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SELECTION OF CORROSION PROTECTION OF FLEXIBLE STEEL STRUCTURES

Sławomir Bilski
JAMALEX Sp. z o.o.

Abstract

The classification of corrosivity of the atmosphere has been presented in PN-EN ISO 12944. Six categories of corrosivity of the atmosphere have been distinguished. This information is of essential importance for the final durability of a structure and influences the design of a corrosion protection system. The basic method of anticorrosive protection of flexible steel structures is hot-dip galvanizing. It is sufficient for environments of low atmospheric corrosivity. With the growth of the corrosivity level the rate of zinc coat loss from the structure grows. In order to provide the required durability of a structure, some additional anticorrosive protection may be necessary and the most common method is painting. The durability of corrosion protection is influenced by both the proper choice of the paint type and the final thickness of painting coat.

The problem of durability of constructions due to the applied anticorrosive protection is a very important issue in the context of the structure's corrosion resistivity as well as the costs of producing the structure and its later operation. According to the regulation by the Minister of Transportation and Maritime Economy of 30th May 2000, concerning technical conditions that road engineering facilities and their location have to meet in Poland, the objects should be built in such a way that their durability throughout a pre-set period of exploitation with the pre-set standard of maintenance must be assured. The durability of flexible constructions that are prone to corrosion depends first of all on the following factors:

- thickness of metal sheet, especially the designed surplus of the thickness,
- corrosivity of the environment in which it is operated,
- applied anticorrosive protection,
- the conditions and quality of protection.

Issues concerning the influence of the thickness of metal sheet on the durability of flexible structures are not dealt with in this paper. Matters concerning the influence of the remaining variables will be discussed below.

According to the principles of the standard PN-EN ISO 12944 six classes of corrosivity of the atmosphere in which steel constructions are used have been distinguished.

Depending on the level of aggression of the atmosphere the yearly losses of steel and zinc are determined as follows.

Table 1. Classification of corrosive environment according to PN-EN ISO 12944-2

Class of corrosivity	Loss in thickness after one-year exposition		Examples of typical environments	
	Carbon steel µm	Zinc µm	Outside	Inside
C1 very low	≤ 1.3	≤ 0.1		Interiors of heated buildings
C2 low	>1.3 – 25	0.1 – 0.7	Mainly countryside	Buildings without heating, warehouses, sports halls
C3 medium	>25 – 50	0.7 – 2.1	Urban and industrial atmosphere of moderate pollution level of SO_2	Production rooms of high humidity and a low air pollution level
C4 high	>50 – 80	2.1 – 4.2	Industrial and seaside areas of a low salinity level	Chemical plants, reservoirs, sea vessels
C5-I very high	>80 – 200	4.2 – 8.4	Industrial regions of high humidity and aggressive atmosphere	Buildings of permanent humidity condensation and high air pollution level
C5-M very high	>80 – 200	4.2 – 8.4	Outer surfaces of sea vessels and oil platforms	

The standard also defines three classes of corrosivity for water and soil, defined as:

- lm1 – concerning fresh waters,
- lm2 – concerning sea waters and slightly saline waters, including among others sea harbor areas together with structures located thereon
- lm3 – concerning soil corrosivity, especially for underground reservoirs and pipelines.

As the data presented in the standard show, the classification of corrosivity of the atmosphere is of crucial importance for the decision concerning the choice of a given solution for anticorrosive protection. By assessing the level of zinc corrosion as the basic protection material of flexible constructions, we can determine whether the protection is sufficient from the investor's point of view.

