ДГКС
Друштво грађевинских конструктера Србије
ASES
Association of Structural Engineers of Serbia
S-1
15. KONGRES
6-8. 9. 2018. Zlatibor

Dunja Radovanović[1], *Nenad Fric*[2]

SISTEMI ANTIKOROZIVNE ZAŠTITE ČELIČNIH KONSTRUKCIJA PREMA STANDARDU EN ISO 12944

Rezime:

Veoma je važno zaštiti čelične konstrukcije od korozije obzirom da je osetljivost na koroziju jedan od dva najveća nedostataka čeličnih konstrukcija. Pored toplog cinkovanja, premazi su najčešće primenjivani sistem zaštite čeličnih konstrukcija od korozije. Oni su praktično nezamenljivi u slučajevima u kojima nije moguće primeniti toplo cinkovanje. U ovom radu prikazani su svi relevantni standardi sa naglaskon na standard SRPS EN ISO 12944 kao najznačajniji za primenu premaza. Objašnjeni su pojmovi kategorija korozivnosti sredine, načini i nivoi pripreme čeličnih površina, metode nanošenja i merenja debljine premaza kao i različite vrste premaza koje se mogu koristiti za antikorozivnu zaštitu čeličnih konstrukcija.

Ključne reči: čelične konstrukcije, korozija, premazi, priprema površina, metode nanošenja

STEEL STRUCTURE CORROSION PROTECTION SYSTEMS ACCORDING TO THE EN ISO 12944 STANDARDS

Summary:

It is very important to protect steel structures against the influence of corrosion since it is one of the two biggest defects of steel structures. In addition to hot-dip galvanizing, coating is the most commonly used system for the protection of steel structures against corrosion. It is practically irreplaceable in cases where use of the hot-dip galvanizing is not possible. In this paper all relevant standards, with emphasis on SRPS EN ISO 12944 as most important for coatings usage, are shown. Terms of corrosivity categories, methods and preparation grades of steel surfaces, methods for coatings applying and measurement of their thickness, as well as which coatings type can be used for corrosion protection of steel structures are explained.

Key words: steel structures, corrosion, coatings, preparation of surfaces, application methods

[1] *MSc, Civil Eng, Velesstroy Construction Company d.o.o, Belgrade, dunjaradovanovic5787@gmail.com*
[2] *PhD, Civil Eng, Assistant professor, Faculty of Civil Engineering University of Belgrade, fric@imk.grf.bg.ac.rs*

1. INTRODUCTION

It is very important to protect steel structures against the influence of corrosion since it is one of the two biggest defects of steel structures. Steel structures can be exposed to different influences if they are unprotected in the atmosphere or immersed (partially or completely) in water or buried in the soil. Therefore, it is necessary to be familiar with the rules as well as with the latest corrosion protection systems. In addition to hot-dip galvanizing, coating is the most commonly used system for the protection of steel structures against corrosion. It is practically irreplaceable in cases where use of the hot-dip galvanizing is not possible.

Standard SRPS EN ISO 12944: *Paints and varnishes - Corrosion protection of steel structures by protective paint systems* includes all measures for anticorrosive protection for painting and consissts of next parts:

- Part 1: General introduction
- Part 2: Classification of environments
- Part 3: Design considerations
- Part 4: Types of surface and surface preparation
- Part 5: Protective paint systems
- Part 6: Laboratory performance test methods
- Part 7: Execution and supervision of paint work
- Part 8: Development of specifications for new work and maintenance
- Part 9: Protective paint systems and laboratory performance test methods for offshore and related structures

In addition to this standard, it is also necessary to know other related ones, which deals with some specific parts od corrosion protection process (e.g. surface preparation, classification of environments etc):

- SRPS EN ISO 8501: Preparation of steel substrates before application of paints and related products - Visual assessment of surface cleanliness, Part 1 to Part 4
- SRPS EN ISO 8502: Preparation of steel substrates before application of paints and related products - Tests for the assessment of surface cleanliness, Part 1 to Part 12
- SRPS EN ISO 8503: Preparation of steel substrates before application of paints and related products - Surface roughness characteristics of blast-cleaned steel substrates, Part 1 to Part 5
- SRPS EN ISO 8504: Preparation of steel substrates before application of paints and related products - Surface preparation methods, Part 1 to Part 4.

2. CATEGORIES OF CORROSIVITY

The corrosion of steel structures at first depends on the environment in which it is located. The environment is described on the basis of:

- category of atmospheric corrosivity,
- category of the environment for constructions immersed in water or buried in the soil and
- data on specific corrosion strains.

