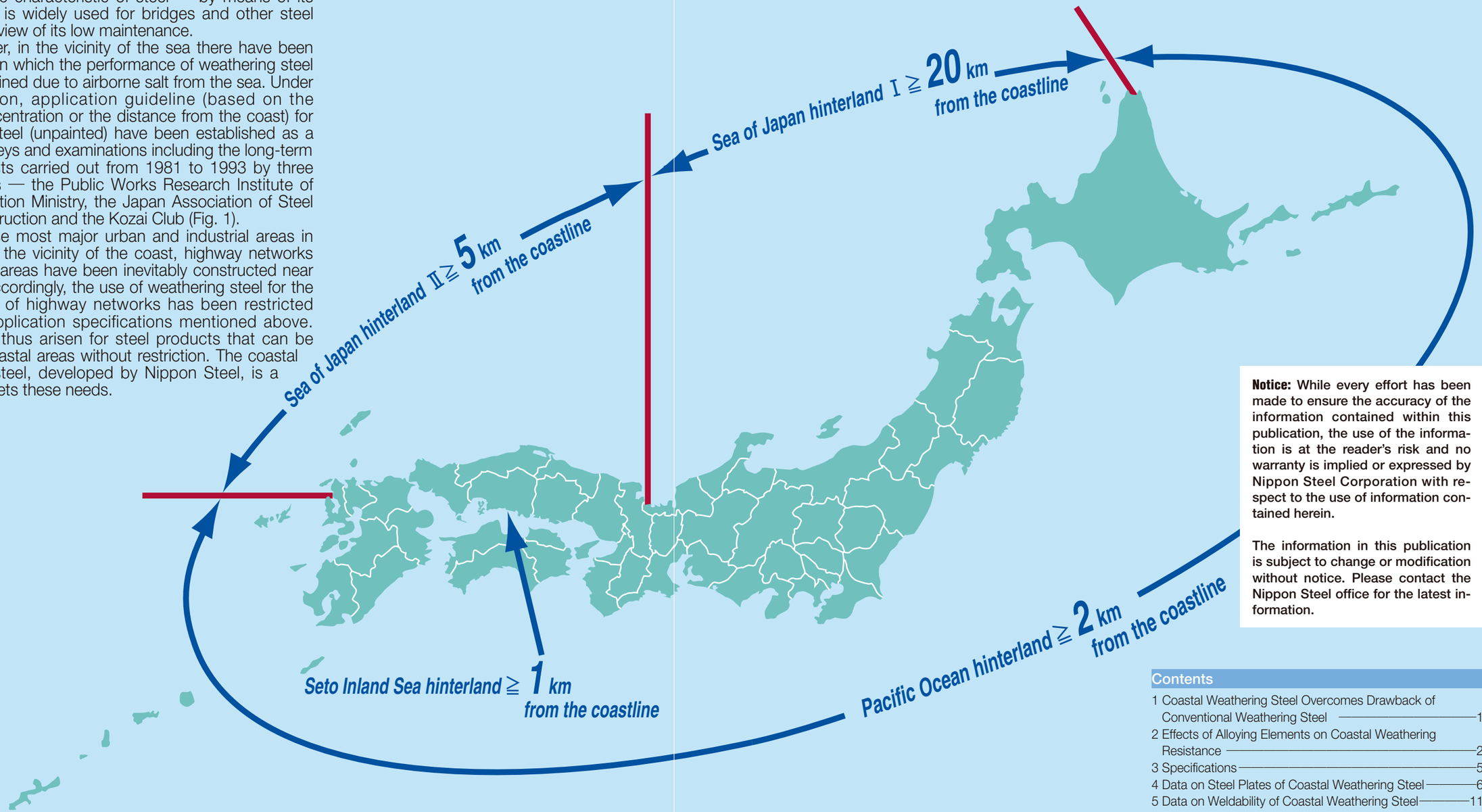
1 Coastal Weathering Steel Overcomes Drawback of Conventional Weathering Steel

Weathering steel, which halts the progress of rusting — an intrinsic characteristic of steel — by means of its own rusting, is widely used for bridges and other steel structures in view of its low maintenance.

However, in the vicinity of the sea there have been many cases in which the performance of weathering steel was not obtained due to airborne salt from the sea. Under such situation, application guideline (based on the chloride concentration or the distance from the coast) for weathering steel (unpainted) have been established as a result of surveys and examinations including the long-term exposure tests carried out from 1981 to 1993 by three organizations — the Public Works Research Institute of the Construction Ministry, the Japan Association of Steel Bridge Construction and the Kozai Club (Fig. 1).

Because most major urban and industrial areas in Japan are in the vicinity of the coast, highway networks linking these areas have been inevitably constructed near the coast. Accordingly, the use of weathering steel for the construction of highway networks has been restricted under the application specifications mentioned above. Needs have thus arisen for steel products that can be applied in coastal areas without restriction. The coastal weathering steel, developed by Nippon Steel, is a steel that meets these needs.

Fig. 1. Application Guideline for Unpainted Weathering Steel (Public Works Research Institute of the Construction Ministry, the Japan Association of Steel Bridge Construction and the Kozai Club)
1) Airborne salt ≦ 0.05 mdd (mg/dm2/day)
2) Measurement of airborne salt may be omitted in the following areas for the use of unpainted weathering steel.