Zinc coatings obtained in the process of hot-dip galvanizing are considered to be the most durable anticorrosive protection. This is, first of all, the result of the nature of the process of hot-dip galvanizing. This process involves immersing the elements of steel structures in melted zinc and is most often carried out at the temperature within the range of 445-455^{o}C. During the process of hot-dip galvanizing a coat of alloy is formed, creating a stable and solid connection between the zinc coating and the steel surface. In this case, the protection of the steel structure does not only consist of the barrier protection, as it is in the case of the majority of anticorrosive protection solutions. Due to its higher reactivity, zinc is, in this case, the metal which will corrode faster than steel. The mechanism of the cathode protection, which involves connecting iron with a metal with a higher electronegative potential is used here.. This is the most effective protection system, providing protection of the steel base owing to the fact that in an electrochemical cell formed in this way, the coating metal takes over the function of the anode. In the case of covering steel surfaces with zinc, even if a scratch or a crevice in the coating metal occurs, an electrochemical cell is formed, in which iron becomes the cathode while zinc is the anode. In this situation ions of zinc pass to the solution but not ions of iron. Thus in the case of covering metals with anodal coats, the covering coat does not need to be absolutely tight. Moreover, the zinc coating, as a result of an oxidizing reaction, produces a layer of zinc oxides and carbonates on its surface , which forms an additional barrier against corrosion. This can be clearly seen when comparing the size of loss in steel and zinc in the same conditions of the corrosivity of the atmosphere, as it has been presented in table 1 above. Generally, it is assumed that in the atmosphere of corrosivity class up to C3, it is sufficient to provide basic anticorrosive protection obtained by hot-dip galvanizing.

Table 2. Thickness of the zinc coat according to the standard PN-EN ISO 1461:2011

Steel thickness	Average tcoat thickness (μm)	Minimum local coat thickness (μm)	Weight of Zn coat (g/m^2)
Below 3 mm	55	45	400
3 – 6 mm	70	55	500
Over 6 mm	85	70	610

Flexible structures are manufactured, depending on the carried loads, from metal sheets of thickness 3 - 7 mm. Depending on the thickness of the metal sheet the required average thickness of the zinc coat is also changed, according to the principles of the standard PN-EN ISO 1461, as presented in Table 2.

Having analyzed the data from this table and assuming that the loss in the coat thickness throughout the whole period of a structure's operation is even, it can be stated that the zinc coat itself provides sufficient protection in the case of the corrosivity of the atmosphere in the class from C1 to C2, regardless of the thickness of applied metal sheet. In the atmosphere of corrosivity class C3, the protection ensured by a zinc coating will depend, to a large extent, on the thickness of the metal sheet and, consequently, on the average thickness of the zinc layer.

The durability of the zinc coating in the case of atmosphere C5-I/M for a structure made from metal sheets over 6 mm thick will be only 10-20 years. Such structures will feature much higher corrosion resistivity, although in most cases not sufficient for the environment C4 (20-40 years). The situation is definitely worse if the structure was built from flexible metal sheets with the thickness within the range of 3-5.9 mm, where the zinc coating is considerably thinner. In this case the zinc protection will last for 8-16 years in the atmosphere of corrosivity class C5-I/M, whereas in the environment C4 it will be 16-30 years. In the case of flexible structures, used in road buliding, another very crucial element affecting its anticorrosive protection appears, namely the occurrence of a mixed corrosive environment. This means synergistic action of corrosive factors on the structure, of the the atmosphere, soil and water. Although all the threats coming from the atmosphere have been thoroughly examined and documented, current levels of soil and water aggressiveness are considerably more difficult to assess when they form the environment. An additional problem, in comparison to e.g. bridge objects,the fact that it is impossible to repair or renovate the structure, especially from the side of the backfill. The designed protection has to carry out its protective function throughout the whole period of the expected durability of the object. The investor has to be conscious and have the knowledge not only within the scope of the present aggressiveness of the environment in which the construction will be operated, but he must also draw ahead some estimation related to the possible changes in the environment throughout the planned operation life of the structure. Very often, even though anticorrosive protection used to fulfill its function some 20-30 years ago, it is insufficient today. On the other hand, considering the enormous pressure put in the recent years on the protection of the environment, let us hope that all the actions of the man and the infrastructure will lead towards limiting the aggressiveness of the environment, which means extending the durability of structures, including flexible structures.

The durability of zinc coatings as shown above, from the point of view of the investor will not prove satisfactory in the higher classes of atmospheric corrosivity. Therefore, it is necessary to provide some additional anticorrosive protection in order to increase the durability of flexible structures. The basic way of protecting the zinc coating from initiating the corrosive processes too early is to put on some painting coats. Apart from the increase in the durability of the construction, they also fulfill some decorative function, and perhaps first of all, reduce the influence of the zinc galvanized structure on the environment. However, our main point of interest is the influence of painting on the increase in the durability of flexible constructions.

PN-EN ISO 12944 in the second section defines the durability of the coat of paint. Three periods of durability are proposed:

- low – 2 to 5 years
- medium – 5 to 15 years,
- high – above 15 years.

