Fastener Corrosion Categories and Protection Against Corrosion

Forewords

Generally, fastener products in use could be exposed to environments including: (1) The air atmospheric environment in contact, generally called an atmospheric corrosive environment; (2) The environment where products are immersed in water or other solutions, called an underwater corrosion or solution corrosion environment; (3) Installation in a solidified material environment or buried in soil, called a soil corrosive environment or a solidified corrosive environment.

In an exposed environment, the signs of corrosion appear as exposure time increases. Therefore, in expected corrosive environment conditions, long-term exposure tests (tests lasting one or more years) are conducted to explore the relationship between corrosion factors and metal corrosion rates. Most of the time, the metal corrosion rate is calculated and evaluated based on the first year of exposure to corrosive environmental conditions. Regardless of the exposure environment types, changes in weight loss or weight gain on the exposed surface of the material may occur. The shedding of the products of corrosion causes weight loss, and the attachment of the products of corrosion causes weight gain. Therefore, the corrosion rate is often measured by the change in corrosion weight per unit of exposed area during the first year, or the surface corrosion depth in the first year. According to ISO 11845-2020, corrosion weight change or corrosion depth is usually measured and calculated after removing the products of corrosion. It is recommended to test fasteners for more than one year with reference to ISO 11845, ASTM G4, ASTM G31, ASTM G50 and other standards. However, due to the very small change in corrosion weight, long-term tests lasting at least one year are often time-consuming. Therefore, international standards, national standards, association test standards and certification standards classify corrosion categories based on corrosion resistance levels corresponding to corrosive environmental conditions.

The corrosive environmental conditions and the corresponding corrosion category classifications defined by international standards are shown in **Table 1.** Considering the environment corrosivity corresponding to corrosive environmental conditions, surface treatment design and protection against corrosion, it is recommended to choose appropriate corrosion prevention methods as well as the evaluation process for fasteners. Since the tolerance of fasteners directly affects the safety of fasteners in use, the European Union Building Regulations 305/2011/EU (CPR) clearly lists the types of construction fasteners expected to be used with corrosion category C3 or above, whose tolerance is in the required items of Technical Document Function Declaration (DOP) for CE certification. In addition, certifications in other countries or regions, such as the American ICC-ES, also have certification requirements for related tolerances.

Table 1. Corrosive Environment Conditions and Relative Corrosion Level Classifications Defined in International Standards

Corrosive Environment Conditions	Categories	Environment Corrosivity	Typical Environment Conditions
Atmospheric Corrosion	C1	Very low corrosivity	Dry room
	C2	Low corrosivity	Dry urban inland
	C3	Medium corrosivity	Coastal or light industrial areas
	C4	High corrosivity	Smooth coastline
	C5	Extreme corrosivity	Wave-pounding coast
	CX	Extreme corrosivity	Harsh wave-pounding coast
Immersive Corrosion	Im1	Immersive corrosion by clean water	Freshwater lakes, rivers
	Im2	Immersive corrosion by semi-salty seawater	Estuaries, saltwater lakes, intertidal zones, and the sea
Soil Erosion	Im3	General soil corrosivity	Embedment in land soil or buildings
	Im4	Semi-salty sea water soil corrosivity	Soil or structures at the bottom of estuaries/saltwater lakes/intertidal zones, and soil or buildings at the bottom of sea

Environment Corrosivity During the Service Life of Fasteners

Fasteners with or without surface treatment should at least be able to perform against the expected environment corrosivity. If so, it will mean the fasteners are endurable against the environment corrosivity during the service life. Take coastal and light industrial areas for example, fasteners should be above corrosion category C3. Fasteners with corrosion categories C1 or C2 do not meet EU's building regulations for outdoor use. According to ISO 14713-1, typical indoor or outdoor environments defined in environment corrosivity categories are shown in **Table 2**.