Contents

2 Effects of Alloying Elements on Coastal Weathering Resistance

Specimens of 0.05%C-0.25%Si-1.35%Mn steel, to which P, Cu, Cr and Ni alloying elements were added individually, were subjected to exposure tests under a simulated coastal environment (5%NaCl spray exposure test for 12 months) and average plate thickness loss due to corrosion was measured. It was found that P, Cu and Ni are effective (Ni in particular) in suppressing corrosion. On the other hand, it was found that Cr, considered to be effective for conventional weathering steel, has an adverse effect (Fig. 2).

Based on these test results, coastal weathering steel has been developed — it is produced by increasing Ni addition to conventional weathering steel as the base material and adding no Cr, which adversely affects the corrosion resistance of weathering steel applied in a coastal environment.

Coastal weathering steel demonstrated excellent performance in exposure tests conducted for several years at coastal quays and at coastal areas in Okinawa, which are a harsh marine environment (Figs. 3, 4 and 5).

Fig. 2. Effects of respective alloying elements on weathering resistance in exposure test under simulated coastal environment (one-year salt-water spray test)

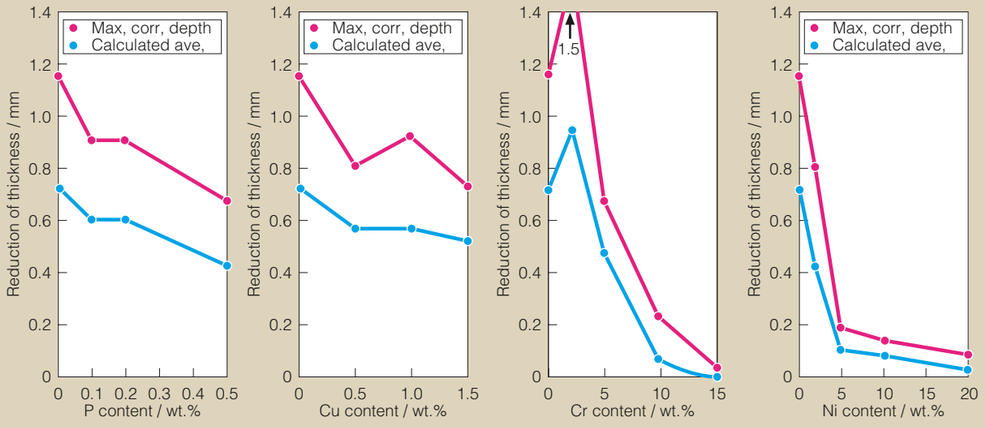


Fig. 3. Effect of Ni addition on coastal weathering resistance (9-year exposure test at Kimitsu quay; Airborne salt 1.3 mdd)

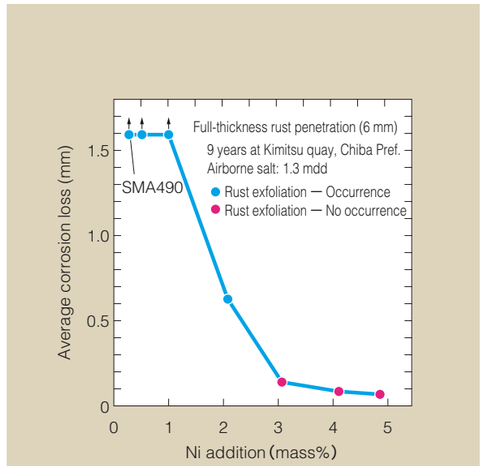
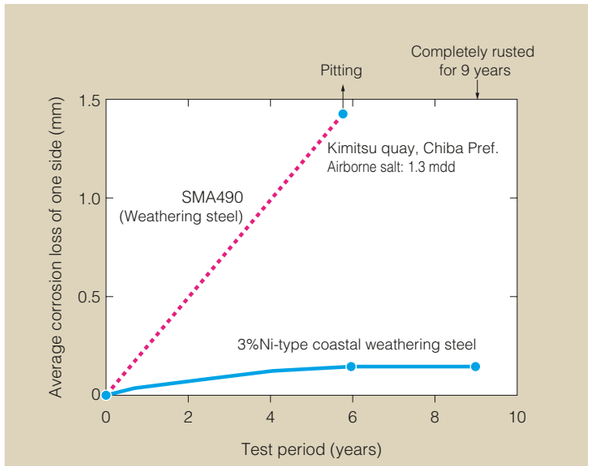


Fig. 4. Secular changes in coastal exposure test (Exposure test at Kimitsu quay, Airborne salt 1.3 mdd)



(Reference)

The rust layer of coastal weathering steel has a structure similar to that of conventional weathering steel, but the amorphous layer (the extinction layer) accounts for a large portion of the internal layer. In EPMA observation, the concentrated Ni portion is found in this internal layer and the penetration of chloride ions to this portion is suppressed (refer to Fig. 5). It is considered that this effect maintains the internal fine rust layer of the coastal weathering steel.

Fig. 5. Schematic drawing of cross-section of rust on coastal weathering steel (from EPMA analysis results)

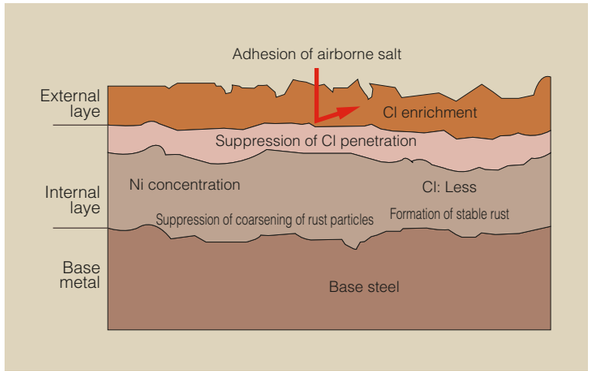


Photo 1. Color tone of exposure test specimen of Ni-type coastal weathering steel

