Dr. Zapfe GmbH
Ingenieurbüro

Dr. Zapfe GmbH

Office for structural engineering and solar plant planning

Dr.-Ing. Cedrik Zapfe
Mobile: 0176 19191280
E-Mail: cedrik.zapfe@ing-zapfe.de

Alustraße 41
83527 Kirchdorf/Haag in Oberbayern
Germany

Phone: +49 8072 9191 280
Fax: +49 8072 9191 9280

http://www.ing-zapfe.de

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Expert statement: Risk of corrosion of mounting racks for photovoltaic plants

In most cases, mounting racks for photovoltaic plants are made of corrosion-free materials. Aluminum extrusion profiles as well as fasteners and fastening elements made of non-corroding steels have prevailed in practical applications. In some cases, also hot-dip galvanized or strip galvanized steel components are utilized, but in these cases, a maintenance-free solution cannot necessarily be taken for granted throughout an intended service life of at least 20 years. In these cases, maintenance costs for the repair of the corrosion protection in the course of the service life of the photovoltaic plant have to be taken into account.

Even if corrosion-free materials are used that are not subject to a limitation of durability by natural corrosion, there are still two risk factors that can lead to corrosion in certain circumstances. In the first place it has to be checked in the course of designing a fastening system that consists of different metal materials, whether or not the combination of materials and the geometric proportions of the components in relation to each other grant a sufficient safety against electrochemical corrosion. When metals of different nobleness are combined, usually the less noble metal serves as a cathodic corrosion protection for the nobler metal. This effect is also known from the areas of tinsmithing and roofing, when eaves made of galvanized steel are connected with copper eaves. Already after a very short time, considerable signs of corrosion can be observed on the galvanized eaves. This effect has especially to be taken into account with clamped fastenings on roof coverings made of metal sheets. If necessary, a separation of the unequal materials by means of separating foils or coatings has to be provided.

The second latent risk of corrosion is the chloride-induced corrosion that can arise at locations close to the sea or in the salt fog area of streets. There is uncertainty in the solar sector about this matter. This uncertainty can be eliminated with normative regulations and research results from the last years.

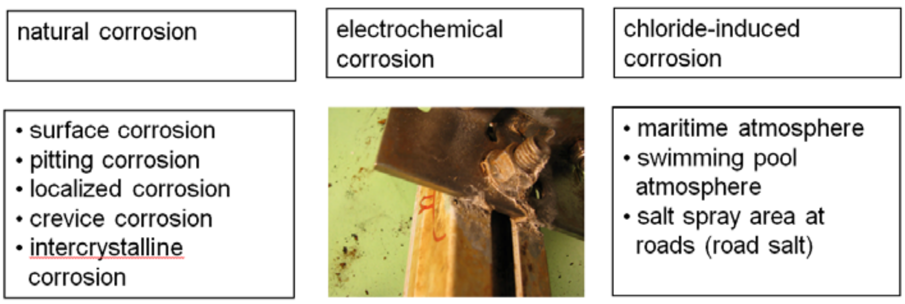


Figure 1: Types of corrosion and causes of corrosion

Experiences from the application of high-grade steels in indoor swimming pools and buildings in maritime areas have shown that also non-corroding materials are prone to rust when they are exposed to chlorides. In this context, often the question is raised up to what distance the aggressive influence of the maritime atmosphere has to be taken into consideration. In this matter, the norms and the technical rules and standards only include vague statements, so that the real risk for the project planner of solar plants cannot be exactly assessed. Figure 2 shows the chloride content of the air in correlation to the distance to the coast. Here, a considerable decrease of the concentration can already be observed after a few hundred meters. The logarithmic display of the ordinate (vertical axis) leads to a visual display of the decrease of the chloride content that looks less significant than it actually is. Already after 400 meters, the chloride content is less than one percent in comparison to the chloride content in the surge zone. Even if the wind conditions could lead to a transport of the aerosols into the mainland, it can be stated that there is no increased risk of chloride-induced corrosion that has to be considered anymore if there is a distance to the coast of about 2 kilometers.

