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High Frequency Electric Resistance Welded Pipe for Offshore Application

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With the recent remarkable progresses in the areas of steel making, hot coil rolling, pipe making, and quality assurance systems, high frequency electric resistance welded (HF-ERW) pipe has become a standard component of Arctic, CO_2 and sour service linepipe applications. However, HF-ERW pipe has not been used for a long period in offshore applications largely due to problems of corrosion and weld quality reliability. This paper describes the new application of HF-ERW pipe to offshore fields, with consideration given to corrosion resistance and longitudinal weld quality reliability and quality assurance.

1 Introduction

Today HF-ERW pipe has gained wide acceptance for use in petroleum and natural gas transportation, including Arctic, CO_2 and sour service applications. However, utilization of HF-ERW pipe in offshore fields has long been limited by corrosion and weld quality reliability problems. Kawasaki Steel has now solved these problems and supplied several customers with HF-ERW offshore linepipe.

This paper describes measures adopted to prevent corrosion and to ensure weld quality and presents typical production results and supply records.

2 Solution of Corrosion-Related Problems

Corrosion is a serious problem affecting operation in a seawater environment. Corrosion in offshore application is of two types: so-called grooving corrosion of the weld and a potential worm-shaped corrosion at the boundary between the seam normalized HAZ (heat affected zone) and the mother metal, such as the ringworm corrosion seen in J55 upset tubing.

2.1 Grooving Corrosion of ERW Weld Seam

As has been reported in several papers,[1-5] the seawater environment often causes grooving corrosion. Grooving corrosion, which is groove-shaped selective corrosion at the seam, mostly occurs with ERW carbon steel pipes; its occurrence varies with application conditions, environments, and the type/characteristics of the fluid within the pipe.[6, 7]

The mechanism of initiation and growth of grooving corrosion of ERW pipe can be summarized as follows:[2, 6, 7] The welded portion of ERW pipe has a different structure from the ferrite-pearlite matrix structure and has local residual stresses due to the hysteresis of rapid heating and cooling. Further the lamellar structure (metal flow) in the rolling direction of the steel hot coil rises towards the inner and outer surfaces of the pipe in the welded area due to pressure-welding and is exposed to the weld-bead machined surface. Nonmetallic inclusions such as MnS exists along this metal flow line and when ERW carbon steel pipe is exposed to

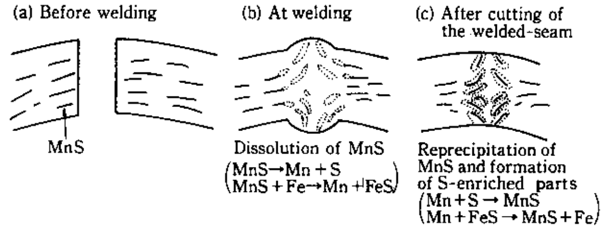


Fig. 1 Formation of S-enriched parts around MnS at the welded seam

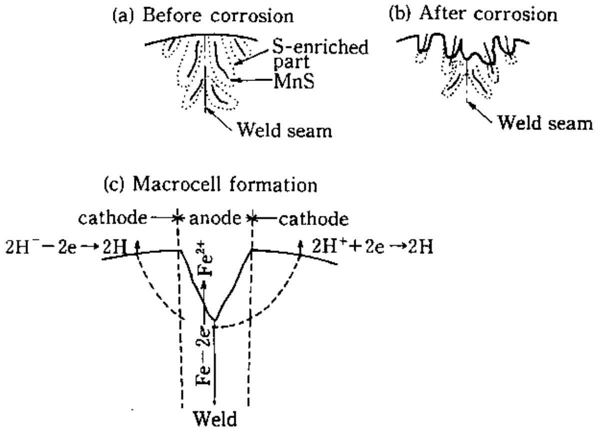


Fig. 2 Schematic illustration of pitting initiation around MnS inclusions and macrocell formed at welded seam

corrosive environments, selective grooving corrosion is initiated from the vicinity of corrosion-susceptible MnS-based nonmetallic inclusions.

