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MARIWEL - Seawater Corrosion Resistant Steel for Welded Structures

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Synopsis :
Three types of weldable seawater corrosion resistant steels, "MARIWEL", have been developed: MARIWEL H50 is a 50kgf/mm2 class low alloy steel containing Cu, Ni and Mo, and has a good corrosion resistance in splash zone; MARIWEL K is a 41 or 50kgf/mm2 class low alloy steel containing Cr and Mo, and has a good corrosion resistance in submerged zone; and MARIWEL R is a 41 or 50kgf/mm2 class low alloy steel containing Cr, Cu and Ni, which shows good corrosion resistance in both splash and submerged zone. The test results for the commercially produced steel plates indicate that these steels have good mechanical properties and weldabilities and well as excellent seawater-corrosion resistance. These steels show about twice corrosion resistance compared with that of ordinary steels such as SM50B.

The body can be viewed from the next page.

MARIWEL—Seawater Corrosion Resistant Steel for Welded Structures*

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Shigeharu SUZUKI ** Taketo OKUMURA *** Tadakazu KYUNO ****

Three types of weldable seawater corrosion resistant steels, "MARIWEL", have been developed: MARIWEL H50 is a 50 kgf/mm² class low alloy steel containing Cu, Ni and Mo, and has a good corrosion resistance in splash zone; MARIWEL K is a 41 or 50 kgf/mm² class low alloy steel containing Cr and Mo, and has a good corrosion resistance in submerged zone; and MARIWEL R is a 41 or 50 kgf/mm² class low alloy steel containing Cr, Cu and Ni, which shows good corrosion resistance in both splash and submerged zone. The test results for the commercially produced steel plates indicate that these steels have good mechanical properties and weldabilities as well as excellent seawater-corrosion resistance. These steels show about twice corrosion resistance compared with that of ordinary steels such as SM50B.

1 Introduction

With a rapid development of the world's oceans including the exploitation of marine resources and the utilization of undersea areas, steels with enhanced corrosion resistance under marine environments have been commercially produced for use in marine structures. These seawater corrosion resistant steels may be used either for general or welded structures. Kawasaki Steel Corporation has since 1967 been manufacturing and marketing MARINER steel, a seawater corrosion resistant steel for general structures under license from U.S. Steel. MARINER steel is a low-alloy steel, containing P, Cu and Ni, and has excellent corrosion resistance even under the most corrosive splash zone in marine environments, and is used for sheet piles, steel pipe piles and H piles. However, because MARINER steel contains a large quantity of P, it is inferior with respect to toughness and weldability, and portions immersed in the sea do not have such high corrosion resistance, leaving some room for improvement.

After long-term seawater corrosion tests at Kawasaki Steel Corporation, the authors clarified the effects of alloying elements on the corrosion resistance under various marine environments including splash and submerged zones. On the basis of these results, a low alloy steel having mechanical properties required for marine structures was developed. This steel, called MARIWEL, is a seawater corrosion resistant steel for welded structures and has not only excellent corrosion resistance but also toughness and weldability equivalent to ordinary steels of the 41 kgf/mm² or 50 kgf/mm² grade. The present report concerns the specifications, mechanical properties, weldability and corrosion resistance of MARIWEL.

2 Specifications and Mechanical Properties

The MARIWEL series includes the five steel types shown in **Table 1**. Their specifications and characteristics are given in **Tables 1** and **2**, respectively. MARIWEL H50 is a 50 kgf/mm² grade low alloy steel containing Cu, Ni and Mo, having corrosion resistance about twice as high as ordinary steel in the splash zone and being suited for applications such as caisson, buoy, dolphin or other marine facilities.

MARIWEL K41 and K50 are low alloy steels of 41 kgf/mm² and 50 kgf/mm² grades, respectively, containing Cr and Mo. Their corrosion resistance is about twice that of ordinary steel in the submerged zone, so they are especially suited for submerged structures. It is possible to improve the corrosion resistance further by adding Ni, if necessary.