It is also emphasized in the standard that the durability of the coat of paint must not be mistaken with its warranty period. Durability is a technical notion which is supposed to help the investor to determine the schedule and the program of renovating the protection. General guidelines concerning the choice of the painting system for a given corrosive environment, durability and the extent surface preparation are described in the standard PN-EN ISO 12944-5. According to the principles of the standard, hot-dip galvanized structures can be painted with paints in which the film forming substance is made from acrylic, epoxy, polyurethane or polyvinyl chloride resins. The kind of the applied paint depends on the corrosive threats of the environment.

Paint coats on the basis of polyvinyl chloride feature quite good protective proprieties, yet as they contain a high content of solvents, they are more and more seldom applied inprofessional anticorrosive protection soultions. The main problem in applying them is the long time between applying consecutive layers and high costs connected withenvironmental protection due to a large emission of volatile organic compounds.

Acrylic varnishes provide very good resistance to UV radiation and other atmospheric factors. However, in most cases, they do not provide suitable protection for structures working under water and in the environment of strong chemical reagents.

Paint coats produced on the basis of epoxy resins are characterized by chemical setting, thanks to which they are very tight. Their characteristic feature is high resistance to chemical reagents and the possibility of working under water. In a dry atmosphere they are resistant to temperatures up to 120-150^{o}C. Their main disadvantage is their low resistance to UV rays, and as a result, their poor colorfastness and loss of gloss. Moreover, the UV radiation brings in the phenomenon of the coat becoming ‘chalky’, which leads to the decrease in resistance of the anticorrosive coat. These defects cause the need of earlier renovation of the coat, especially when it must simultaneously function as a decorative finish.

Resistance of polyurethane coats to damp conditions and chemical reagents is similar to that of epoxy coats. In the case of aliphatic polyurethanes, their chemical resistance is lower, yet their very high resistance to UV radiation is the argument for applying them, as it makes them a perfect finishing coat.

A wide choice of paints enables us to obtain varied parameters of ready-made painting systems, depending on the conditions in which the structure will be used. On the basis of the painting systems recommended by PN-EN ISO 12944-5 it can be said, that:

- for the atmosphere of corrosivity class C3 paints based on all the above mentioned film-forming substances can be applied. To provide a long period of durability systems with a total coat thickness 160 μm will do,
- to provide a long period of durability in the atmosphere of corrosivity class C4, it is necessary to use systems with a minimum total coat thickness of 240 μm forpaints based on polyvinyl chloride and acrylic systems, and the minimum thickness of 160 μm for epoxy and epoxy-polyurethane systems,
- to provide a long period of durability of the painting coat in the atmosphere of corrosivity class C-5I/M, it is only admissible to apply painting systems based on epoxy or polyurethane paints of the total thickness not less than 320 μm.

The normative principles presented above unambiguously illustrate the influence of proper assessment of the extent of corrosivity of the atmosphere on the choice of a painting system and, what follows, on the costs of the protection used, and later on, on the costs of operation and maintenance of a flexible structure.

Referring to flexible structures made by the ViaCon Polska Sp. z o.o. (Ltd) company and used in Poland, yet another set of regulations in force must be used Designing and technological recommendations for flexible structures made of corrugated steel'. This document refers to the instruction no. 9, issued by General Manager of National Roads and Highways, of 18th March 2004. The instruction has determined the required minimum anticorrosive protection depending on the class of aggressiveness of the atmosphere, soil and water. According to this instruction, a zinc coating applied in the process of hot-dip galvanizing is recommended to be the standard protection of flexible structures. In the case of an higher aggressiveness of the environment, some additional protection was provided in the form of painting coats with the use of epoxy or epoxy-polyurethane systems, where the total coat thickness is not less than 200 μm. Considering what has been said above about anticorrosive protection, as provided by the standard PN-EN ISO 12944-5, this statement seems to be too far simplified. It can generally be accepted that this instruction treats all the categories of corrosivity above the class C3 as if they were of the same grade. As it was already presented earlier, the corrosivity higher than the class C3 mentioned above brings in quite broad differentiation in the thickness of the painting system, and what follows, the costs of the anticorrosive protection of the structure will be different too.