For evaluation of the atmospheric corrosivity, the local environment and microsound are of the main importance. The location of the structure itself affects corrosion depending on whether the structure is exposed to atmospheric conditions, whether it is in a covered or indoor conditions. In the enclosed area, local corrosion can also occur as a result of condensation. In the case of structures exposed to atmospheric influences, there are a total of six categories of corrosivity and they are shown in Table 1.

Table 1 – Categories of corrosivity [1]

Atmosferic-corrosivity categories	
C1	Very low
C2	Low
C3	Medium
C4	High
C5 - I	Very high (industrial)
C5 - M	Very high (marine)

For water-immersed constructions, the type of water (sweet, salty or saturated) plays an important role, as well as other factors, such as the presence of plants or a higher concentration of oxygen that can accelerate corrosion. The influence of corrosion on structures buried in the soil is increased due to the presence of various organic and inorganic substances, water or oxygen. This type of corrosion is particularly harmful for linear systems such as pipelines, tunnels, tanks, because the content of oxygen or changes in groundwater level through the soil layers can be changed and cause the appearance of extreme shaft corrosion, also called pitting. The categories of corrosivity for structures immersed in water and buried in the soil are shown in Table 2.

Table 2 – Corrosivity categories for structures immersed in water or buried in soil [1]

Category	Environment	Examples of environment and structures
lm1	Fresh water	Structures in rivers or hydropower plants
lm2	Sea or brackish water	Port structures
lm3	Burial in soil	Subterranean containers, steel beams and similar structures

3. SURFACE PREPARATION

In order to ensure good adhesion of the basic coating as well as to reduce impurities and harmful substances that can cause corrosion, steel surface preparation depends on various factors such as the age of the structure and location, type and aggressiveness of the environment, the condition of the existing coating system, the planned coating system and other.

Before cleaning the surface, the degree of rustling is determined, which is assessed in accordance with SRPS EN ISO 8501-1 [2]. This standard contains photographs, which classify surface states into 4 categories as shown in Table 3.

Table 3 – Rust grades [2]

Rust grades	Representative photographs	Descriotion
A		Steel surface largely covered with adhering mill scale but little, if any, rust
B		Steel surface which has begun to rust and for which the mill scale has begun flake
C		Steel surface on which the mill scale has rusted away of from which it can be scraped but with slight pitting visible under normal vision
D		Steel surface on which the mill scale rusted away and on which general pitting is visible under normal vision

3.1. SURFACE PREPARATION METHOD

As mentioned, before applying a protective coating system, the surface must be prepared, or cleaned from grease, oil, salt and other pollutants. This can be done in several different ways, such as mechanical cleaning and cleaning with hand tools, flame and water cleaning or with solvents and chemicals.

The most common and most effective way of cleaning is abrasive cleaning. It involves the cleaning of steel surfaces with the help of compressor which provides the air volume and pressure to move the abrasive media though the hose and blast nozzle until it hits the target surface. This process is known as "dry cleaning" and is environmentally unacceptable in view of the waste that remains after it, however, by introducing a water immediately after the abrasive, the piling up and dispersal of waste is eliminated [3].

Manual and machine cleaning involves the usage of various tools, brushes, scrapers, rotating wire brushes, vibrating hammers and others. When the usage or accumulation of abrasive is not allowed, these procedures are generally applied, but it should be kept in mind that they give poorer effects in terms of cleaning the surface.

In the case of flame cleaning, rust and thick oxide layer produced by thermal treatment of steel are removed under the action of an oxygen-acetylene flame that is applied on the surface. After that, the surface is machined with mechanical brushes and dust and other dirt must be removed before painting.

3.2. PREPARATION GRADES OF STEEL SURFACES

Each degree of surface preparation is indicated by the appropriate lettering (which defines the preparation process) and the degree of cleaning from rust or previous coatings. Standard SRPS EN 8501-1 [2] contains photographs of reference samples, which are marked by the degree of rust, in addition to the degree of preparation.

Table 4 – Blast-cleaning preparation grades [2]

Category	Cleaning method	Surface description
Sa1	Easy abrasive blast cleaning	The surface after cleaning, without any magnification, must be free of visible traces of oil, grease and dirt, and rusts, incisors, coatings and foreign matter that are poorly adhered must be removed.
Sa2	Careful abrasive blast cleaning	The surface after cleaning, without any magnification, must be free of visible traces of oil, grease and dirt, and most of rust, honeycomb, coating and foreign matter must be removed. Any residual pollution must be firmly fixed.
Sa21/2	Very carefully abrasive blast cleaning	The cleaning area observed without magnification must be free of visible traces of oil, grease and dirt and must be free from rust, haze, coating and foreign matter. Any residual imprints of impurities can only be as bright spots in the form of strips or dots.
Sa3	Abrasive blast cleaning up to clean metal	The cleaning area observed without magnification must be free of visible traces of oil, grease and dirt and must be free from rust, haze, coating and foreign matter. The surface must have a uniform metallic glow.