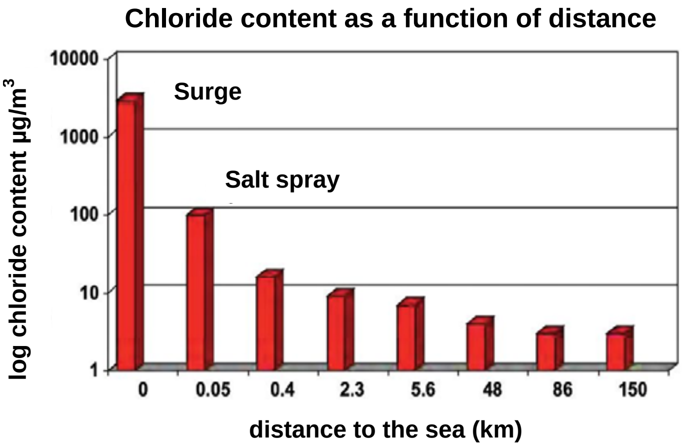


Figure 2: Chloride content in the atmosphere in coastal areas

In figure 3 and figure 4, typical optical characteristics of mounting racks in proximity to the sea are displayed. On the aluminum surfaces, white precipitations may occur due to vaporized condensation water. Usually, these precipitations can only be observed in areas that are sheltered from the rain, as rain has a cleaning effect and washes away the precipitations. These white precipitations only have a visual effect and do not lead to any significant increase of the corrosion risk. In figure 3, signs of corrosion can be observed on the thread of a hanger bolt. Even if the right materials are chosen, such effects can occur if the thread was cut with ordinary steel cutting tools. This is a finite state process.

Figure 3: Corrosion signs in a coastal area

Figure 4: Precipitations on rain-protected surfaces

On the basis of the explanations above, it can be stated that only at locations in close proximity to the sea special measures regarding corrosion protection have to be taken. The correct choice of the high-grade steel components that are used can already considerably lower the risk of corrosion. Chart 1 contains an excerpt of the general approval by the building authorities Z-30.3-6 "products, fastening elements and components made of non-corroding steels". In the photovoltaic sector, typically the material 1.4301 is utilized that can be regarded as rust-free in normal atmospheric conditions. Colloquially, this material is also called V2A. In a high-chloride atmosphere, the corrosion-resistance of high-grade steels can be considerably increased by adding the alloy element molybdenum. High-grade steels of this category are often called V4A. The most common material of this group has the material number 1.4571.

Chart 1: Material selection regarding high-grade steel as a function of the risk of corrosion

	steel grade		strength class and form of manufacture					Corrosion	
Nr.	name	W-Nr.	S 235	S 275	S 355	S 460	S 690	resistance class	exposure and typical application
1	X2CrNi12	1.4003	B,Ba, H, P	D,H,S,W	D, S	D,S	-	I/low	indoor constructions with exeption of damp locations
2	X6Cr17	1.4016	D, S, W	-	-	-	-		
3	**X5CrNi18-10**	**1.4301**	**B,Ba,D,H,P,S, W**	**B,Ba,D,H,P, S**	**B, Ba, D, H, S**	**Ba, D, H, S**	**S**	II/moderate	accessible constructions without significant contents of chlorides and sulphur dioxides, no industrial atmosphere
4	X2CrNi18-9	1.4307	B, Ba, D, H, P, S, W	B, Ba, D, H, P, S	Ba, D, H, S	Ba, D, S	S		
5	X3CrNiCu 18-9-4	1.4567	D,S,W	D,S	D,S	D,S	-		
6	X6CrNiTi18-10	1.4541	B, Ba,D,H,P,S,W	B,Ba,D,H,P,S	Ba, D,H,S	Ba, D, H, S	-		
7	X2CrNiN18-7	1.4318	-	-	B,BA,D,H,P ,S	B,Ba,H	-		
8	X5CrNiMo17-12-2	1.4401	B,Ba,D,H,P,S,W	B,Ba,D,H,P,S	Ba,D,H,S	Ba,D,S	S	III/medium	constructions with moderate chloride and sulphur dioxide contamination and inaccessible constructions
9	X2CrNiMo17-12-2	1.4404	B,Ba,D,H,P,S,W	B,Ba,D,H,P,S	Ba,D,H,S	Ba,D,H,S	D,S		
10	X3CrNiCuMo17-11-3-2	1.4578	D,S,W	D,S	D,S	D;S	-		
11	**X6CrNiMo Ti17-12-2**	**1.4571**	**B,Ba,D,H,P,S,W**	**B,Ba,D,H,P,S**	**Ba,D,H,S**	**Ba,D,H,S**	**D,S**		
12	X2CrniMoN17-13-5	1.4439	-	B,Ba,D,H,S,W	-	-	-		
13	X2CrNiMoN22-5-3	1.4462	-	-	-	B,Ba,D,P,S, W	D;S	IV/severe	high exposure to corrosion due to chlorine and / or chlorides and / or sulphur dioxides and high atmospheric humidity as well as a high concentration of contaminants
14	X1NiCrMoCu25-20-5	1.4539	B,Ba,D,H,P,S,W	B,Ba,D,P,S	D,P,S	D,S	D,S		
15	X2CrNiMnMoNbN25-18-5-4	1.4565	-		-	B,Ba,D,S	-		
16	X1NiCrMoCuN25-20-7	1.4529	-	B,D,S,W	B,D,H,P,S	D,P,S	D,S		
17	X1CrNiMoCuN20-18-7	1.4547	-	B,Ba	B,Ba	-	-		