The initiation and growth processes of grooving corrosion can be explained by the following three steps:

(1) Formation of S-enriched area around the MnS at the weld due to rapid reprecipitation of MnS after MnS dissolution **(Fig. 1)**
(2) Selective pitting initiation at the site of MnS accumulation **(Fig. 2)**
(3) Macrocell formation between the weld and matrix (Fig. 2)

2.2 Measures against Grooving Corrosion

2.2.1 Application of heat treatment

Heat treatment after welding can contribute to (1) reduction of the S-enriched area around MnS inclusions, (2) lessening of structural difference between the weld and matrix, (3) reduction of residual stress, and (4) reduction of macrocell formation.

However, the short term seam anneal/normalizing practical in ERW manufacturing can not completely eliminate grooving corrosion, as seen in **Fig. 3**.

2.2.2 Modification of chemical composition

Lowering S content of the steel is an effective way

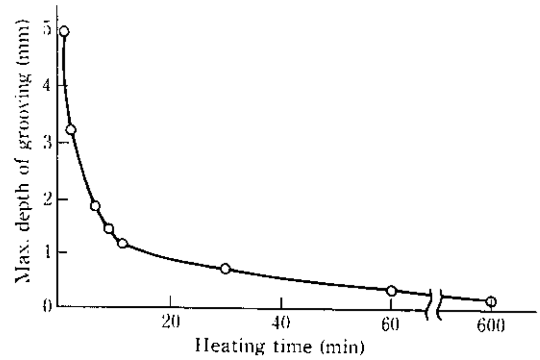


Fig. 3 Effect of heating time at 920°C on maximum depth of grooving corrosion (artificial seawater, 50°C, 50 m/min, 15 ppm O_2, 90 d)

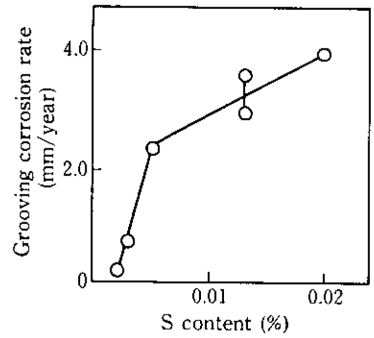


Fig. 4 Effect of S content on grooving corrosion rate in artificial seawater (50°C, 50 m/min, 15 ppm O_2, 90 d)

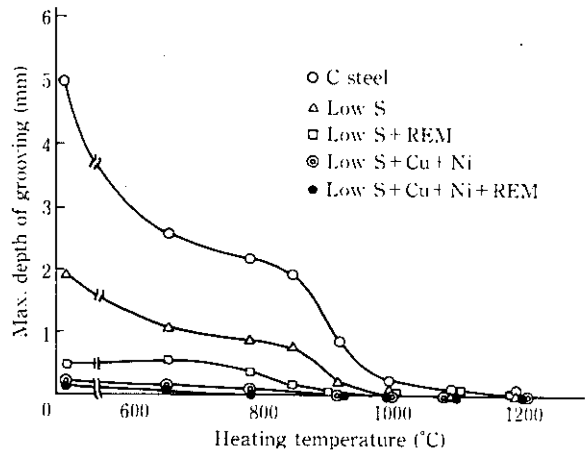


Fig. 5 Effect of heating temperature for 10 min on the maximum depth of the grooving corrosion (artificial seawater 50°C, 50 m/min, 15 ppm O_2, 90 d)

of reducing S-enriched area around MnS inclusions and can help eliminate grooving corrosion initiation, as shown in **Fig. 4**.

Elemental Cu and Ni alloyed in the carbon steel cap-

Table 1 Results of corrosion test in actual pipeline

		Crude oil pipe line	Natural gas pipe line	Geothermal steam pipe line
Test condition	Total pressure (atm)	12	100	8.4
	P_{CO_2} (atm)	0.48	6.8	0.009
	P_{H_2S} (atm)	0.00004	0.001	0.00001
	Temperature (℃)	5~30	40~80	140
	Flow velocity (m/min)	4.2	55	2
	Solution	Containing brine	Containing brine	99.4% steam
	pH	7.7	6.8	4.5 (condensed water)
Corrosion rate*1) (mm/year)	Carbon steel	0.60 (GC)	0.74 (GC)	0.21 (SGC)
	Low S-Cu-Ni steel	0.45 (NGC)	0.34 (NGC)	0.17 (NGC)
	Ultralow S-Ca steel	0.46 (NGC)	0.41 (NGC)	0.18 (NGC)