Table 2. Typical Indoor or Outdoor Environments Defined in Environment Corrosivity Categories

Category	Typical Environmental Conditions	
	Indoor	Outdoor
C1	Heated spaces with relatively low humidity and low pollution, such as dry indoor environments without condensation, offices, schools, museums	Dry or cold zone: Atmospheric environment with very low pollution and low humidity. For example: some deserts, the North and South Poles.
C2	Unheated spaces subject to changes in temperature and relative humidity. Low condensation frequency, low pollution, and there is temporary condensation in the indoor environment. For example: storage room, gym.	Temperate zone: low pollution in the atmospheric environment (SO2, < 5 μg/m 3). For example: rural areas. Dry or cold areas, atmospheric environments with short wet periods (for example: deserts, polar regions)
C3	Manufacturing plant, a space with moderate condensation frequency and moderate pollution. For example: food processing plants, laundries, breweries, dairies.	Temperate zone: moderate air pollution (SO 2: 5 μg/m 3 ~ 30 μg/m 3) or with some degree of impact from chloride. For example, cities, coastal areas with low chloride deposition rates. Subtropical and tropical areas: low atmospheric pollution. (SO2, < 5 μg/m 3)
C4	Manufacturing plant, a space with high condensation frequency and/or serious pollution. For example: industrial processing plants, swimming pools.	Temperate zone: high atmospheric pollution (SO 2: 30 μg/m 3 ~ 90 μg/m 3) or with substantial impact from chloride. For example: polluted urban areas, industrial areas, coastal areas where salt water is not sprayed. Subtropical and tropical areas: Moderately polluted atmosphere.
C5	Manufacturing plant, a space with very high condensation frequency and/or serious pollution, such as mineral processing, industrial caves, unventilated sheds in subtropical and tropical areas.	Temperate and subtropical zones: extremely high atmospheric pollution (SO 2: 9 0 μg/m 3 ~ 250 μg/m 3) and/or have significant chloride effects. For example: industrial areas, coastal areas.
CX	Manufacturing plant, a space with almost permanent condensation or prolonged exposure to extreme humidity and/or high pollution. For example: unventilated sheds in humid tropics allow penetration of outdoor contaminants, including airborne chlorides and corrosion-activating substances or particles.	Subtropical and tropical areas (extremely high humidity): Extremely high levels of SO 2 pollution in the atmospheric environment (above 250 μg/m 3) including factors formed in the process of corrosion and/or strong effects of chlorides. For example: extreme industrial areas, coasts and offshore areas.

In addition, in the AS 4312 standard, the recommended corresponding corrosivity categories for environmental conditions are based on the distance from the coastline, as shown in **Table 3**. The corrosivity category for fasteners is evaluated based on the destination countries or regions to which the fasteners are sold.

Table 3. Recommended Corresponding Corrosivity Categories for Environmental Conditions Based on The Distance from the Coastline (Data Source: as 4312)

Location	Distance from Coastline					
	0 ~ 50 M[a]	50 ~ 100 M[a]	100 ~ 500 M[a]	0.5 ~ 1 KM[a]	1 ~ 10 KM[b]	10 ~ 100 KM[c]
Temperate zone: Wave-pounding coast	CX	CX/C5	C5	C4	C3	C3
Temperate zone: Semi-shaded coast	C5	C4	C4	C3	C3	C2
Temperate zone: Coast with calm waves	C4	C3	C3	C3	C2	C2
Tropical: Coast with calm waves	CX	CX	C5/C4	C3	C2	C2

According to the EU standard EN 1993-1-4-2006+A1-2015, the risk index (F1) of exposure to chloride in salt water or deicing salt is assessed based on the distance from the coastline or road; risk index (F2) of exposure to SO2 is assessed based on environment status.; risk index of exposure to water vapor (F3) is evaluated based on cleaning by using cleaning agents or by exposing to rain. Calculate the corrosion resistance factor (CRF) risk index of stainless steel fasteners corresponding to environment conditions (CRF = F1 + F2 + F3), and then determine the corrosion resistance category (CRC) of the fasteners using CRF. According to EU standards, if the distance from the coastline is < 0.25 km, the risk of corrosion is extremely high; if the distance from the coastline is 0.25 km - 1 km and the distance from road is ≤ 0.01 km, the risk is high; if the distance from the coastline is 1-10 km, and the distance from road is between 0.01 km and 0.1 km, the corrosion exposure risk is medium; If the distance from the coastline is > 10 kilometers and the distance from the road is 0.1 kilometers, the corrosion exposure risk is low. **The smaller the CRF risk index, the better the corrosion tolerance. The risk index is usually referred to low corrosion resistance.** The corrosion resistance categories of stainless steel completed by EU standards are divided into 5 categories, as shown in **Table 4**.

