B4 - CORROSION CASE STUDIES AND PREVENTION OF STAINLESS STEEL PIPING AND EQUIPMENT IN BUILDING PIPING SYSTEMS

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Abstract

It was at 1960's that the stainless steel piping was used for the building piping systems for the first time in Japan. The stainless steel piping was mainly used for the hot water supply line and the water supply line as a corrosion resistance piping material that replaced the galvanized steel pipe. Afterwards, the using results have increased because the standard in Japan concerning the equipment piping and the joint was enacted. Stainless steels came to be used as an equipment material. It is one of the main piping materials and the main equipment materials in the hot water supply piping system and the water supply piping system now. However, it will comparatively cause accidents of the rusting and the water leak, etc. in a short term by generating the localized corrosion when the welding condition, the construction method or directions are mistaken. In this report, the transition of the corrosion prevention technology for the stainless steel piping and the equipment is shown, and, in addition, the corrosion case studies and the corrosion prevention of the stainless steel piping and equipment are shown. As corrosion cases, (1) rusting in water supply tank inside, (2) pitting corrosion, stress corrosion cracking, and crevice corrosion in hot water supply piping, (3) crevice corrosion in cooling water piping, (4) galvanic corrosion in water supply piping are shown. Finally, some figures and tables are shown about the corrosion factors and corrosion prevention of the stainless steel piping and equipment.

Keywords

The stainless steel piping and equipment, The transition of the corrosion prevention technology for the stainless steel piping and the equipment, Rusting, Pitting corrosion, Crevice corrosion, Stress corrosion cracking, Galvanic corrosion, Corrosion factor, Corrosion prevention

1 Introduction

Stainless steel piping first came into use for cold and hot water pipes in Japanese buildings in the early 1970s. Later, in 1980, a standard was established for stainless steel pipes in buildings in the form of JIS G 3448 "Light Gauge Stainless Steel Tubes for General Piping" followed by "Performance Standard for Stainless Steel Pipe Fittings for General Piping" (Japan Stainless Steel Association Standard SAS322, 1988) for pipe fittings. Early problems associated with corrosion of welds and pipe fittings have been gradually solved since that time. The use of stainless steel piping has increased and stainless steel is now one of the major materials used for cold and hot water supplies. Table 1 shows how corrosion protection technology for stainless steel piping systems has improved over time. The high corrosion resistance of stainless steel derives from a passivity film (of hydrated chromium hydrating oxyhydroxide with a thickness not more than 10^{-8} m)[1)] which forms on the surface of the metal. As a result, stainless steel pipes suffer little or no corrosion due to the elution of ions, unlike pipes made of other metals, so they are used extensively in hospitals, restaurants, food processing plants, and other facilities. However, problems due to localized corrosion do arise occasionally depending on conditions such as weld treatment and the structure of pipe fittings, as well as water quality (chloride ion concentration and free chlorine in particular). Figure 1 indicates the typical forms of stainless steel corrosion that occur in building equipment and piping. In actuality, crevice corrosion, pitting corrosion intergranular corrosion occur in welds and fittings. In a hot water supply system, these corrosion pits as a starting point leads to the development of stress corrosion cracking (SCC). The rust seen occasionally in stainless steel water supply tanks actually consists of fine corrosion pits spread over a large area. Case studies of various forms of stainless steel corrosion are presented below to assist in the design of corrosion protection measures.

Table 1 - Transition of corrosion protection technology of stainless steel piping and equipment [2)]

		1960–2010
Stainless steel piping	Crevice corrosion	▲ JIS G 3448 (c. 1980); TIG Welding; ▲ SAS322 (c. 1990); Improvement of gasket material; Water quality judgment indicator (c. 2000)
	Pitting corrosion	▲ JIS G 3448 (c. 1980); TIG Welding; ▲ SAS322 (c. 1990); Water quality judgment indicator (c. 2000)
	SCC (Stress corrosion cracking)	▲ JIS G 3448 (c. 1980); TIG Welding; ▲ SAS322 (c. 1990); Review of heat insulation material (1990–2000)
Steinless steel receiving tank	Rusting of gas phase part	Painting of gas phase part (c. 2000); Use of SUS329J4L (2000–2010)
Steinless steel hot water storage tank	SCC (Stress corrosion cracking)	Electrolytic corrosion protection (Cathodic protection) (c. 1980); Use of SUS344 (c. 2000)