*1. NGC: No grooving corrosion SGC: Slight grooving corrosion GC: Grooving corrosion

ture S^{--} on the corrosion pit surface, which is generated by the dissolution of MnS and solid solution S accompanying a pH drop in the pit, forming a non-soluble film of Cu_2S and Ni_2S_3. The elements thus concentrate in the rust layer of the base iron surface and effectively suppress corrosion.

Experimental data on low S-Cu-Ni carbon steels together with other several chemical compositions is shown in **Fig. 5**. It is noted that low S-Cu-Ni steel shows the best grooving corrosion resistance, even when heat treatment is not applied. **Table 1** shows the corrosion test with actual pipe line. In summary a low S-Cu-Ni chemical composition is the best selection for avoiding grooving corrosion.

2.2 Worm-Shaped Corrosion along Longitudinal Seam HAZ

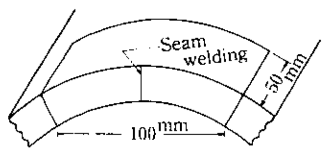
Ringworm corrosion, which commonly occurres at the HAZ of upset J55 tubing (as-rolled type) is well known.[8] This kind of corrosion is caused by microstructural difference incidental to thermal history at the welding or the upsetting. Some researchers point out the possibility of the similar attack to ringworm corrosion along the seam-normalized HAZ due to the microstructural difference between the post-normalized area and the untreated area (base metal). However, another possible explanation is that ringworm corrosion might be governed by the size and amount of cementite available as a cathode. If so, no problems with seam normalizing and girth welding should occur with ERW linepipe, which is lower in carbon content ($C \leq 0.12\%$) than OCTG ($C = 0.47\%$) and is therefore lower in cementite. To support this idea, the following tests were conducted.

Seam normalized and full body QT (quenched and tempered) materials of the typical linepipe chemical composition shown in **Table 2** were prepared. The specimens for test were cut out from the seam weld portion. A list of test conditions and a diagram of the test apparatus with which ringworm corrosion occurred in J55 upset tubing are shown in **Table 3** and **Fig. 6** respectively. Test results are shown in **Photo 1** (appearance) and **Table 4** (wall thickness measurements).

Table 2 Chemical Composition of a typical linepipe specimen for the ringworm corrosion test (wt %)

C	Si	Mn	P	S	Al	Nb	V	Cu	Ni	Ca
0.06	0.20	1.20	0.010	0.001	0.040	0.040	0.022	0.17	0.17	0.0044

Table 3 Ringworm corrosion test conditions

Test condition	
Solution*1	Artificial seawater ASTM D-1141
Temperature	50℃
Velocity	50 m/min
CO_2 content	0.2 l/min
Period	100 d
Test piece	