MARIWEL R41 and R50 are low alloy steels of the 41 kgf/mm² and 50 kgf/mm² grades, and contain Cr, Cu and Ni. Their corrosion resistance is about

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** Research Laboratories
*** Chiba Works
**** Technical Division

Table 1 Specification of MARIWEL

<table>
<tr><th colspan="2" rowspan="2">Designation</th><th rowspan="2">Thickness range (mm)</th><th colspan="10">Chemical composition (%)</th><th rowspan="2">Thick-ness (mm)</th><th colspan="3">Tensile properties (JIS No.1A)</th><th rowspan="2">Charpy impact value, min. $_{V}E_{0}$(kgf·m)</th></tr>
<tr><th>C Max.</th><th>Si Max.</th><th>Mn Max.</th><th>P Max.</th><th>S Max.</th><th>Cu</th><th>Ni Max.</th><th>Cr</th><th>Mo Max.</th><th>Other elements</th><th>Yield point min. (kgf/mm^2)</th><th>Tensile strength (kgf/mm^2)</th><th>Elongation min. (%)</th></tr>
<tr><td rowspan="6">MARIWEL H50</td><td rowspan="2">A</td><td rowspan="6">6 – 40</td><td rowspan="6">0.15</td><td rowspan="6">1.00</td><td rowspan="6">1.50</td><td rowspan="6">0.030</td><td rowspan="6">0.030</td><td rowspan="6">0.20 – 0.60</td><td rowspan="6">0.50</td><td rowspan="6">—</td><td rowspan="6">0.50</td><td rowspan="30">Alloying elements may be added if necessary</td><td rowspan="3">≦16</td><td rowspan="3">33</td><td rowspan="6">50-62</td><td rowspan="3">18</td><td rowspan="2">—</td></tr>
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<tr><td rowspan="2">B</td><td rowspan="2">2.8</td></tr>
<tr><td rowspan="3">>16</td><td rowspan="3">32</td><td rowspan="3">21</td></tr>
<tr><td rowspan="2">C</td><td rowspan="2">4.8</td></tr>
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<tr><td rowspan="6">MARIWEL K41</td><td rowspan="2">A</td><td rowspan="6">6 – 40</td><td rowspan="6">0.15</td><td rowspan="6">1.00</td><td rowspan="6">1.20</td><td rowspan="6">0.030</td><td rowspan="6">0.030</td><td rowspan="6">—</td><td rowspan="6">—</td><td rowspan="6">0.80 – 1.50</td><td rowspan="6">0.50</td><td rowspan="3">≦16</td><td rowspan="3">25</td><td rowspan="6">41-52</td><td rowspan="3">19</td><td rowspan="2">—</td></tr>
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Table 2 Grade and characteristics of MARIWEL

Designation	Suitable environments	Characteristics	Main uses
MARIWEL H50	Splash zone	Offers about twice the corrosion resistance of ordinary steel in splash zone and about the same in submerged zone	Caissons, buoys, dolphins, etc.
MARIWEL K41 MARIWEL K50	Submerged zone	Offers about twice the corrosion resistance of ordinary steel in submerged zone and about the same in splash zone	Subsea structures, piping systems, etc.
MARIWEL R41 MARIWEL R50	Splash zone and submerged zone	Offers about twice the corrosion resistance of ordinary steel in both splash and submerged zones	Foundation piles, pipe piles, ships, piers, floats, etc.

twice that of ordinary steel in both splash and submerged zones. They are suited for foundation piles, ships and oil well drilling rigs. It is possible to improve the corrosion resistance further by adding Mo.

The mechanical properties of any of these steel types can be improved still further by adding Nb and V.

3 Base Metal Characteristics and Weldability

The characteristics required for seawater corrosion resistant steel for welded structures involve high strength and toughness of base metal and weld, as well as good weldability.

The results of testing specimens of MARIWEL for these properties are given in **Table 3**.

Table 3 Chemical composition of tested steel plates

Designation	Chemical composition (%)											
	C	Si	Mn	P	S	Cu*	Ni	Cr	Mo	Nb	C_{eq}*	P_{CM}**
MARIWEL H50C	0.08	0.61	1.22	0.018	0.002	0.45	0.21	—	0.10	0.027	0.34	0.19
MARIWEL K50C	0.08	0.50	1.07	0.017	0.005	—	—	1.08	0.21	0.020	0.55	0.22
MARIWEL R41C	0.05	0.52	0.75	0.014	0.003	0.32	0.17	1.03	—	—	0.41	0.18
MARIWEL R50C	0.11	0.52	1.24	0.018	0.004	0.32	0.18	1.03	—	—	0.55	0.26