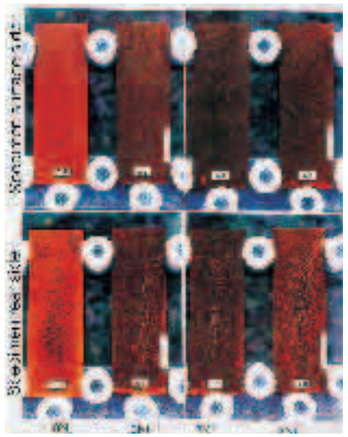
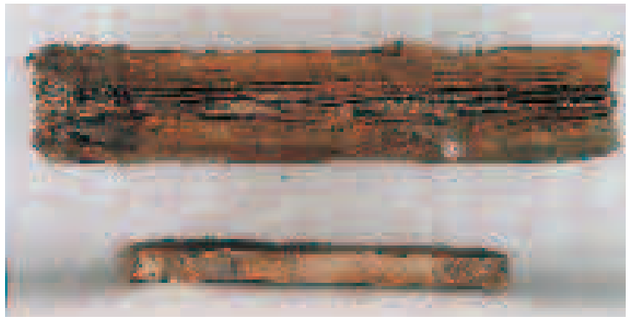


Photo 2. Cross-section of specimen after exposure test (9 years) at Kimitsu quay



Cross-sections of conventional weathering steel (above) and coastal weathering steel (below). both having a thickness of 6 mm and exposed for 9 years at Kimitsu quay

Fig. 6. Exposure test site, Kimitsu quay
Exposure site: Kimitsu quay (about 10 m from the sea)

Photo 3. Exposure test implementation conditions at Kimitsu quay

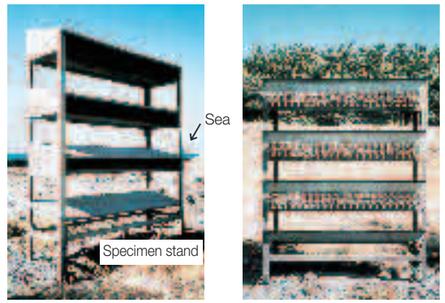


Photo 4. Shin-Nittetsu Minami Ohashi Bridge: Application of coastal weathering steel
Completion: September 1994 at Nippon Steel's Nagoya Works

Coastal weathering steel (5% Ni-type) was used for parts of Shin-Nittetsu Minami Ohashi Bridge.

Photo 5. Rust generation of bridge plate girder (medium girder) made of coastal weathering steel (after 2.5 years' service)

3 Specifications

Because coastal weathering steel has higher Ni content than conventional weathering steel and no Cr addition, the steel does not conform to JIS G 3114 in terms of chemical composition but conforms in all other aspects. Accordingly, "-MOD" is suffixed after the "Designation" in JIS G 3114 as the designation of coastal weathering steel.

●Coastal Weathering Steel SMA490W-MOD and SMA570WQ-MOD

Table 1. Chemical composition

Designation	Thickness (mm)	Chemical composition (mass%)							
		C	Si	Mn	P	S	Cu	Ni	Cr
SMA490W-MOD SMA570WQ-MOD	6≦t≦100	0.18 max	0.15 ～ 0.65	1.40 max	0.035 max	0.035 max	0.30 ～ 0.50	2.50 ～ 3.50	0.08 max

(Reference: Hot-Rolled Atmospheric Corrosion Resisting Steel for Welded Structures in JIS G 3114)

SMA400W SMA490W SMA570WQ	6≦t≦100	0.18 max	0.15 ～ 0.65	1.40 max	0.035 max	0.035 max	0.30 ～ 0.50	0.05 ～ 0.30	0.45 ～ 0.75

Table 2. Tensile test

Designation	Yield point or proof stress (N/mm²)				Tensile strength (N/mm²)	Elongation		
	Thickness (mm)					Thickness (mm)	Specimen	%
	≦16	16<t≦40	40<t≦75	75<t≦100				
SMA490W-MOD	≧365	≧355	≧335	≧325	490～610	t≦16	JIS No. 1A	≧15
						t>16	JIS No. 1A	≧19
						t>40	JIS No. 4	≧21
SMA570WQ-MOD	≧460	≧450	≧430	≧420	570～720	t≦16	JIS No. 5	≧19
						t>16	JIS No. 5	≧26
						t>40	JIS No. 4	≧20

Table 3. Charpy absorbed energy

Designation	Testing temperature (℃)	Charpy absorbed energy (J)	Specimen
SMA490BW-MOD	0	≧27	JIS No. 4 rolling direction
SMA490CW-MOD	0	≧47	
SMA570WQ-MOD	-5	≧47	

4 Data on Steel Plates of Coastal Weathering Steel

Table 4. Chemical composition (actual results)

(mass %)

	C	Si	Mn	P	S	Cu	Ni	Cr	V	Pcm
Composition A	0.10	0.20	0.61	0.006	0.002	0.40	3.07	0.02	–	0.21
Composition B	0.09	0.19	1.33	0.004	0.002	0.38	2.97	0.02	0.02	0.23
(Reference: JIS)	≦0.18	.15/.65	≦1.40	≦.035	≦.035	.30/.50	.05/.30	.45/.75	–	

Table 5. Mechanical tests of base metal (tensile test, Charpy impact test)