JIS G 3448:Stainless steel pipe for general piping

SAS322:Pipe fitting performance standard of stainless steel pipe for general piping

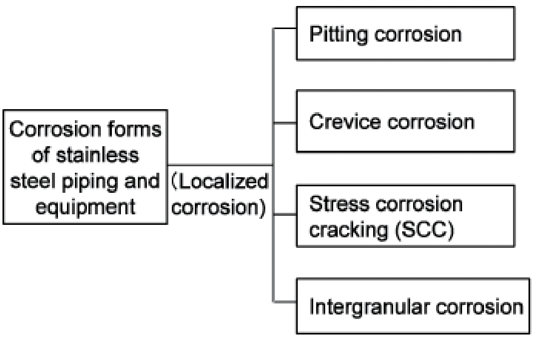


Fig.1: Typical corrosion forms of stainless steel piping and equipment for building piping system

2 Case studies of piping and equipment corrosion

2.1 Corrosion in stainless steel water supply tank

Figure 2 illustrates the configuration of materials used for water supply tanks designed to corrosion-resistant specifications, while Fig. 3 is a photograph of a typical tank with these specifications (but not the actual tank described in the case study). The water level in the case-study tank had dropped about two years previously, exposing the inner surfaces of the side panels to the atmosphere. Corrosion occurred in the Type 444 stainless steel side panels and Type 304 stainless steel stiffeners. On the side panels, corrosion was concentrated at the welds. Figure 4 shows the corroded parts of the tank. No corrosion was found on the Type 329J4L stainless steel in the vapour phase section of the tank or on the Type 444 stainless steel in the immersed section below water level in Figure 2. As reported by Nakata[3)], the cause of the corrosion was that free chlorine (which is added to tap water for sterilization) vaporised from the water and dissolved into condensation that formed on the internal surfaces of the vapour phase section, creating an environment where high concentrations of chloride ions were present and the pH was low, as shown in Figure 5. To take countermeasure against the problem, the water level in the tank was raised to its original level (in the Type 329J4L stainless steel section). Earlier practice was to paint the stainless steel in the vapour phase section of tanks, but these days highly corrosion resistant austenitic-ferritic duplex stainless steel, such as 329J4L, is used as indicated in Fig. 2. Types 444, 304, 304L, 316, and 316L stainless steels are used in the liquid phase section (the immersed section).

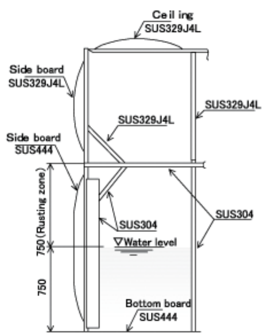


Fig.2: Material specification of receiving tank [2)]

Fig.3: Externals of receiving tank (example)

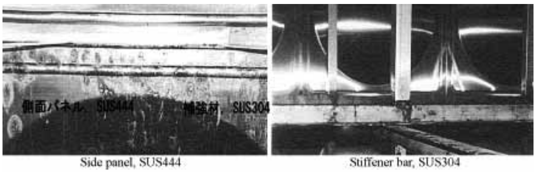


Fig.4: Rusting of vapour phase part in stainless steel receiving tank inside, 2 years use [2]

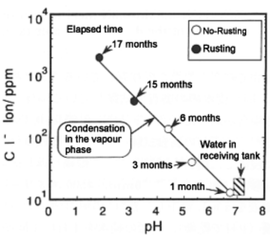


Fig.5: A correlation between Cl^- ion concentration and pH of the condensation formed in the vapour phase environment in receiving tank (without compulsive ventilation, 25Cr-14-0.8Mo-0.2N steel)[3]

2.2 Pitting corrosion and stress corrosion cracking of welds in water supply piping

Welded joints in hot water supply piping (of Type 304 stainless steel) in Hotel A suffered corrosion as shown in Figure 6. Leakage of hot water through one corroded weld occurred after 1.1 years of use. The whole inner surface of the pipe had turned a brownish-red colour and oxidised scale was present on the weld. The brownish-red colouring was caused by corrosion of metals other than stainless steel. The presence of Fe, O, and Si was detected by energy dispersive X-ray (EDX) analysis.