* $C_{eq} = C + Si/24 + Mn/6 + Ni/40 + Cr/5 + Mo/4 + V/14$

** $P_{CM} = C + Si/30 + Mn/20 + Ni/60 + Cr/20 + Mo/15 + Cu/20 + 5B$

Table 4 Mechanical properties

Designation	Thickness (mm)	Direction	Tensile test (JIS No.1A)			Charpy impact test(JIS No.4)			Bend test (JIS No.1A) 180°, 1.5t
			Yield point (kgf/mm²)	Tensile strength (kgf/mm²)	Elongation (%)	$_VE_{-20}$ (kgf·m)	$_VE_0$ (kgf·m)	$_VT_S$ (°C)	
MARIWEL H50C	32	L	—	—	—	10.7	17.1	−15	—
		C	46.3	58.5	28	12.1	17.6	−20	Good
MARIWEL K50C	32	L	—	—	—	13.6	19.6	−30	—
		C	43.3	58.0	25	12.5	15.6	−22	Good
MARIWEL R41C	32	L	—	—	—	36.4	35.9	−74	—
		C	35.0	45.2	39	36.8	35.6	−63	Good
MARIWEL R50C	32	L	—	—	—	19.1	24.5	−25	—
		C	35.3	53.2	34	20.0	20.5	−18	Good

Table 5 Chemical composition of weld metals(%)

Designation	Electrode	C	Si	Mn	P	S	Cu	Ni	Cr	Mo
MARIWEL H50C	KSM-50H	0.038	0.61	0.98	0.014	0.004	0.36	0.27	—	0.17
MARIWEL K50C	KSM-50K	0.040	0.58	0.88	0.014	0.005	—	—	1.00	0.19
MARIWEL R50C	KSM-50R	0.041	0.55	0.87	0.015	0.004	0.31	0.22	1.08	—

3.1 Characteristics of Base Metal

The mechanical properties of the base metal are shown in **Table 4.** Both strength and toughness satisfy the specifications adequately, giving the steel excellent characteristics.

3.2 Weldability and Properties of Welded Joint

The coated electrodes shown in **Table 5** have the same chemical composition as that of the base metal so as to bring the seawater corrosion resistance to that of the base metal without deteriorating the usability of an electrode. Their mechanical strength is adjusted by reducing the C content.

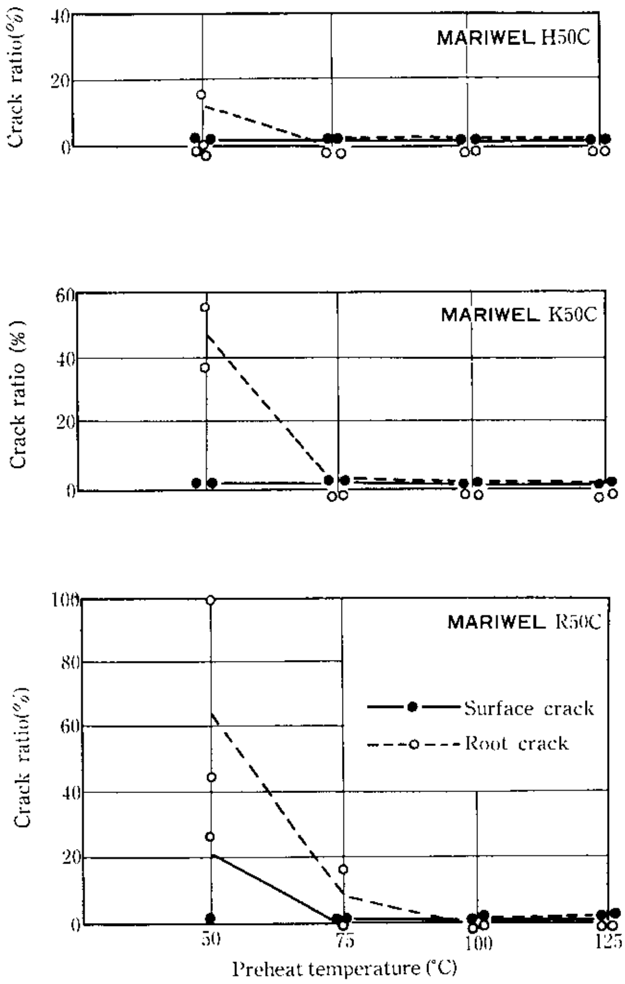
The results of the y-groove cracking test for various steel types are shown in **Fig. 1**. The welding was performed at a 170 A current, a 24 V voltage, and a 150 mm/min welding speed. The electrodes were used after being dried at 350°C for an hour.