The technical regulations on the corrosion resistance of aluminum materials are less clear. DIN EN 1991 (Eurocode 9) contains explanations and regulations that leave the planner a considerable decision range. In chart 2, the typical aluminum wrought alloys with subdivision of resistance classes (RC) as well as an estimation of the depth growth of the localized corrosion/pitting corrosion per year are shown. The categories EN-AW-30xx and EN AW-50xx are usually used for the production of metal sheets, straps and plates and have the best corrosion resistances. Extrusion profiles are typically produced from a wrought alloy of the EN AW-60xx group with the main alloy element silicon. Materials of this class have a higher mechanical strength, but regarding corrosion resistance, they are class B. Aluminum-zinc alloys (EN AW-70xxx) are even stronger, but in terms of corrosion they have to be categorized as less favorable. According to DIN 81249-1, most wrought alloys from these categories are suitable for maritime applications. Alloys of the type EN AW-6005A are especially preferable, and experts also call these types of aluminum "ship aluminum". According to EN 13195-1, the typical wrought alloys for extruded profiles (EN AW 60xx) are suitable for ship construction, maritime and offshore technology.

Chart 2: Aluminum wrought alloys

		RC	depth growth [mm/a]
EN AW-30xx	AlMn x	A	0.03-1.0
EN AW-50xx	AlMn x	A	0.03-1.0
EN AW-60xx	AlSi x	B	0.05-0.1
EN AW-70xx	AlZn x	C	0.02-1.2

Eurocode 9 contains an evaluation scheme as a function of the environmental conditions and the resistance class of the respective wrought alloy. On the basis of this scheme it has to be determined, whether or not additional anti-corrosion measures have to be taken. In chart 3, the conditions are displayed in relation to the resistance class according to chart 1. Extrusion profiles usually are part of resistance class B. Entry “0” means that no anti-corrosion measures are required. The entries “(P)” and “P” leave the decision to the planner in charge. “NR” means, that the utilization cannot be recommended. Only in severe industrial atmospheres or in severe proximity to the sea, the evaluation is left to the responsibility of the planner. In this context "severe proximity to the sea" means "surge area". Anodization of the surfaces or powder-coating of the profiles are recommended as protective measures.

Chart 3: Evaluation scheme on the need for corrosion-protective measures according to Eurocode 9

Resistance class	Material thickness in mm	Corrosion protection depending on the environmental conditions							
		atmospheric						under water	
		rural	industrial/urban		close to the sea			Sweet water	Salt water
			moderate	severe	rural	moderate	severe		
A	All	0	0	P	0	0	P	0	(P)
B	<3	0	(P)	P	(P)	(P)	P	P	P
	≥ 3	0	0	P	0	(P)	P	(P)	P
C	All	0	(P)	P	(P)	(P)	P	(P)	NR

In summary, it can be stated that protective anti-corrosion measures are not required when typical extruded profiles made of AlSi alloys are used in rural and moderate industrial or maritime atmospheres. With coast distances ≤ 2 km or severe industrial atmospheres, the utilization of special alloys, powder coatings or anodizations of the surfaces make sense.

The verification of the resistance against electro-chemical corrosion of material combinations with different metals by means of calculation is only possible to a very limited extent. Usually, the verification is carried out by means of experiments. As corrosion is a lengthy process, the examination is carried out by means of salt spray tests based on DIN EN ISO 9227 in combination with DIN EN ISO 12994-6. Due to the extremely salt-containing atmosphere, the corrosion processes are considerably accelerated. Exposure times of more than 1000 hours allow for an applicability of the results for the durability of solar plants in normal atmospheric conditions. At the same time, the risk can also be tested in "close to the sea" conditions. Figure 5 shows a test body with a material combination made of galvanized steel, aluminum and high-grade steel screws before and after the test series. In the present case, no corrosion damage could be observed.