Corrosion was found in a weld between a pipe and a lap joint (also of Type 304 stainless steel). The weld bead was pitted, as was the heat-affected zone around the weld bead on the lap joint side, and stress corrosion cracking had developed from the bottom of the pits. This is shown in Figure 6. In other welds, also, pits had formed deep in the clearances left by incomplete weld penetration, from where stress corrosion cracking developed and penetrated through the pipe. The pipe cross section also presented in Figure 6 clearly shows cracking on the outer surface of the pipe.

The cracking was caused when water leaked from the weld and eluted chloride ions from the thermal insulation material surrounding the pipe, creating a corrosive environment on the outer surface of the pipe with a high chloride ion concentration. Table 2 gives the results of an analysis on the quality of the (well) water. It has a pH of 7.1 and the residual free chlorine concentration is 0.5-0.6 mg/L, both within the normal range. The chloride ion concentration of 3 mg/L is very low for tap water. The hot water temperature was about 60°C and the chemical composition of the piping material was within the standards.

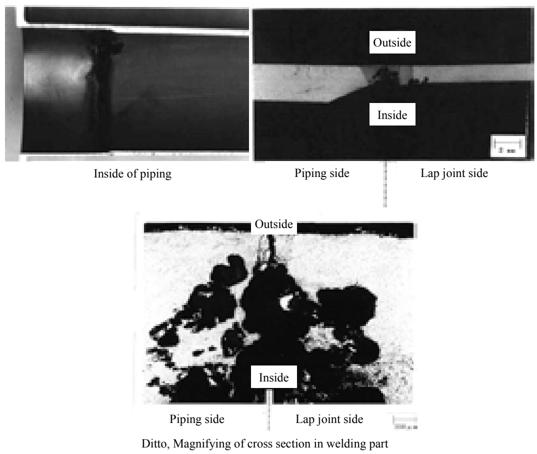


Fig.6: Pitting corrosion generated in welding pat of stainless steel pipe hot water supply, about 2 years use, 75Su(65A)[2]

Table 2 - Analysis of tap water quality(well water)on hotel A[2)]

Analysis item	Unit	Analysis value
Turbidity	NTU	0
Color	TCU	1
pH		7.1
Free Cl_2	mg/L	0.5-0.6
Total hardness (as $CaCO_3$)	mg/L	93
Cl^-	mg/L	3
Total residue	mg/L	148
$KMnO_4$ Consumption	mg/L	0.9
HNO_3-N and HNO_2-N	mg/L	1.8

2.3 Crevice corrosion of hot water pipe flange face

Also in Hotel A, crevice corrosion was found on the flange face of a hot water pipe (Type 304 stainless steel) as shown in Figure 7, though it did not penetrate the flange. Analysis was carried out on a solution obtained by adding 100 mL of water to 1 g of the gasket material and boiling for five minutes before cooling. Table 3 presents the results of this analysis, showing that chloride and sulphate ions had eluted from the gasket. It is clear that an environment with a high chloride ion concentration formed in the clearance between the gasket and the stainless steel flange face. The passivity film on the stainless steel surface was broken down locally by the action of the chloride ions, resulting in crevice corrosion.