For MARIWEL R50C which had the highest crack sensitivity, the crack suppressing temperature was 100°C. Despite the high Cr content, the weldability was good because of reduced C content.

Then, the mechanical properties of welded joints using three grades of MARIWEL were examined. The welding heat input was 18 kJ/cm in the flat position.

The chemical composition of welded metal, the mechanical properties of welded joint materials, the hardness distribution at the welded joint and the results of the Charpy test are shown in **Tables 5** and **6, Figs. 2** and **3**, respectively.

It is evident from these results that the welded joints have excellent mechanical properties.



Welding condition : 24 V, 170 A, 150 mm/min, using electrodes dried at 350°C for an hour

Fig. 1 Results of y-groove cracking test

Table 6 Mechanical properties of welded joints (SMAW)

Designation	Tensile test (JIS Z 3121)		Side bend test (JIS Z 3122) 180°, 1.5*t*
	Tensile strength (kgf/mm²)	Fractured position	
MARIWEL H50C	59.5	Base metal	Good
MARIWEL K50C	62.8	Base metal	Good
MARIWEL R50C	57.2	Base metal	Good

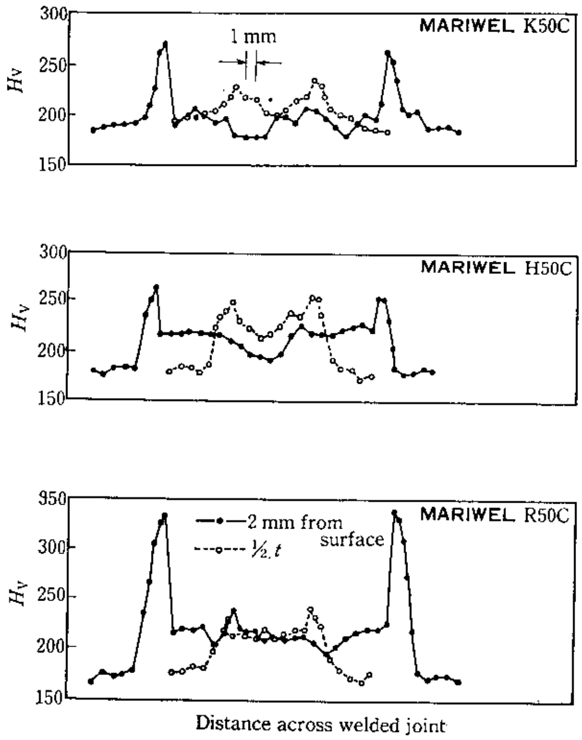


Fig. 2 Distribution of Vicker's hardness (10 kg load) in welded joints

4 Seawater Corrosion Resistance

From the commercial steels of MARIWEL H50C and R50C, long (8t × 50 × 5 500 mm) and short (8t × 200 × 300 mm) test-pieces were made and subjected to a seawater corrosion test for 3–4 years at Chiba, with SM50B and MARINER steel used as the reference material. The surface of the test-piece was finished by machine grinding.

The corrosion rate determined from the mean decrease of thickness in the long test-pieces is shown in **Fig. 4**. Evidently, the long test-piece extending from the atmospheric zone to the underground zone indicated a general tendency for the splash and submerged zones to show greater corrosion rate and for the atmospheric, tidal and underground zones to give relatively smaller corrosion rates. MARIWEL H50C, K50C and R50C gave corrosion rates about a half of that of ordinary steel at the splash zone, the submerged zone and both splash and submerged zones, respectively, proving their excellent corrosion resistance.

As shown in **Photo 1**, the corroded surface of MARIWEL R50C was fine-pitted in the splash zone, while pitting became increasingly irregular in the tidal and submerged zones, like the surface conditions of ordinary steel.