Designation	Composition	Thickness (mm)	Tensile test			Charpy test	
			YP (N/mm^2)	TS (N/mm^2)	EL (%)	Test temperature (℃)	Absorbed energy (J)
SMA490W-MOD	A	9	439	531	28	0	163*
	A	25	405	512	26	0	230
	B	80	418	543	34	0	263
SMA570WQ-MOD	B	12	510	618	37	-5	357
	B	25	590	670	29	-5	279
	B	40	599	666	29	-5	310
	B	80	519	620	31	-5	285

*Subsize specimen 10×5 mm

(Reference: JIS G 3114)

SMA490BW-MOD	≦16	≧365	490～610	≧15	0	≧27
	16＜t≦20	≧355	490～610	≧19		
SMA490CW-MOD	20＜t≦40	≧355	490～610	≧19	0	≧47
	40＜t≦75	≧335	490～610	≧21		
	75＜t≦100	≧325	490～610	≧21		
SMA570WQ-MOD	≦16	≧460	570～720	≧19	-5	≧47
	16＜t≦20	≧450	570～720	≧26		
	20＜t≦40	≧450	570～720	≧20		
	40＜t≦75	≧430	570～720	≧20		
	75＜t≦100	≧420	570～720	≧20		

Table 6. Z-direction tensile test

Designation	Thickness (mm)	Location	Testing direction	Z-direction tensile test	
				TS (N/mm^2)	RA (%)
SMA490W-MOD	25	All-thickness	Z	522	56
SMA570WQ-MOD	25	All-thickness	Z	682	74
	40	All-thickness	Z	715	70

Table 7. Strain-aging Charpy impact test

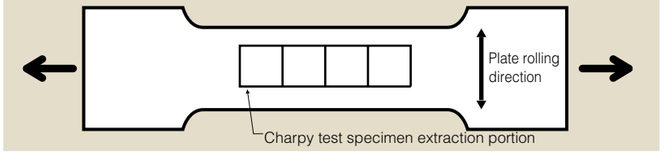
Designation	Thickness (mm)	Testing direction	Strain: 5%		Strain: 10%		Pre-strain direction	Aging treatment condition Temperature×Time
			Testing temperature (℃)	Absorbed energy Ave. (J)	Testing temperature (℃)	Absorbed energy Ave. (J)		
SMA490W-MOD	9	C	0	76*	0	57*	C	250 (℃) × 60 (min)
			-20	65*	-20	53*		
	25	C	0	147	0	99		
			-20	117	-20	60		
SMA570WQ-MOD	25	C	-5	249	-5	239		
			-20	250	-20	260		
	40	C	-5	264	-5	266		
			-20	265	-20	248		

(Testing position: Below the surface)

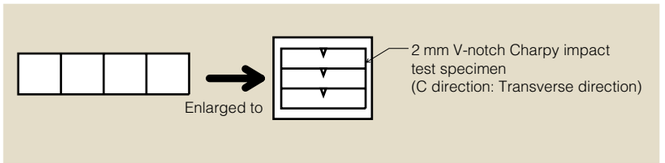
*Subsize specimen 10×7.5 mm for t=9 mm

Fig. 7. (Reference: Strain-aging Charpy impact test – Methods of preparing specimens and providing strains)

1) Provision of the prescribed strain for tension test specimen
(All-thickness tension: It is necessary to confirm whether or not the strain is the prescribed one.)



2) Implementation of aging treatment (aging heat treatment: 250℃×60 min)
3) Extraction of Charpy impact test specimen

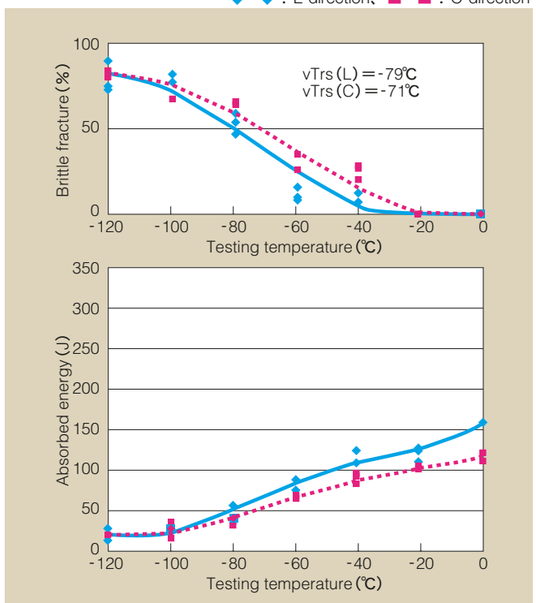


When the thickness is set at t, the inside bending radius R and the strain ε, ε=t/(2R+t) or R=t(1-ε)/2ε. Accordingly, the 5% strain corresponds to the 9.5t inside bending radius, and the 10% strain to the 4.5t inside bending radius.