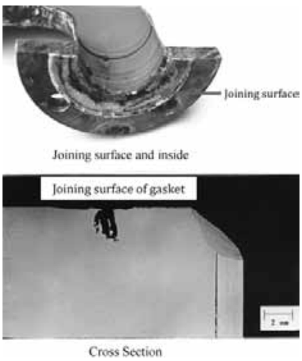


Fig.7: Crevice corrosion generated in flange joining surface of stainless steel piping for hot water supply, about 2 years use, 75Su(65A)

Table 3 - Analysis result of dissolution elements from gasket (mg/L)

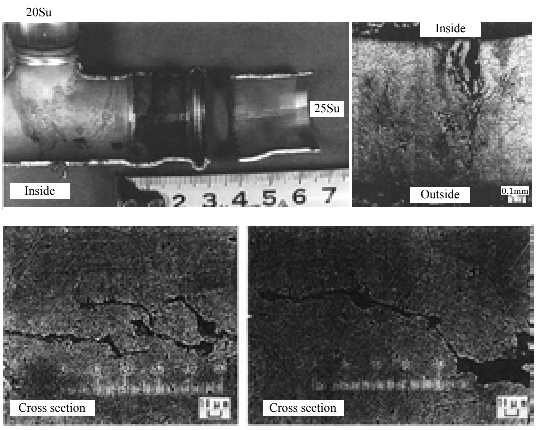
Cl^-	SO_4^{2-}
152	2,353

2.4 Crevice corrosion of hot water pipe fitting

In Hotel B, the inner surface of a press-type pipe fitting (T-shaped) in the hot water supply piping (Type 304 stainless steel) suffered corrosion. The fitting had been leaking, as shown in Figure 8. This particular fitting had been in use for 7.17 years, and water had been leaking for several years. Localized corrosion was found in several places on the inner surface of the fitting. In the clearance between the outer surface of the pipe (Type 304 stainless steel) and the inner surface of the fitting (also Type 304 stainless steel), there was corrosion around the whole circumferences. Beneath this localized corrosion on the inner surface of the fitting, pitting corrosion had occurred (as shown in the cross section at top right in Figure 8). Stress corrosion cracking had developed from the bottom of the pits and penetrated through the wall of the fitting. In addition, the outer surface of the pipe exhibited stress corrosion cracking of transgranular type within the fitting.

Table 4 shows the results of an analysis on the quality of the water (well water). Although the chloride ion concentration is not particularly high, the ratio of chloride to sulphate ion concentrations is high (4.0) and the M alkalinity is high (124 mg/L), and seemed these were factors in the corrosion.[4)] The stress corrosion cracking that began developing at the outer surface of the pipe within the pipe fitting was caused by an environment with a high chloride ion concentration in the clearance, leading to crevice corrosion. Further, since the well water is treated with chlorine after filtration, it can be imagined that management of the residual free chlorine concentration might have been a factor in the advance of crevice corrosion and pitting corrosion of the stainless steel. All of the stress corrosion cracking was of transgranular type. It is said that transgranular stress corrosion cracking (TGSCC) occurs in a harsh environment while intergranular stress corrosion cracking (IGSCC) occurs in a neutral pH and low chloride ion environment.[5)] It is inferred from this that a high chloride ion environment was formed in the clearance between pipe and fitting.

Crevice corrosion is a localized corrosion that is apt to occur in a neutral pH and low-salt content freshwater environment, such as in tap water, even in the absence of material degradation caused by poor welding. Figure 9 illustrates the mechanism of crevice corrosion, which proceeds as follows. As the oxygen in the clearance is consumed, reducing its concentration, the passivity film on the crevice surfaces is maintained by a reduction reaction (reduction of dissolved oxygen) outside the crevice. The solution within the clearance becomes electrically positive (+) as metal ions (such as Fe^{2+} and Cr^{3+}) elute, but in order to maintain the electroneutrality of ions within the clearance, anions (such as chloride ions; Cl^-) enter the clearance from outside by ionic conduction. As a result the solution inside the clearance becomes high in chloride ions. Further, the hydrolysis of metal ions inside the clearance considerably reduces the pH of the solution, leading to local breakdown of the passivity film.