Test body   Screw detail   State of the zinc foundation

Figure 5: Material selection regarding high-grade steel in relation to the risk of corrosion

Salt spray tests have been carried out by expert institutes like the welding training and testing institute SLV or the specific departments of the Landesgewerbeanstalt LGA (federal craft institute). At the same time, the report contains an expert evaluation of the corrosion risk. Figure 6 shows a series of test bodies after completion of the salt spray tests with positive results. On the surfaces of the test bodies, salt precipitations and spray traces can be observed. In these examples, no significant corrosive action was observed that would give reason to suspect any danger to the structural safety of the photovoltaic plant during the intended service life.

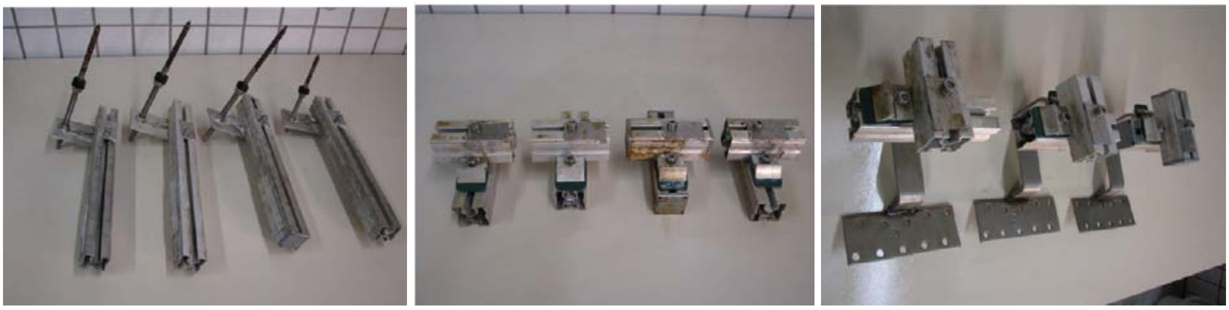


Figure 6: Test bodies with different fastening details after a successful salt spray test

In figure 7, a test body consisting of a high-grade steel standing seam clamp on a standing seam roof with aluminum profile is displayed, where the salt spray test showed a negative result. Due to the negativity differences of the electrodes, the aluminum profile was affected so severely by corrosion at the contact areas that the basic material was punctually consumed. Thus, respective connections should not be designed without a separation layer. Standing seam roofs made of sheet copper or zinc-titanium sheet metal are examples for problematic constellations. In the latter case, usually the roof cladding is locally consumed by corrosion.

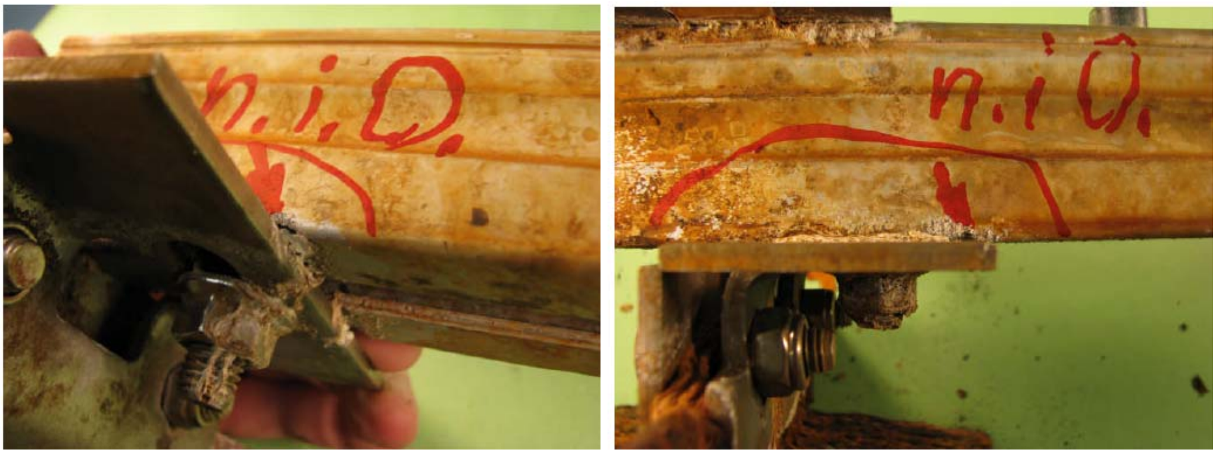
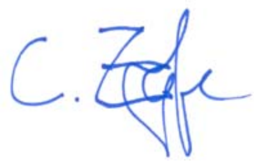


Figure 7: Test body of a fastening clamp with negative result

The main purpose of the explanations above is to point out the general risks of corrosion and to provide an overview of the conditions that imply a risk of corrosion and what measures are reasonable in order to minimize the risk of corrosion.



Dr.-Ing. Cedrik Zapfe

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