The cost of using an anticorrosive protection is quite often the key argument for the investor. Although the cost of the zinc coating is to some extent a constant value, as the thickness of the zinc coating depends on the thickness of the steel structure, but not on the aggressiveness of the environment in which the construction is to be operated. thereforem the cost of applying a painting coat is of a much more controversial nature. This is caused by the wide range of available painting products and a variety of painting systems recommended by paint manufacturers, which are supposed to ensure comprehensive protection of the object. Having to deal in our everyday practice with both zinc and painting coats, we often encounter the problems connected with an inappropriate assessment of the aggressiveness of the environment. The main point to start with, when looking for economy, is to design the protection properly, especially the protection in the form of additional painting coats. It often happens that economizing is sought only on the side of the contractor ofanticorrosive protection. It should, however, be noticed that the low cost of producing painting coats does not always have to go hand in hand with suitable durability of the protection. Due to a wide range of factors which exert an influence on the protective proprieties of the painting system, the investor has to take a deeper look at the very process of painting.

The most important factors which impact the durability of the applied painting coat are:

- atmospheric conditions,
- preparation of the surface,
- method of application,
- choice of paints making up the protective system,
- limitations related to the time of the process of painting.

Experience has shown that only few investors show suitable interest in the way the painting coats are made. ViaCon Poland is a positive exception in this area. In co-operation with this company we have developed a quality system, which guarantees both that technological requirements are met and providing final quality of the product.

When preparing the surface of the structure as well as during the time of painting, weather conditions constitute the key factor which has the main influence on the durability of the painting system. What is meant here is the temperature of the painted base and the temperature of air and its relative humidity, particularly the relation between these values, i.e. the dew point temperature. In spite of all the endeavors to provide stable climatic parameters inside the painting shop, these factors are characterized by very high and frequent variability. That is why, continuous measurement of the conditions during the process of applying and seasoning the produced painting coats has become a basic requirement.

It is hard to talk about any contractor's responsibility without fulfilling this condition. These factors are of key importance for the final durability of the coat.

The next important factor affecting the durability of the painting coat is the preparation of the surface. When dealing with a hot-dip galvanized steel surface the nature problem is somewhat different, when compared to the steel structure. In this case we do not have to deal with the products of steel corrosion, but only with the roughness of the surface and some dirt on it. The coat obtained in the process of hot-dip galvanizing features low roughness. Therefore, it is indispensable to roughen the zinc coat in order to improve the adhesiveness of paints, which can be done with the help of vapour blasting. In the case of zinc coats one should remember, that on the one hand it is vital not to damage the coat excessively, on the other hand not to introduce to the coat any particles coming from the steel abradant, in order to avoid potential corrosion centers created in this way. This is the matter of a choosing the right abradant.

The notion ofsurface roughness has been described in the set of standards ISO8503, which also defines the comparative standard in the form of a comparative plate. For painting coats applied on the surface of zinc it is accepted for surface roughness to be 50-70 μm. Other factors related to the cleanliness of the surface include the degree of surface contamination with dust or the occurrence of ion contamination.

The method of applying paints is an extremely crucial factor influencing the durability of the painting coat. The basic factors that can affect corrosion resistivity are:

- the diameter of the spraying nozzle,
- the angle of the nozzle,
- application pressure,
- the temperature of the paint.

The dangers resulting from badly-chosen parameters of application of the painting coat are, first of all, various types of defects of the painting coats, which to larger or smaller extent influence the resistivity to corrosion.

Based on our experience it is clearly visible that investors are concerned the least with the proper timing of the technological process of painting. Due to the fact that more and more modern paints used nowadays are based on forming chemical bonds, this is a very serious problem. For all the paints in their technical specification cards there is some information regarding the minimum time that must pass between applying individual layers of the paint and the time required for the complete setting of the coat. It is particularly the last parameter that is of vital importance in the case of structure from flexible corrugated steel sheets. While assembling the structures the coat in the places of bolt and nut connections undergoes large forces at the moment of tightening of the nuts. The coat that has not hardened completely creates the danger of the zinc coat peeling off , and as a result, the danger of limiting, or even totallly destroying the anticorrosive protection in the place of damage.