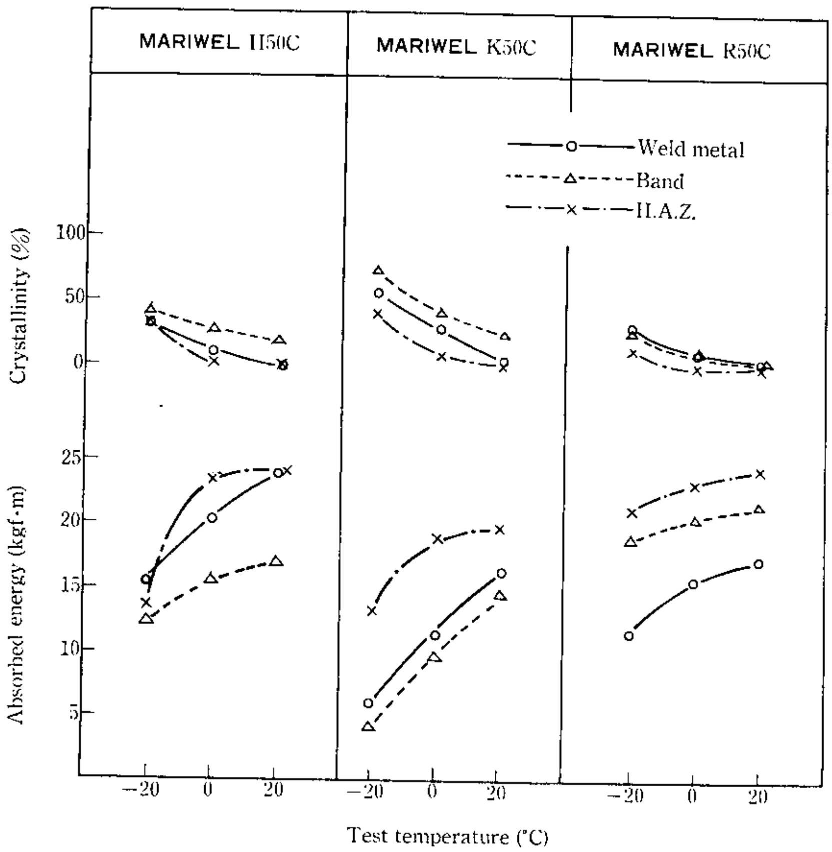


Fig. 3 Results of V-notch Charpy test of welded joints

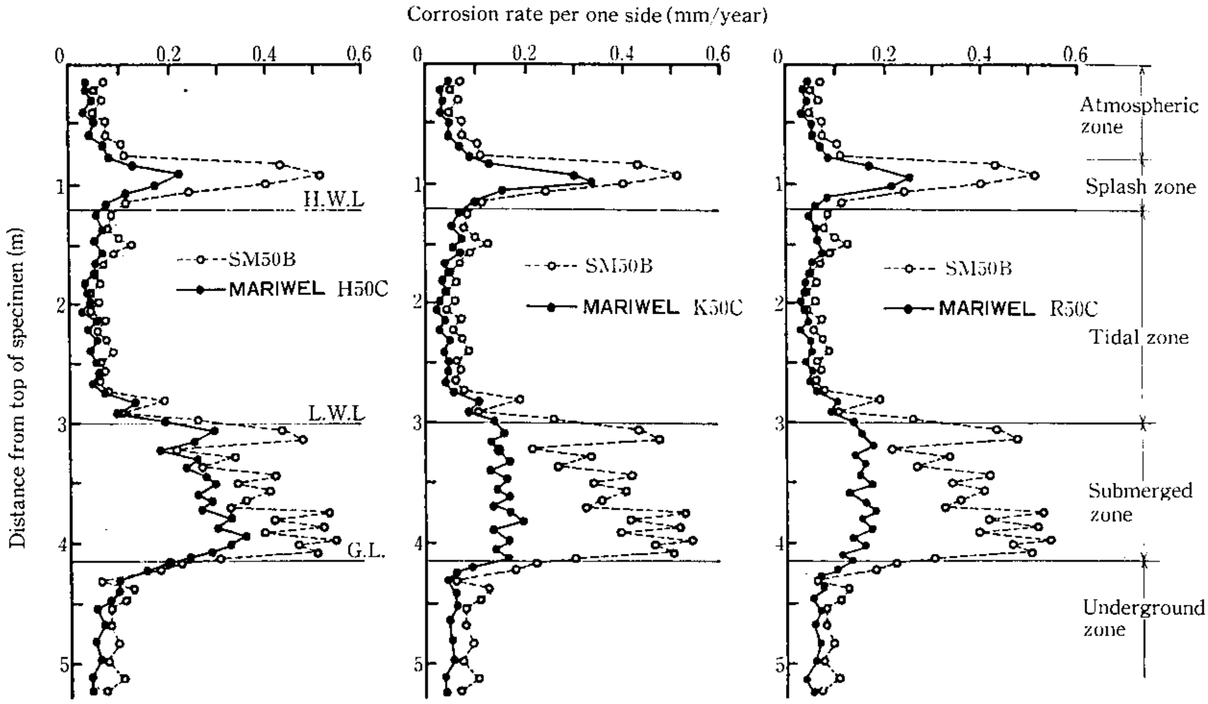


Fig. 4 Results of seawater exposure tests at Chiba for 3 years (Specimen: 8*t* × 50 × 5 500 mm)