Magnifying of part A, Transgranular cracking   Magnifying of part B, Transgranular cracking

Fig.8: Crevice corrosion generated in press pipe fitting, 7.17years use, 25Su x 20Su[2)]

Table 4 - Analysis of tap water quality (well water) on hotel B[2)]

Analysis item	Unit	Analysis value
pH		7.52
Electric conductivity	mS/m	32.5
M-Alkalinity (as $CaCO_3$)	mg/L	124
Total hardness (as $CaCO_3$)	mg/L	106
Cl^-	mg/L	24
SO_4^{2-}	mg/L	6
Total residue	mg/L	220.5
Soluble SiO_2	mg/L	29.6
Fe	mg/L	<0.02
Mn	mg/L	<0.10

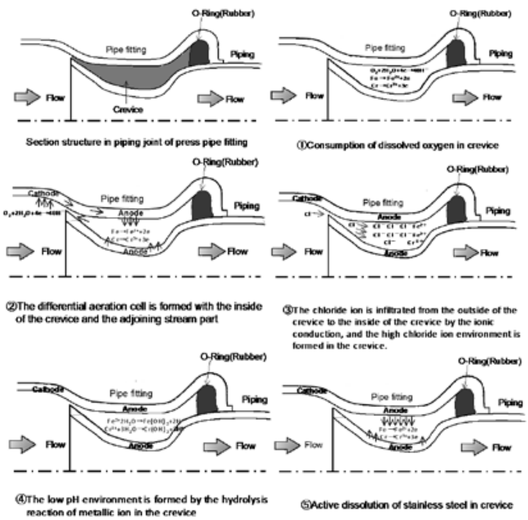


Fig.9: Mechanism of crevice corrosion in press-type pipe fitting of stainless steel piping

2.5 Stress corrosion cracking of storage tank (hot water storage tank)

Stress corrosion cracking occurred in the structure of a hot water storage tank (Type 304 stainless steel; plate thickness: 1.0 mm; hot water temperature: about 50°C) after about five years of use. Figure 10 shows the corroded inner surface (left) and a cross section through the plate (right). The photo of the corroded inner surface indicates that there was heavy corrosion toward the top of the tank. The cross section is taken from a point near the centre of this photo. (The purple-red colouration in the photo results from a dye penetration test.) The cross section indicates that the cracks originated from the outer surface of the tank, beneath the thermal insulation material that surrounded the tank. The cause of the cracking is that chloride ions became concentrated under the thermal insulation material as water leaked through the corrosion, leading to the development of stress corrosion cracking, which penetrated the tank, from the localized corrosion pits that occurred on the outer surface of the tank.

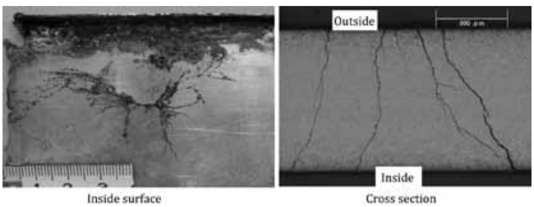


Fig.10: Stress Corrosion cracking generated in hot water storage tank made of SUS304, about 2 years use[6)]

2.6 Crevice corrosion of cooling water pipe flange face

Corrosion occurred on an expansion-type flange face (Type 304 and Type 250 SU stainless steel) of an open cooling water piping system, leading to water leakage from the flange face after 2.58 years of use. The corrosion rate calculated from the whole period of use is 1.6 mm/year, but when the time of actual operation of the cooling system is considered the corrosion rate is 3.0 mm/year. The corrosion occurred on the flange face, as shown in Figure 11. Irregularly shaped pits were formed on the flange face around inner circumference. The stainless steel base metal was exposed in deep pits, with rust of brown and brownish-red colour present around the deep pits. On the flange face and on its angles, deep jagged pitting corrosion had developed in the pits and penetrated through the flange, as shown in Figure 11. The chemical composition of the piping material was within the range of the JIS standards, and the stainless steel was of austenitic structure, as shown in Figure 11 (lower right). The gasket used for the flange was of PTFE (trade name: Teflon) sandwiched with a cushioning material. A test of chloride ion elution from the PTFE gasket indicated that the chloride ion concentration was low, 7 mg/L. The whole inner surface of the pipe was covered with a very thin grey and light brown deposit, but had not corroded.