Fig. 8. Charpy transition curves

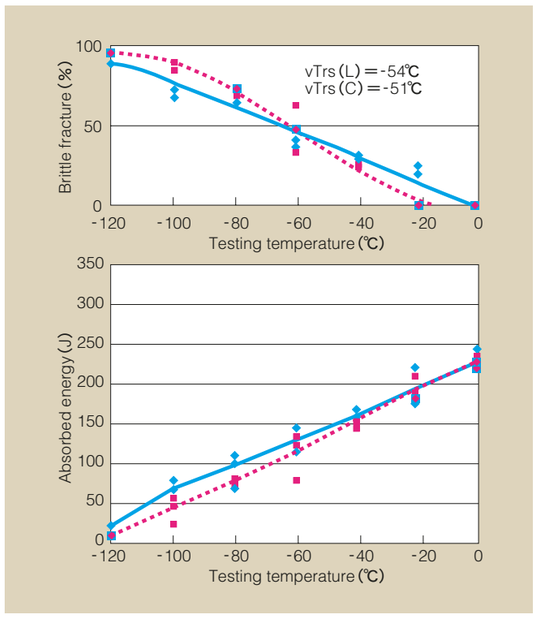
●490 N/mm² grade coastal weathering steel　SMA490W-MOD

【t=9 mm】*
【1/4t】

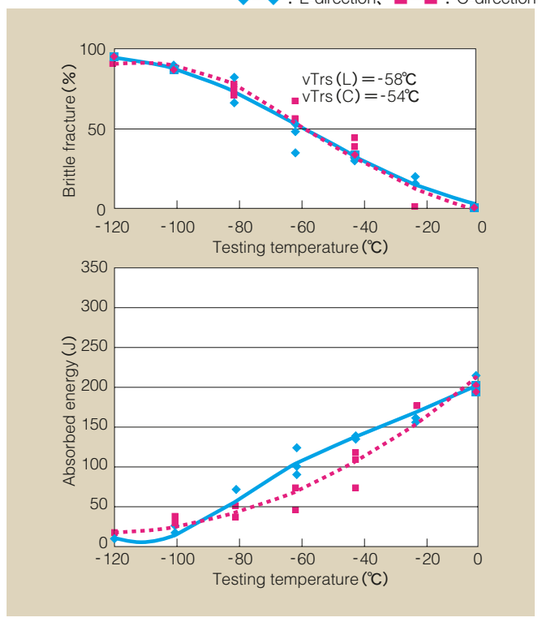


* Sub-size specimen for t=9mm: 10×7.5mm

【t=25 mm】
【1/4t】

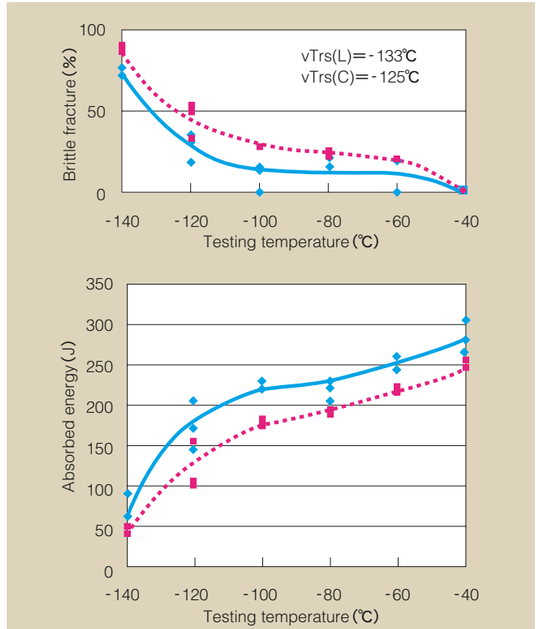


【1/2t】

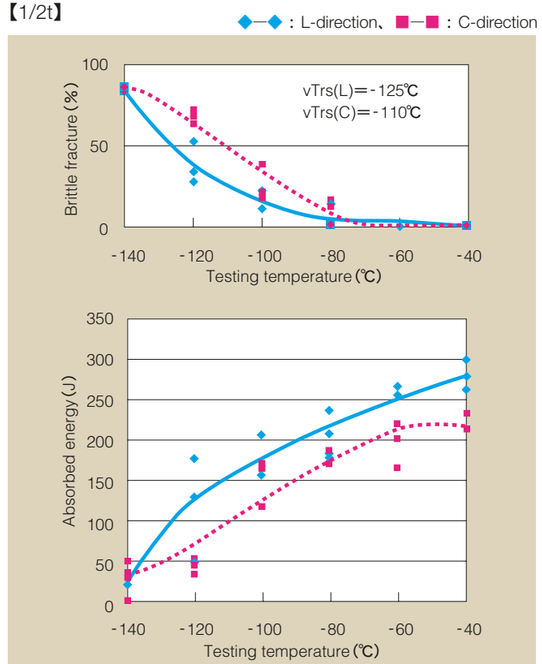


●570 N/mm² grade coastal weathering steel　SMA570WQ-MOD

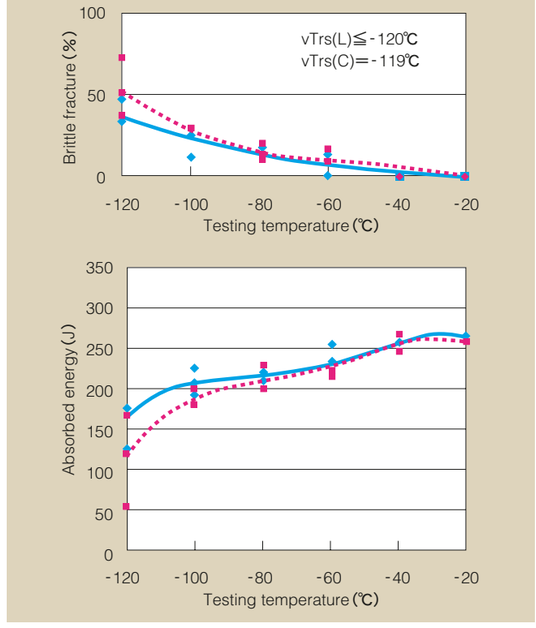
【t=25 mm】
【1/4t】



【1/2t】



【t=40 mm】
【1/4t】



【1/2t】

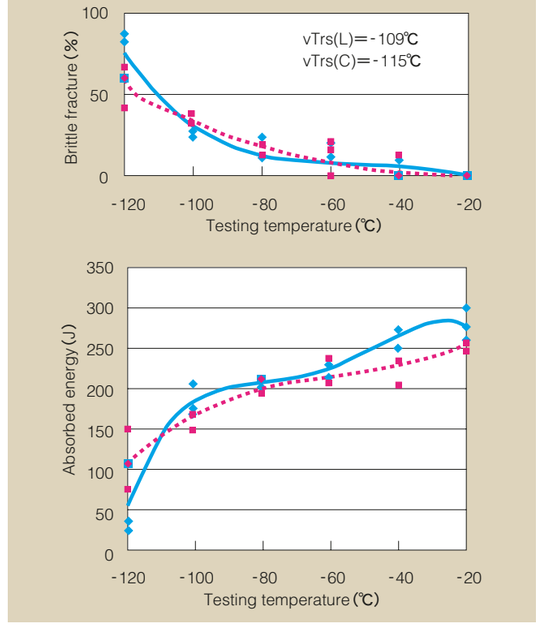
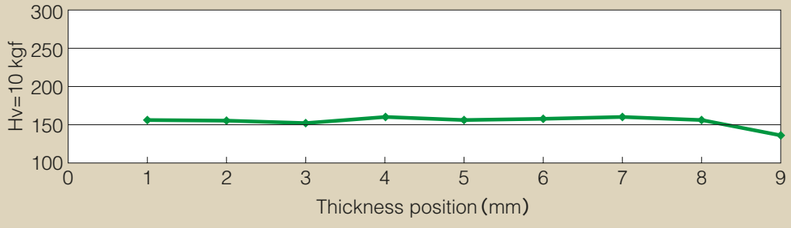


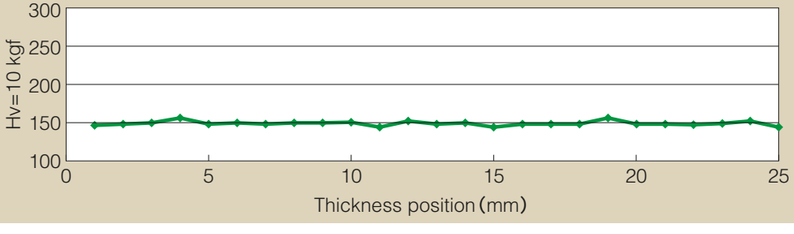
Fig. 9. Hardness distribution in plate cross-section

●490 N/mm² grade coastal weathering steel　SMA490W-MOD

【t=9 mm】

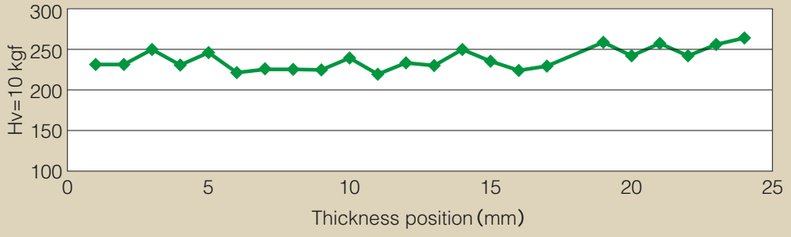


【t=25 mm】

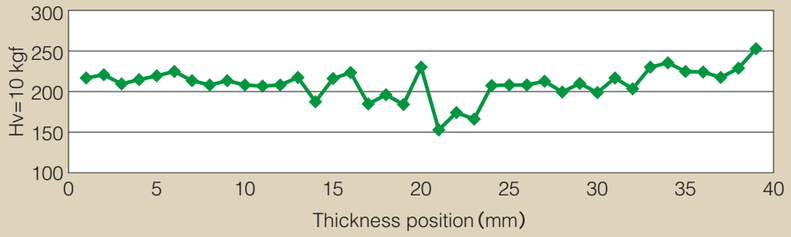


●570 N/mm² grade coastal weathering steel　SMA570WQ-MOD

【t=25 mm】



【t=40 mm】



5 Data on Weldability of Coastal Weathering Steel

●570 N/mm² grade coastal weathering steel　SMA570WQ-MOD

Table 8. Maximum hardness test (JIS Z 3101)

Welding conditions	Welding rod	Current	Voltage	Speed	Heat input	Atmospheric temperature	Humidity
	CT-60N	170A	24V	15 cm/min	17 kJ/cm	20℃	60%

Test results	Thickness	Preheating temperature (℃)	20	50	100	150	200