*1 Artificial seawaler is changed once each two weeks

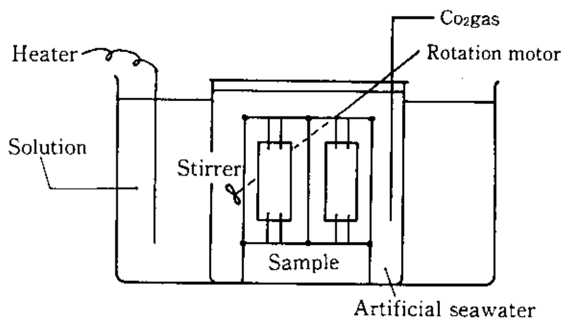


Fig. 6 Testing apparatus for ringworm corrosion of linepipe

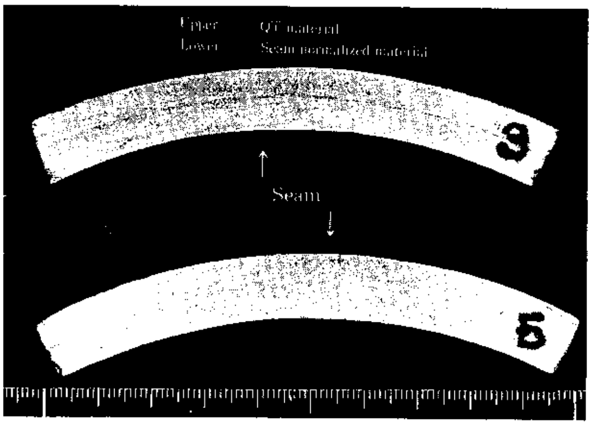


Photo 1 Cross sectional view of ERW specimens after ringworm corrosion test (No. 3, QT material; No. 5, seam-normalized material)

Table 4 Change in wall thickness in ringworm corrosion test

(mm)

		Wall thickness measurements (6 point)						Average
Before heating		13.00	13.00	12.94	12.92	12.86	12.82	12.92
QT material	1	12.33	12.33	12.30	12.28	12.25	12.08	12.26
	2	12.33	12.30	12.18	12.18	12.13	12.08	12.20
Seam-normalized material	1	12.20	12.10	11.96	11.95	11.86	11.85	11.99
	2	12.05	12.02	12.00	12.00	11.90	11.88	11.98
Mother metal		12.20	12.18	12.15	12.13	12.10	12.08	12.14

QT treatment made the microstructure uniform and improved the resistance to CO_2 corrosion. The seam-normalized specimens as well as the QT treated material, however, did not show any selective attack near the seam weld. The average corrosion rate of the seam-normalized specimens was approximately 4 mm/year which was in good accordance with the data from the nomograph calculated by C. de Waard.[9]

Mechanism of the ringworm corrosion has been reported as below.[8] Steels heated at certain temperatures lower than their Ac_1 have finely divided cementite (Fe_3C). Cementite acts as cathode and brings about a lot of microcell with ferrite. In the upset tubing, microstructure of the boundary region between the tapered portion and the pipe body corresponds to that of the above steel. Hence, the galvanic corrosion of the ferrite with cementite will be larger in this boundary region than in any other portions, resulting in the ringworm corrosion in CO_2 services. The most important factor affecting the ringworm corrosion is the amount and the state of the divided cementite.

ERW linepipes have generally one order of magnitude lower carbon content than OCTG, and hence the amount of cementite is much less in the outside of the normalized area of ERW linepipes than in the tapered portion of an upset OCTG. Why the specimens of the ERW linepipe did not suffer from the selective attack in a CO_2 environment will be attributed to their low carbon content. And the same will hold to girth weld HAZ of the ERW linepipes.

3 Seam Weld Reliability and Quality Assurance

In offshore application of ERW pipe, seam weld reliability and quality assurance are even more critical than with onshore applications. Many techniques contributing to the enhancement of weld quality reliability and quality assurance have been developed and applied by Kawasaki Steel.[10-12]

Typical example are summarized as follows:

(1) Techniques for Enhancement of Weld Quality Reliability

Trimming: Edge miller
Forming: Edge bending
Full cage forming
Downhill forming
Seam guide arrangement
Welding: Automatic heat input control
Gas shield welding
Spark detector
Seam ann.: Automatic heat input and positioning control

(2) Equipment/Technique for Weld Quality Assurances

Coil: Coil edge ultrasonic testing (on-line)
Forming: Mill ultrasonic testing (on-line)
Finishing: Seam ultrasonic testing (on-line)
Full body: rotary type full body ultrasonic testing (off-line)
Pipe end: Manual ultrasonic testing for seam and lamination (on-line)

An automatic heat input control system (**Fig. 7**) is one of the representative methods to enhance the weld quality reliability, namely welding temperature can be controlled at a desired level by bringing the informations of material speed and wall thickness measured before forming section into thyristor control unit even if they change during production.[10-12]

More stable welding temperature, which leads to weld quality reliability, can be obtained through the use of an automatic heat input control irrespective of rapid wall thickness changes, as shown in **Fig. 8**.