Table 5 presents the results of an analysis on the quality of the cooling and make-up water. The electric conductivity was significantly high in relation to the chloride and sulphate ion concentrations, at about three times the level (800 µS/cm or 80 mS/m) in the guidelines for water quality for refrigerators and air conditioners specified by the Japan Refrigeration and Air Conditioning Industry Association.

Corrosion occurred on an expansion-type flange where there had been difficulty tightening the flange bolts and preventing water leakage at the time of construction. Corrosion did not recur after the leaking sections were replaced. Considering this, the primary cause of corrosion is determined as crevice corrosion of the flange face due to defective expansion. The width and extent of the clearance between the flange faces were factors affecting this crevice corrosion. Chloride and other ion concentrations in the clearance increased and the localized breakdown of the passivity film was promoted by the mechanism presented in Figure 9.

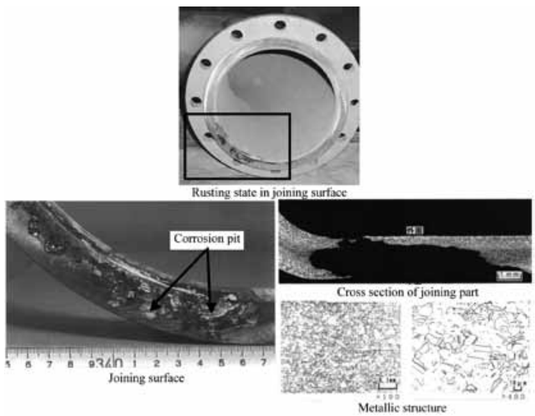


Fig.11: Crevice corrosion in expansion type flange of cooling water piping, 2.6 years use, 250Su[2)]

Table 5 - Analysis of cooling water quality and makeup water quality[2)]

Analysis item	Unit	Cooling water	Makeup water
Appearance		Yellowish and transparent, a little suspended	Colorless and transparent
pH		8.3	6.9
Electric conductivity	mS/m	240	22
M-Alkalinity (as $CaCO_3$)	mg/L	250	61
Total hardness (as $CaCO_3$)	mg/L	130	57
Ca-hardness (as $CaCO_3$)	mg/L	95	42.5
Cl^-	mg/L	180	18
SO_4^{2-}	mg/L	350	43
Total residue	mg/L	1,500	140
Total SiO_2	mg/L	90	20
Fe	mg/L	0.31	0.23

2.7 Galvanic corrosion of cast iron fitting connected to stainless steel nipples

Severe local corrosion occurred at both ends of an epoxy-resin coating pipe fitting in the water supply piping system of an office building after 16 years use. The elbow fitting (cast iron), which was connected to stainless steel nipples (Type 304 stainless steel) at both ends, had been penetrated by corrosion at one end, as shown in Figure 12. A galvanic cell was formed between the stainless steel, which acted as cathode, and the cast iron (anode) leading to accelerated corrosion of the cast iron. The inner surface of the elbow was coated with epoxy resin, but the corrosion began at the threaded end and developed under the coating. Because the galvanic current was concentrated on a path of low resistance between the cathode and anode, localized corrosion developed.

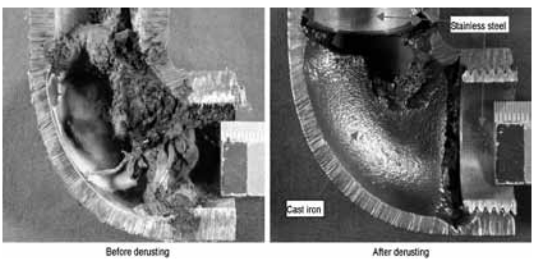


Fig.12: Galvanic corrosion generated in cast-iron pipe fitting (inside plastic coating) connected with SUS304 water supply piping, 16 years use [7)]

3 Factors influencing corrosion and corrosion protection measures of stainless steel used for pipes and equipment in buildings

Figure 13 shows the major corrosion factors affecting stainless steel used for pipes and equipment in buildings. These factors can be classified roughly into environmental and material factors. On the environmental factor side, sulphide ions (S^{2-}) and suspended solids (SS) contained in some water, such as hot springs, affect corrosion. Sulphide ions convert passivity films into sulphides and significantly decrease the corrosion resistance of stainless steel. Suspended solids are a factor that leads to deposit attack (oxygen-concentration cell corrosion). It should also be noted that there are examples of localized corrosion of stainless steel where it is in contact with materials of higher electric potential, such as activated carbon. The material factors include those attributed to poor welding and to the formation of crevices in pipes and equipment. These are strongly related to the corrosion seen in the case studies.