	40 mm	Vickers hardness	329	339	308	287	274

Table 9. y-groove weld-crack tests (JIS Z 3158)

Welding conditions	Welding rod	Current (A)	Voltage (V)	Speed (cm/min)	Heat input (kJ/cm)	Atmospheric temperature (℃)	Humidity (%)
	CT-60N	170	24	15	17	20	60

Test results	Thickness	Preheating temperature 20℃			Preheating temperature 50℃		
		Surface cracking	Cross-section cracking	Root cracking	Surface cracking	Cross-section cracking	Root cracking
	40 mm	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0	0, 0, 0

Table 10. T-groove weld-crack tests (JIS Z 3153)

Testing conditions	No.	Surface cracking		Cross-section cracking			Judgment
		1st pass	2nd pass	1	2	3	
SM400 × SMA570WQ-MOD (3%Ni)	1	○	○	○	○	○	No cracking
	2	○	○	○	○	○	
	3	○	○	○	○	○	
SMA570WQ-MOD (3%Ni) × SMA570WQ-MOD (3%Ni)	4	○	○	○	○	○	No cracking
	5	○	○	○	○	○	
	6	○	○	○	○	○	
The same as above Gap (1.6 mm) existence	7	○	○	○	○	○	No cracking
	8	○	○	○	○	○	
	9	○	○	○	○	○	

1st pass: Target leg length 8 mm, current 260 A, voltage 28 V, welding speed 25 cm/min
2nd pass: Target leg length 6 mm, current 260 A, voltage 28 V, welding speed 35 cm/min

6 Welding Materials for Coastal Weathering Steel

Various kinds of welding materials for welding coastal weathering steel are supplied by Nippon Steel Welding Products & Engineering Co., Ltd.