● **Table 4. EU Standard Stainless Steel Corrosion Resistance Category (CRC)**

CRC	I CRF=1	II 0 ≥ CRF > 7	III -7 ≥ CRF > - 15	IV -15 ≥ CRF ≥ 20	V CRF < 20
Stainless steel type	1.4003 (AISI 410L)	1.4301 (AISI 304)	1.4401 (AISI 316)	1.4439 (AISI 317 LMN)	1.4565 (UNS S34565)
	1.4016 (AISI 4 3 0)	1.4307 (AISI 304L)	1.4404 (AISI 316L)	1.4462 (AISI 318 LN)	1.4529 (AISI 9 26)
	1.4512 (AISI 4 09)	1.4311 (AISI 304LN)	1.4435 (AISI 316 L)	1.4539 (AISI 904 L)	1.4547 (UNS S31254)
		1.4541 (AISI 321)	1.4571 (AISI 316 Ti)		1.4410 (UNS S32750)
		1.4318 (AISI 301L)	1.4429 (AISI 316 LN)		1.4501 (UNS S327 6 0)
		1.4306 (AISI 304L)	1.4432 (AISI 316L)		1.4507 (UNS S32550)
		1.4567 (AISI 304Cu)	1.4162 (UNS S32101)		
		1.4482 (UNS S32001)	1.4462 (AISI 318 LN)		
			1.4362 (UNS S32 304)		
			1.4062 (UNS S32 202)		
			1.4578 (AISI 303Cu)		

ISO 3506-1 A2 stainless steel fasteners are equivalent to the corrosion resistance category (II) of steel type 1.4301; A3 stainless steel fasteners are equivalent to the corrosion resistance category (II) of steel type 1.4541; A4 stainless steel fasteners are equivalent to the corrosion resistance category (III) of steel type 1.4401 and 1.4404; A5 stainless steel fasteners are equivalent to the corrosion resistance category (III) of steel type 1.4571. **A1 stainless steel fasteners have low corrosion resistance and high risk indicators, and should not be used as corrosion resistance fasteners without surface protection.** Agricultural environment, urban environment, industrial environment, and ocean environment are used to evaluate four different environment conditions. **Table 5** shows the recommended stainless steel corrosion resistance categories corresponding to ISO 3506-1 stainless steel fasteners.

● **Table 5. Anti-Corrosion Steel Types Suitable for Stainless Steel Fasteners Corresponding to the Environment**

Corresponding steel types for stainless steel fasteners	Environment Conditions and Corrosion Risks											
	Agricultural Environment			City Environment			Industrial Environment			Ocean Environment		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
1.4003, 1.4016 ISO 3506-1 Grade F1	Y[1]	X	X	Y I	X	X	X	X	X	X	X	X
1.4301, 1.4311, 1.4541, 1.4318. ISO 3506-1 Grade A2 or A3	Y	Y	Y	Y	Y	(Y)	(Y)	(Y)	X	Y	(Y)	X
1.4362, 1.4401, 1.4404, 1.4406, 1.4571 ISO 3506-1 Grade A4 or A5	O	O	O	O	Y	Y	Y	Y	(Y)	Y	Y	(Y)

Low: Tempering through low humidity or low temperature
Medium: Typical corrosion conditions
High: Persistent high humidity, high surrounding temperatures, or particularly aggressive air pollutants

O: Potentially out of specification judging from a corrosion perspective
Y: Probably the best choice for corrosion resistance and cost.
YI: For indoor applications only. Avoid using ferritic stainless steel on bathrooms or toilets
X: May be subject to excessive corrosion
(Y): Appropriate precautions may be considered

However, stainless steel fasteners under ISO 3506-1 do not have specific corresponding corrosion categories. **In addition to the chemical composition of steel, inappropriate solution heat treatment, sensitization due to processing the sensitizing zone, microstructure deformation due to processing-induced deformation, and reduced corrosion resistance due to stress concentration during processing, are the reasons for corrosion of stainless steel fasteners.** Therefore, stainless steel fasteners should be classified into corresponding corrosivity categories (C1, C2, C3, C4, C5, CX) according to ISO 11845, ASTM G4, ASTM G31, ASTM G50 among other standards, and should be tested for over a year to observe the actual corrosion rate, and then classify the fasteners (under ISO 3506-1) for their corresponding actual corrosion rates specified in international standards.