4 Actual Production Results

Kawasaki Steel first supplied ERW offshore linepipe for practical use in March 1986 based on our study and no problems have been reported to date. Typical specifications and production results for ERW offshore applications are presented in **Tables 5, 6, and 7**. In addition to the requirements from the customer, material design (lowering S and addition of Cu and Ni) was carefully engineered from the standpoint of seawater corrosion

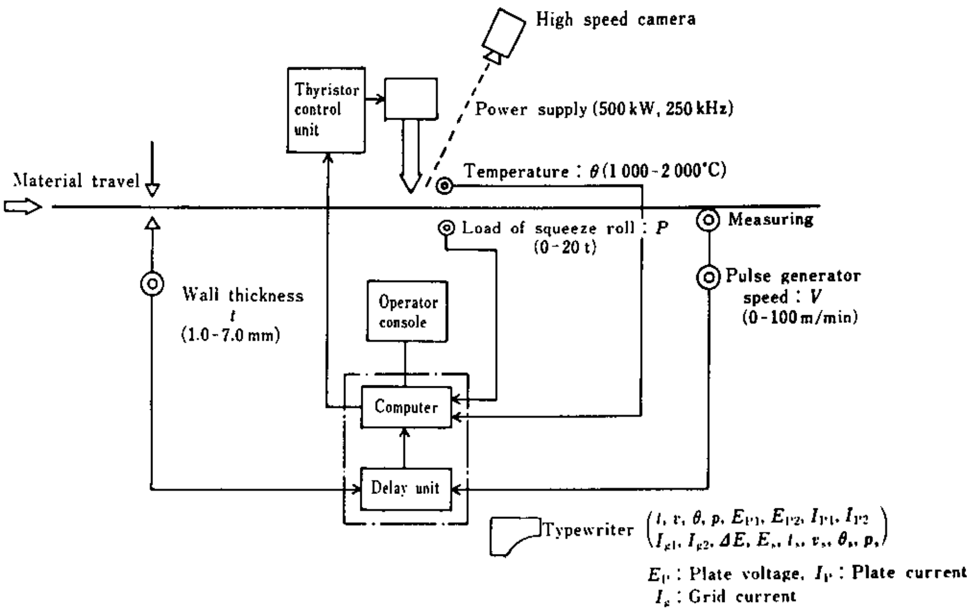


Fig. 7 Automatic heat input control system in 26″ ERW mill

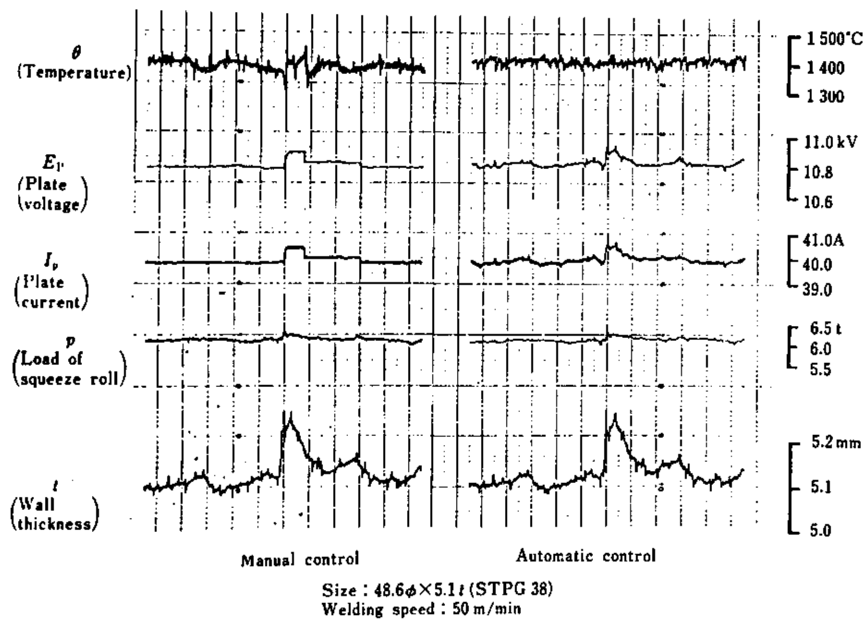


Fig. 8 Comparison of welding conditions between manual and automatic control

Table 5 Chemical composition of ERW offshore linepipe (API 5L X52, 16″ × 0.625″)