Table 11. List of welding materials for coastal weathering steel

Welding method	Strength classification		Reference-Characteristics
	490 N/mm² grade	570 N/mm² grade	
SAW	Wire Y-3NI Flux NB-55LM	Wire Y-3NI Flux NB-55L	Flux: Bond flux
MAG	YM-3N Shield: Ar-CO_2	YM-3N Shield: Ar-CO_2	Ar-CO_2: Ar-5～20%CO_2
FCAW	SF-60WN	SF-60WN	All-position
SMAW	CT-50N	CT-60N	

Table 12. Characteristics of welding materials for coastal weathering steel

Welding method		SAW	MAG	FCAW	SMAW
Brand name		Y-3NI × NB-55LM	YM-3N	SF-60WN	CT-60N
Chemical composition of weld metal (%)	C	0.08	0.04	0.06	0.07
	Si	0.27	0.30	0.30	0.52
	Mn	1.31	0.70	1.23	0.71
	P	0.010	0.006	0.008	0.011
	S	0.004	0.004	0.003	0.005
	Cu	0.25	0.31	0.35	0.45
	Ni	2.92	3.56	3.23	3.27
	Cr	0.02	0.02	0.03	0.02
Mechanical properties of weld metal	YP N/mm²	524	540	546	585
	TS N/mm²	596	610	629	647
	EL (%)	29	29	25	28
	vE (J)	vE-20＝176	vE-40＝200	vE-20＝114	vE-20＝161
Welding current range	Welding position Wire diameter-Current	Flat-position: AC 4.0 mm: 400～600A 4.8 mm: 550～800A Hi: 3-5kJ/mm	Flat-position: DC(＋) 1.2 mm: 100～350A 1.6 mm: 200～450A Vertical-position (upward): DC(＋) 1.2 mm: 180～250A (Automatic welding)	Flat-position･Horizontal-position: DC(＋) Horizontal fillet: DC(＋) 1.2 mm: 180～280A Vertical-position (upward): DC(＋) 1.2 mm: 180～250A (Automatic welding)	Flat-position: AC, DC(＋) 3.2 mm: 100～140A 4.0 mm: 140～190A 5.0 mm: 190～250A 6.0 mm: 250～310A Vertical position-Overhead-position: AC, DC(＋) 3.2 mm: 90～130A 4.0 mm: 120～170A 5.0 mm: 140～190A 6.0 mm: —

＊Standard practice for the initial layer in SAW welding from the viewpoint of preventing high-temperature cracking: 500 A and under for the wire diameter of 4.0 mm, 600 A and under for the wire diameter of 4.8 mm

7 Weld Joint Characteristics

●570 N/mm² grade coastal weathering steel SMA570WQ-MOD

Table 13. Weld joint tension test performance

Welding method Welding material	Thickness (mm) / Groove configuration	Heat input (kJ/mm)	Tensile strength of joints (JIS short gauge)	Strength of weld metal			
				0.2YS (N/mm²)	TS (N/mm²)	EL (%)	RA (%)
SMAW CT-60N	25/X	3	637 N/mm²	527	645	23	74
	40/X	2	658 N/mm²	536	621	29	76
SAW Y-3NI NB-55LM	40/X	5	659 N/mm²	517	676	30	70
MAG YM-3N	40/X	1.6	698 N/mm²	520	621	24	70
FCAW SF-60WN	25/X	2/Vertical-position (upward)	688 N/mm²	560	708	26	56
	40/X	1.9/Flat-position	644 N/mm²	517	612	29	70