Table 3. Results of investigation on the corrosion resistance of painting systems - tests according to the standard ISO 6270

Painting system	Thickness of the coats	Method of testing	Time of the test	Class of corrosion resistivity
Teknoplast HS150 Teknoplast HS150	120µm 120µm	Water condensation	720h	C5 High
Teknoplast Primer 7 Teknoplast HS150	80µm 80µm	Water condensation	480h	C4-High C5- Medium
Inerta Mastic Miox Teknodur 0090	120µm 40µm	Water condensation	480h	C4-High C5-Medium
Teknoplast HS150 Teknoplast HS150	100µm 100µm	Water condensation	720h	C4-High

As it can be seen, the number of factors affecting the durability of the painting coat, and consequently, the durability of the structure is quite high. The final resistivity of the coat to the corrosive factors will depend on the weakest link in the whole chain of dependence. As it has been mentioned earlier, the lack of possibility to repair or renovate of the painting coat from the side of the backfill or water does considerably enforce the need of a professional approach both from the side of the investor and the contractor to the issue of the durability of the coat. Throughout many years of co-operation with the ViaCon Poland company we have conducted, together with the supplier of paints, the TEKNOS company, an array of laboratory investigations on the corrosion resistance of different painting coats in order to confirm the possibility of ensuring suitable quality of the coating throughout the periods specified in the standards. The results of individual investigations on the resistivity of various painting systems are presented in Table 3.

Continuous development of painting products has led to the attempt to assess the durability of coats applied with an omission of the process of zinc coat roughening. At the present stage, it can be claimed that these results are highly satisfactory. However, the problem of repeatability of the received results occurs, especially on the zinc coats obtained in different plants. The fact of high differentiation of the zinc coat produced in individual zinc-galvanizing plants is generally well known. It results from the specifics of chemical processing of steel, the composition of the melted zinc bath, the temperature of hot-dip galvanizing and also of the way of processing after the process of hot-dip galvanizing itself, e.g. the way of cooling down the galvanized elements. Therefore, we can relate the obtained results only to the coat made in our zinc-galvanizing plant. Nowadays in our zinc-galvanizing plant we are conducting investigations related to the implementation of the process of passivization of galvanized elements.. Although our suppliers use the term ‘passivation’, it is not an adequate notion in the sense so far understood by the anticorrosive trade. The increasing limitations connected with environmental protection and human health have forced the manufacturers of preparations used for passivation to withdraw all products based on chromium. The solution applied in our zinc-galvanizing plant to counteract the phenomenon zinc corrosion means applying a thin coat of acrylic copolymers which react with zinc. Preventing the contact between the zinc coat and the atmosphere enables the elimination of the phenomenon of white rust appearing on zinc even throughout the period of 2 years, and what is more, this coat of acrylic copolymers is entirely biodegradable. Yet at this stage it is still too early to draw any binding conclusions.

The information presented above shows unambiguously to what extent the suitable choice and implementation of anticorrosive protection influences the durability of the structure. Continuous measurement of weather conditions in all the facilities made by the Jamalex company, tens of thousands of coat parameters measurements, and continuous improvement of our knowledge by participating in international conferences concerning anticorrosive protection, allow us to state that the technological process worked out together with the ViaCon company is today the optimum one. The great pressure put on creativity in this scope requires a lot of time-consuming research, whose main direction in the years to come will be meeting more and more restrictive requirements connected with the protection of the environment.

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Streszczenie

Klasyfikacja korozyjności atmosfery została przedstawiona w normie PN-EN ISO 12944. Wyróżniono sześć kategorii korozyjności atmosfery. Te informacje mają kluczowy znaczenie dla końcowej trwałości konstrukcji i wpływają na projektowanie systemów ochrony przed korozją. Podstawowym sposobem zabezpieczania podatnych konstrukcji stalowych przed korozją jest cynkowanie na gorąco. Jest ono wystarczające dla atmosfery o niskiej korozyjności. Wraz ze wzrostem poziomu korozyjności rośnie poziom utraty powłoki cynkowej konstrukcji. Aby zapewnić wymaganą trwałość konstrukcji, konieczne może być zastosowanie dodatkowej ochrony przed korozją, przy czym najczęściej stosowaną metodą jest malowanie. Na trwałość ochrony przed korozją wpływa zarówno odpowiedni wybór rodzaju farby, jak i końcowa grubość warstwy farby.