	C	Si	Mn	P	S	Al	Cu	Ni	Nb	Cr	Mo	V	Ti	N	Ca	CE*1
Specification	≤0.12	≤0.35	≤1.35	≤0.025	≤0.008	≤0.07	≤0.26	≤0.26	≤0.05	≤0.10	≤0.08	≤0.08	≤0.03	≤0.014	—	≤0.40
Actual production	0.06	0.20	0.85	0.010	0.001	0.040	0.17	0.17	0.015	—	—	0.007	—	—	0.0030	0.23

*1 CE = C + Mn/6 + (Cr + Mo + V)/5 + (Cu + Ni)/15

(grooving corrosion) resistance. Furthermore, not only transverse mechanical properties but also longitudinal mechanical properties, which are important for offshore application, were checked.

All customer's requirements were met and measures against corrosion were taken. Successive shipments of ERW for offshore applications are summarized in **Table 8**. All are presently performing satisfactorily.

Table 6 Mechanical properties of ERW offshore linepipe (API 5L X52, 16″ × 0.625″)

Direction	Location		n	$\bar{x}$	σ	Acceptance limit
T	Body	YS (psi)	28	66145	1340	52000~72000
		YS (psi)	28	74325	1180	63000~78000
		Yield ratio (%)	28	89.00	1.19	≦93%
		El (%)	28	43.18	1.49	≧27%
	Weld	TS (psi)	28	76430	925	≧63000
L	Body	YS (psi)	28	65520	2030	No specification
		YS (psi)	28	72730	1065	
		Yield ratio (%)	28	90.10	2.47	
		El (%)	28	44.74	1.38	

Table 7 Charpy impact test results of ERW offshore linepipe (API 5L X52, 16″ × 0.625″, 32°F, full size)

Location	Direction	Energy (J)				Shear area*2 (%)		
		Results			Spec.*1			
Base metal	L	420	400	415	No spec.	100	100	100
Base metal	T	408	402	403	≧73/60	100	100	100
HAZ	T	395	402	400	≧73/60	100	100	100
Weld	T	340	370	390	≧63/51	100	100	100

*1 For the average of three test results/for any individual result.
*2 No specification.

Table 8 Supply records of ERW offsore linepipe

Shipment	Area of application	Grade	OD × WT	Quantity (t)	Depth (ft)	Application	Coating
Mar. 1986	Gulf of Mexico	X52	16″ × 0.625″	10590	300~490	Gas & oil gathering	Epoxy fusion
Apr. 1986	Gulf of Mexico	X52	14″ × 0.625″	5000	350	Gas & oil gathering	Epoxy fusion
May. 1987	Gulf of Mexico	5LB	10¾″ × 0.500″	130	200~230	Gas line between platforms	Thin film
July. 1987	South China Sea	X52	10¾″ × 0.500″	1320	200~230	Gas gathering	Coaltar
Feb. 1988	South China Sea	X52	10¾″ × 0.500″	2700	200~230	Gas gathering	Coaltar
Mar. 1988	South China Sea	X52	16″ × 0.500″	2300	200~230	Gas gathering	Coaltar

5 Conclusions

Prior to entry into the new field of offshore application, the corrosion properties and seam weld reliability and quality assurance of ERW pipe were studied and the following findings were obtained:

(1) Lowering the S content of the steel is an effective way to reduce the S-enriched area around MnS inclusions, which causes the initiation of grooving corrosion.

(2) Addition of Cu and Ni contribute to formation of a non-soluble film, thus improving corrosion resistance.

(3) As a result of its low carbon content, the longitudinal seam normalized HAZ of ERW linepipe is resistant to worm-shaped corrosion.

(4) To enhance weld quality reliability and quality assurance, many techniques, especially emphasizing welding control and non-destructive examination, have been developed and applied.

Based on the above findings, HF-ERW linepipe has been supplied by Kawasaki Steel to several customers for use in offshore applications, all such linepipe has performed satisfactorily to date.

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