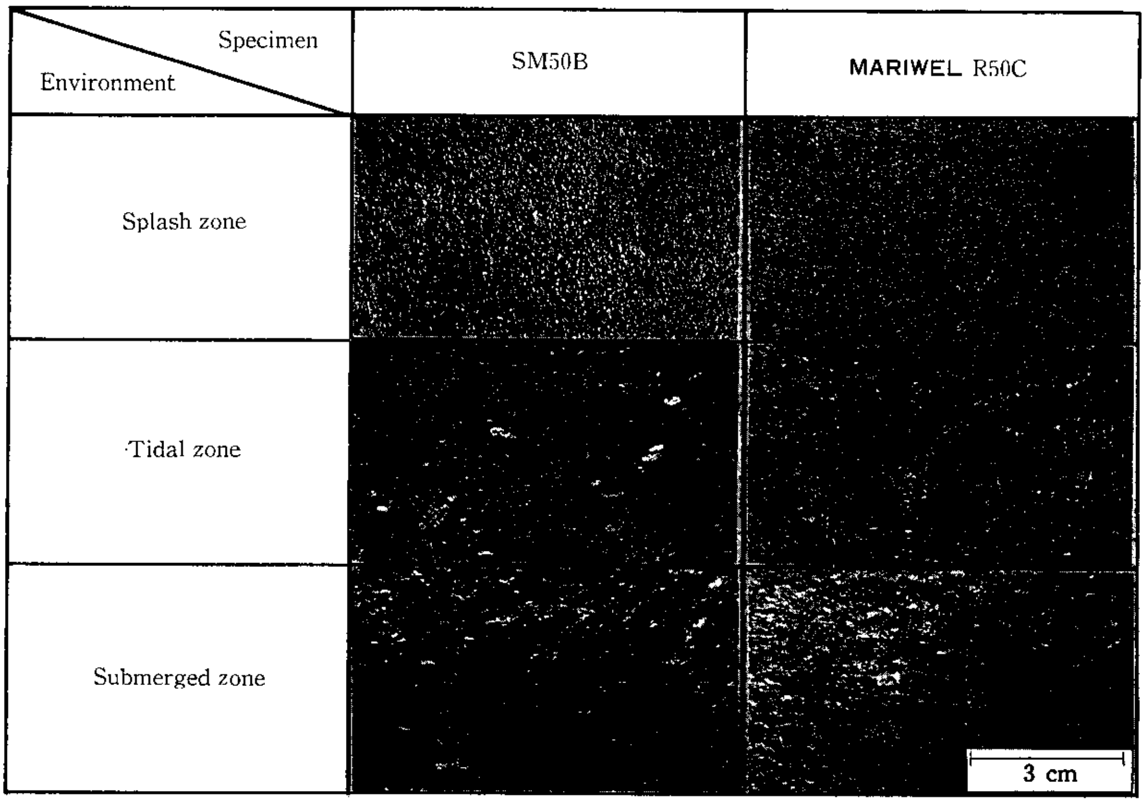


Photo 1 Appearance of corroded steel surface after 3 year exposure

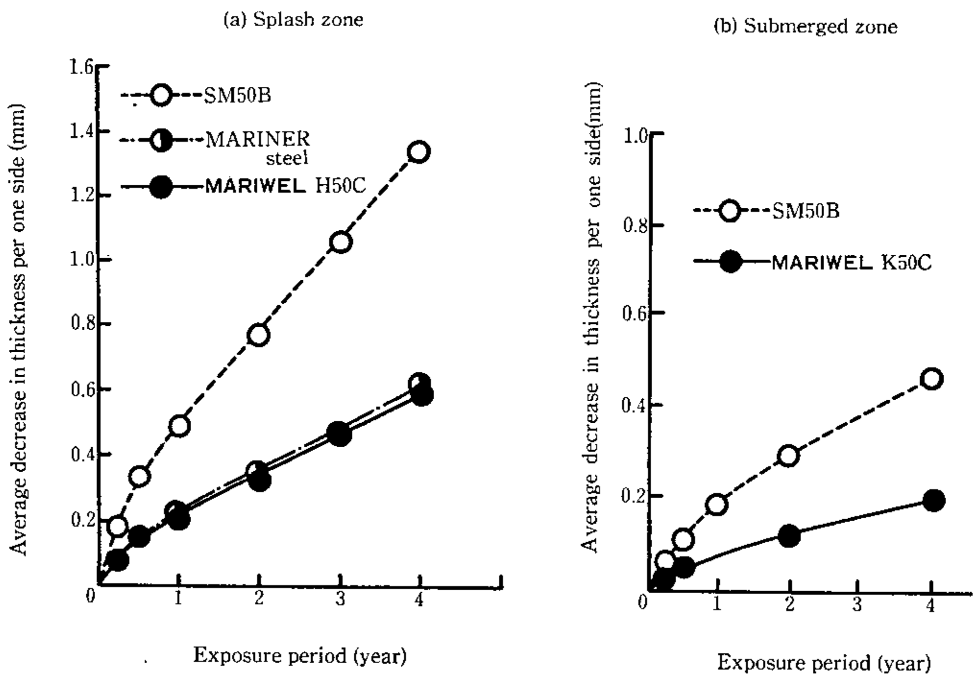


Fig. 5 Results of seawater exposure tests at Chiba (Specimen: 8*t* × 200 × 300 mm)

In the test with short test-pieces, as shown in **Fig. 5**, the corrosion advanced linearly in respect of time in the splash zone for MARIWEL H50C and in the submerged zone for MARIWEL K50C. The corrosion of MARIWEL H50C and K50C in these test environments was about a half of that of ordinary steel. In the splash zone, the corrosion of MARIWEL H50C was nearly equal to that of MARINER steel.

5 Conclusion

There types of MARIWEL seawater corrosion resistant steel for welded structures were developed for different applications. MARIWEL H50 is a low alloy steel of the 50 kgf/mm² grade, having excellent corrosion resistance in the splash zone. MARIWEL K41 and K50, of 41 kgf/mm² and 50 kgf/mm² grades, respectively, are highly corrosion-resistant in the submerged zone. MARIWEL R41 and R50, of 41 kgf/mm² and 50 kgf/mm², respectively, are corrosion resistant in both splash and submerged zones.

The characteristics of the 50 kgf/mm² grade process materials of these steel types were tested. Consequently, it was confirmed that the mechanical properties and weldability of base metal as well as the properties of welded joints were satisfactory, and the corrosion resistance of these steels under various test environments was about twice as good as that of the ordinary steel.

Corrosion of steel structures in the marine environment is prevented by painting, organic lining, inorganic lining and anticorrosive metal lining in splash and tidal zones, and by a cathodic protection or a combination of cathodic protection and painting in submerged and underground zones. The development of new corrosion resistant coating materials and coating systems has also been pursued. However, there is not yet an available means for overall corrosion-prevention with good durability, workability, repairability and economy, and different techniques are currently used selectively for different corrosive environments.

The MARIWEL seawater corrosion resistant steel for welded structures developed by Kawasaki Steel will extend service life and reduce weight, if used in marine structures as a means of corrosion prevention. According to another experiments, painting or cathodic protection of MARIWEL steels gave more favorable results than of ordinary steel. It is expected that MARIWEL will play an important role in corrosion prevention for marine structures.