Table 14. Charpy impact test performance

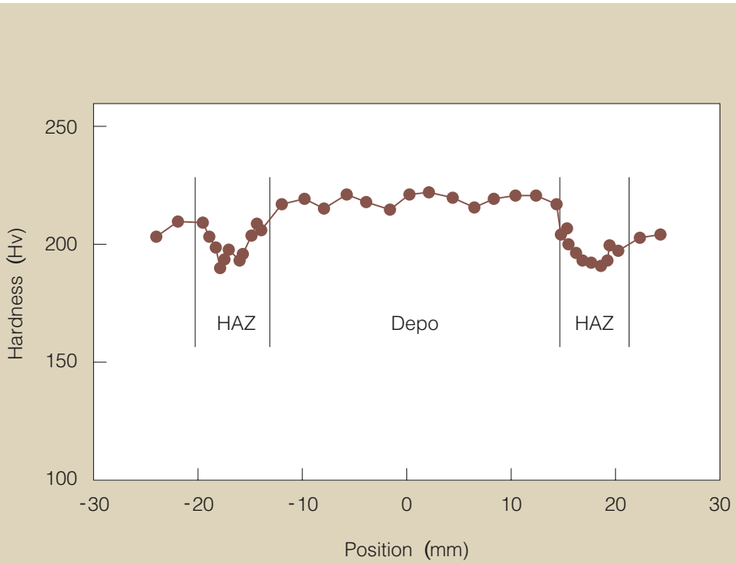
Welding method Welding material	Thickness (mm)/ Groove configuration	Heat input (kJ/mm)	Position	-5℃		-20℃	
				Weld metal	Bond	Weld metal	Bond
SMAW CT-60N	25/X	3	C	165, 182, 198 av 182J	236, 244, 204 av 228J	168, 172, 170 av 170J	192, 179, 170 av 180J
			Center				
			BP	174, 161, 172 av 169J	220, 213, 212 av 215J	162, 157, 157 av 159J	226, 208, 211 av 215J
	40/X	2	C	194, 199, 196 av 196J	263, 255, 277 av 265J	177, 190, 191 av 186J	226, 263, 216 av 235J
			BP	223, 236, 221 av 227J	215, 242, 260 av 239J	185, 192, 185 av 187J	208, 271, 234 av 238J
SAW Y-3NI NB-55LM	40/X	5	FP	112, 124, 122 av 114J	227, 197, 181 av 202J	126, 121, 110 av 119J	162, 171, 158 av 164J
			BP	126, 127, 124 av 126J	183, 180, 185 av 182J	119, 118, 121 av 119J	155, 144, 167 av 155J
MAG YM-3N	40/X	1.6	FP	151, 167, 123 av 147J	128 ,178, 286 av 197J	187, 173, 181 av 177J	189, 186, 178 av 184J
			BP	181, 178, 178 av 179J	212, 224, 209 av 215J	191, 183, 204 av 196J	214, 199, 219 av 211J
FCAW SF-60WN	25/X	2/Vertical-position (upward)	C	90, 90, 90 av 90J	90, 106, 95 av 97J	76, 82, 82 av 80J	106, 101, 92 av 100J
			BP	79, 79, 76 av 78J	134, 134, 140 av 136J	79, 74, 64 av 72J	131, 128, 120 av 126J
	40/X	1.9/Flat-position	C	103, 112, 109 av 108J	103, 92, 98 av 98J	101, 92, 101 av 98J	79, 82, 82 av 81J
			BP	131, 126, 126 av 128J	101, 71, 106 av 93J	126, 120, 126 av 124J	92, 92, 90 av 92J

Table 15. Results of Charpy impact test of heat-affected zone

Steel	Welding method	Current	Voltage	Heat input
25 mm X Groove 40 mm X Groove	SAW (Y-3NI 4.8 mm)	800A	36V	5 kJ/mm

Steel plate	Thickness position	Testing temperature (℃)	Absorbed energy by notch position (J)			
			Bond	HAZ 1 mm	HAZ 3 mm	HAZ 5 mm
25 mm	1/4 (FP)	-5	136, 136, 144 av 139J	232, 159, 281 av 224J	299, 317, 326 av 314J	314, 322, 307 av 314J
		-20	117, 121, 124 av 121J	145, 149, 146 av 147J	312, 315, 314 av 314J	272, 295, 299 av 289J
40 mm	1/4 (FP)	-5	227, 197, 181 av 202J	291, 303, 324 av 306J	321, 312 318 av 317J	309, 308, 298 av 305J
		-20	162, 171, 158 av 164J	155, 270, 334 av 253J	313, 171, 267 av 250J	307, 301, 289 av 299J

Fig. 10. Hardness distribution in SAW welded portion
(2 mm below FP surface: 25 mm thick, NB-55LY-3NI)



8 Examples of Applications of Coastal Weathering Steel

Photo 6. Installation conditions for Hokuriku Shinkansen Bridge (tentative name) in Oumi, Niigata Pref.

Coastal weathering steel was used for the piers of Hokuriku Shinkansen bridge over tha Hokuriku Expressway.

Photo 7. Installation conditions for Tanoguchi Bridge of Oita Highway

Coastal weathering steel (3%Ni-type) is applied at the left side of the spliced portion and the conventional weathering steel at the right side.

9 High-strength Bolts for Coastal Weathering Steel

Steel bolts containing 3%Ni are marketed by Nippon Steel Bolten Co., Ltd. as high-strength bolts for coastal weathering steel.

Table 16. Mechanical properties of high-strength bolts for coastal weathering steel

Steel grade	Specification	Mechanical properties of JIS No. 4 specimen				Mechanical properties of products		Hardness	Reference
		Proof stress kgf/mm²	Tensile strength kgf/mm²	Elongation %	Reduction of area %	Tension load kgf	T/Ae kgf/mm²	HRC	Tempering temperature ℃
	F8T Spec	64 min.	80～100	16 min.	45 min.	24,200 min.	—	18～31	
	F10T Spec	90 min.	100～120	14 min.	40 min.	30,300 min.	—	27～38	
Coastal weathering steel	F8T	89.2	93.8	21.1	67.2	28,690	94.7	27	545
	F10T	104.8	107.7	18.5	66.9	32,740	108.0	32	425

＊1 Ae: Effective sectional area of screws 303 mm²
＊2 Quenching temperature 880℃

Table 17. Mechanical properties of nuts and washers for coastal weathering steel

Steel grade	Nut (F10T)			Washer (F35)	
	Guaranteed loading test	Hardness HRC	Reference Tempering temperature ℃	Hardness HRC	Reference Tempering temperature ℃
	30,300 kgf	HRB95 (HRC16) ～HRC35		35～45	
Coastal weathering steel	Accepted	27	630	39	290

＊1 Hot rolling and water quenching for nuts
＊2 Quenching temperature 900℃ for washers