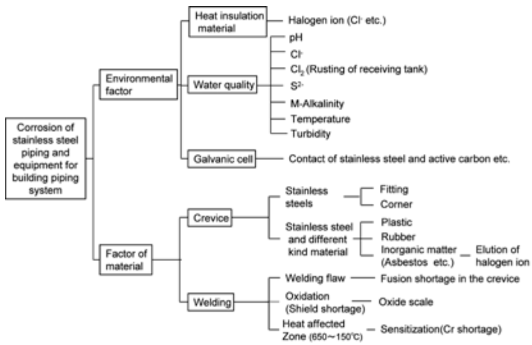


Fig.13: Corrosion factors of stainless steel piping and equipment for building piping system

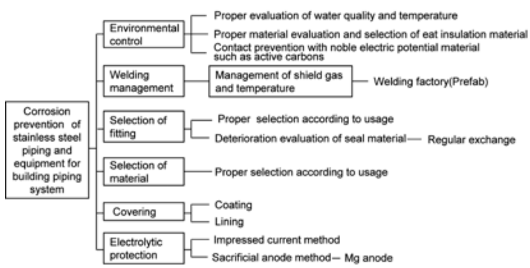


Fig.14: Corrosion prevention method of stainless steel piping and equipment for building piping system

Figure 14 lists the measures available to prevent corrosion in stainless steel piping and equipment in buildings. Because of the great difficulty in strictly controlling on-site welding operations, pipes may be welded in a workshop under strict management (prefabricated) and then fabricated on site. The choice of corrosion-resistant pipe fittings is also important, while the periodical replacement of rubber seals, which have a shorter life span than the pipe fittings themselves, is necessary. As environmental factors, figure 15 shows a corrosion evaluation according to water quality parameters as drawn up by the Expert Committee on Widespread Use of Piping of the Japan Stainless Steel Association. Here, the parameters for evaluating water quality are M alkalinity (the amount of acid consumed at pH 4.8), chloride ion concentration, and the ratio of chloride to sulphate ion concentrations (mg/L). M alkalinity is a factor that leads to scale, chloride ion concentration is a corrosion factor that leads to local breakdown of the passivity film, and the ratio of chloride to sulphate ion concentrations is a factor that controls the corrosive properties of chloride ion.

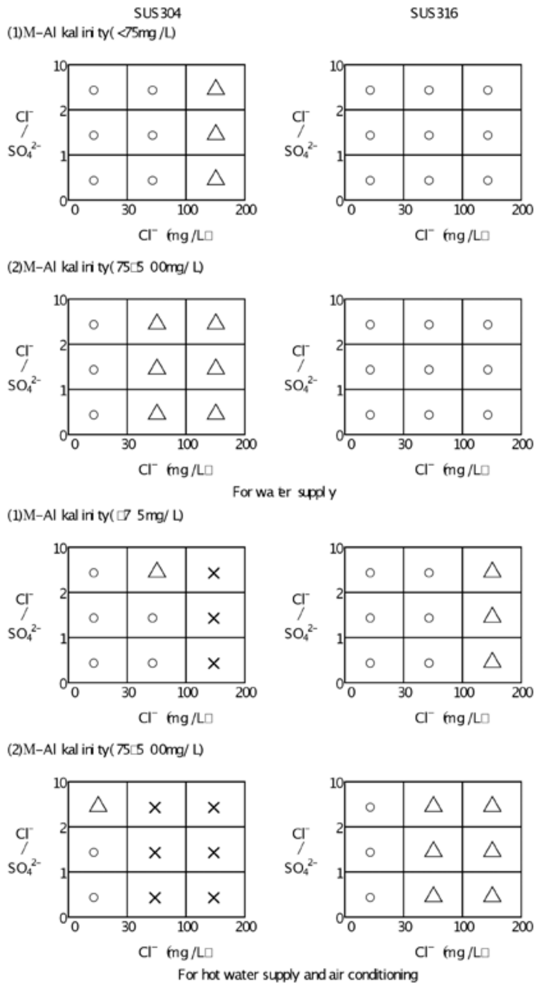


Fig.15: Water quality classification for corrosion judgment of stainless steel piping[4)]