Resistance Test and Corrosion Categories Specified In International Standards

Based on the time frame of possible corrosion protection failure, ISO 12944-1 further divides each corrosion category into 4 endurance levels and their possible failure time frames as shown in **Table 6**.

● **Table 6: Endurability and Required Hours of Endurance Test During Possible Failure of Corrosion Protection**

Corrosivity Category ISO 9223	Tolerance ISO 12944-1		Withstand Test Requirements ISO 12944-2		
			Required Hours of Endurance Test (h)		
	Endurance Level	Post-failure Maintenance Cycle	Iso 6270 Water Vapor Condensation Test	Iso 9227 Salt Water Spray Test	12944-6 _ Cyclic Aging Test
C1	Low	Under 7 years	Unspecified (not applicable)	Unspecified (not applicable)	Unspecified
	Medium	7 to 15 years			
	High	15 to 25 years			
	Extremely High	Over 25 years			
C2	Low	Under 7 years			
	Medium	7 to 15 years	48		
	High	15 to 25 years	120		
	Extremely High	Over 25 years	240	480	
C3	Low	Under 7 years	48	120	
	Medium	7 to 15 years	120	240	
	High	15 to 25 years	240	480	
	Extremely High	Over 25 years	480	720	
C4	Low	Under 7 years	120	240	
	Medium	7 to 15 years	240	480	
	High	15 to 25 years	480	720	
	Extremely High	25 years	720	1,440	1,680
C5	Low	Under 7 years	240	480	Unspecified
	Medium	7 to 15 years	480	720	
	High	15 to 25 years	720	1,440	1,680
	Extremely High	Over 25 years	Unspecified	Unspecified	2,688
CX	Low	Under 7 years	Unspecified		
	Medium	7 to 15 years	Unspecified		
	High	15 to 25 years	Unspecified		
	Extremely High	Over 25 years	Unspecified		

For example, we usually use salt water spray test hours to indicate the endurability of ASTM F1941 or ISO 4042 certified stainless steel fasteners. According to ISO 12944-2 resistance test requirements, fasteners should be verified with their required resistance tests and hours, as shown in Table 6. Endurability test methods include ISO 6270 water condensation test, ISO 9227 neutral salt water spray test, and cyclic aging test specified in12944-6 Annex B.

Take a fastener passing 120 hours of salt water spray test for example. With a stable condition of corrosivity category C2, there is almost no risk of corrosion within 7 years. Maintenance starts between 7 and 15 years of service. With corrosivity category C3, although corrosivity could occur within 7 years, endurability could last up to 7 years. With fasteners of corrosivity categories C4 and C5, considering the extremely high risk of damage by corrosive environments, the fasteners should be verified to meet the resistance test requirements to avoid the risk of corrosion damage. Fasteners passing less than 240 hours of salt spray resistance test cannot deliver the basic protection at corrosivity category C4. “Fewer salt spray resistance test hours” leads to a higher risk of corrosion, and is more likely to cause damage and reduce the said fasteners’ service life. Such fasteners are not suitable for corrosivity category C4, C5, and CX environments.

Fasteners for corrosivity category CX should cater to higher environment corrosion risks based on actual corrosive environmental conditions, corrosion protection design and actual corrosion rates, so as to clearly specify the required endurance test methods, verification hours

and verification standards. For example, acid rain test standardizes the number or hours and cycles. When using resistance test hours to indicate the fastener endurability, the resistance test method and the verification criteria for compliance should be clearly shown. Refer to ISO 12944 to see if the endurance test result meets the corrosion categories defined by international standards. **Given the uncertainty in the environment where a fastener is used, the service life of fasteners cannot be indicated simply with corrosivity categories or guaranteed number of service years. Without standard regulations for fastener resistance test methods, corrosivity categories should not be used to indicate the service life of fasteners.** ■

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