Figure 16 outlines the basic methods of preventing the galvanic corrosion mentioned in Section 2.7. These recommended procedures are (1) choose combinations of metals in consideration of their different electrical potentials, (2) for combinations where corrosion is a concern, increase the resistance of the circuit, (3) reduce the ratio of cathodic to anodic areas, (4) modify the environment, and (5) change to a closed system if possible from the viewpoint of cost and construction.

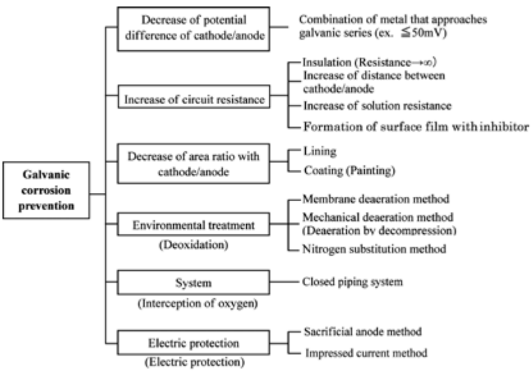


Fig.16: Idea and measures for galvanic corrosion prevention[7) 8)]

Table 6 can be used to determine whether electrical isolation is necessary to prevent galvanic corrosion in building equipment and piping systems when dissimilar metals are in contact. Organised by piping service, it is based on test results and actual use of equipment and pipes in buildings. In the case of an open air-conditioning system with a thermal storage tank, the finish of the internal surface of the tank affects the quality of the circulation water and, if a resin-based finish material is used, it cannot be expected that water quality will improve because of elution of alkalis from mortar surfaces and electrical insulation is necessary. Insulation is unnecessary for fire pipes, closed cold/hot water pipes, and cooling water pipes because no dissolved oxygen is supplied. If a large volume of water leaks from ground packing, because dissolved oxygen is supplied with the makeup water, galvanic corrosion may occur. In this case, it is necessary to control the water quality by paying attention to changes in circulation water quality (such as the dissolved oxygen and iron concentrations).

Table 6 - The table to judge whether insulation for galvanic corrosion prevention in the building piping system[7) 8)]

Joint Equipment / Pipe			Joint				Pump			Tank				
			Cast iron	Gunmetal	Brass	SUS	Cast iron	Lining steel	SUS	Steel	Lining steel	SUS	Cu	Al
Water supply and hot water supply		Lining steel	○	×	×	×	○	○	×	○	○	×	×	×
		Cu	×	○	×	○	×	×	○	×	×	○	○	×
		SUS	×	○	×	○	×	×	○	×	×	○	○	×
		Brass	×	×	○	×	×	×	×	×	×	×	×	×
Fire extinguishing		SGP	○	○	○	○	○	○	○	○	○	○	○	○
Cold water and hot water	Open system	SGP	○	×	×	×	○	○	×	○	○	×	×	×
		SUS	×	○	×	○	×	×	○	×	×	○	○	×
	Closed system	SGP	○	○	○	○	○	○	○	○	○	○	○	○
		SUS	○	○	○	○	○	○	○	○	○	○	○	○
Cooling water	Open system	SGP	○	×	×	×	○	○	×	○	○	×	×	×
		SUS	×	○	×	○	×	×	○	×	×	○	○	×
	Closed system	SGP	○	○	○	○	○	○	○	○	○	○	○	○
		SUS	○	○	○	○	○	○	○	○	○	○	○	○

○: Insulation unnecessary, ×: Insulation (Contact is not allowed)

SGP, Steel, Cast iron contain the zinc plating material

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5 Presentation of Author

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