Table 5 – Hand and power tool preparation grades [2]

Category	Cleaning method	Surface description
St2	Thorough hand and power tool cleaning	The surface after cleaning, without any magnification, must be free of visible traces of oil, grease and dirt, and rusts, incisors, coatings and foreign matter that are poorly adhered must be removed.
St3	Very thorough hand and power tool cleaning	The surface is cleaned just like St 2 only much more carefully and all the way until the metallic shine of the substrate is achieved.

Table 6 – Flame preparation grades [2]

Category	Cleaning method	Surface description
Fl	Flame cleaning	The surface after cleaning, observed without magnification, must be free from holes, rust, paint and foreign matter. Only traces of impurities in the form of shades of different colors must remain on the surface.

The described grades of preparation (Table 4, 5 and 6) are used for steel surfaces which did not contain coatings or which contained it, but provided that coating was removed to the extent that the degree of preparation was achieved.

Table 7 – Preparation grades after localized removal of previous coatings [4]

<table>
<tr><th>Category</th><th>Cleaning method</th><th>Surface description</th></tr>
<tr><td>PSa2</td><td>Careful localized abrasive blast cleaning</td><td rowspan="5">Coatings that adhere well do not touch.

The same descriptions apply as for the standard preparation grades for the primary surface preparation.

For comparison only images with the C or D standard SRPS EN 8501-1 [2] are used, with an equivalent degree of preparation and the choice depends on the intensity of the corrugated corrosion.</td></tr>
<tr><td>PSa21/2</td><td>Very carefully localized abrasive blast cleaning</td></tr>
<tr><td>PSa3</td><td>Localized abrasive blast cleaning up to clean metal</td></tr>
<tr><td>PSt2</td><td>Thorough localized hand and power tool cleaning</td></tr>
<tr><td>PSt3</td><td>Very thorough localized hand and power tool cleaning</td></tr>
<tr><td>PMa</td><td>Localized mechanical abrasion</td><td>It is carried out by using a disc with abrasive paper or rotating wire brushes in combination with a needle pistol. Same description of prepared surfaces as for PSa 21/2. Photos are contained in SRPS EN ISO 8501-2 [4].</td></tr>
</table>

Standard SRPS EN 8501-1 [2] contains 28 representative photographs with which steel surfaces should compare. Of the total, 4 photographs represent the degree of corrosion and they are taken from the German standard DIN 55928, and the other 24, which illustrate the degree of preparation of surfaces obtained in the 3 described ways, are taken from the Swedish standard SIS 055900: 1967. They are only printed in Sweden and only their application is allowed.

4. PROTECTIVE PAINT SYSTEMS

The process of painting or colouring is the most commonly used procedure. It does not require a specially trained manpower and can be applied to all types of objects or elements, regardless of the shape and complexity of the cross-section.

Systems consist of basic, intermediate and final coating layer. The primary coating purpose is to provide good adhesion to the metal surface (or old coating) and to protect the metal until the next coating is applied, as well as throughout the entire working life. The interlayer serves to reduce or completely prevent moisture penetration through the paint system and it must be compatible with the final coating. The final coating contributes to the protection against corrosion and gives the required colour.

4.1. DETERMINATION OF PAINT FILM THICKNESS

The thickness of the dry film (DFT) is important for the coating. It represents the thickness of the coating that remains on the surface after curing.

As a rule, the DFT is measured on the whole color system, and if it is found to be appropriate, the thickness of the dry film of the basic coating or other parts of the system can be measured individually.

The thickness of the dry film is measured in relation to the nominal thickness of the dry film (NDFT), which is defined as the determined thickness of the dry film for each coating or for the entire color system, which ensures the required lifetime. If the parties do not agree differently, the DFT must be at least 80% of the NDFT, and the individual values between 80% and 100% of the NDFT are acceptable only if the total mean value is greater than or equal to the nominal thickness of the dry film. The largest acceptable thickness of dry film is the thickness above which characteristics of the system are considered to be worse. In order to avoid this, the aim is to apply colors in a thin layers as thick layers can cause additional strains and failure of the system. It is recommended that the maximum acceptable thickness is at most three nominal thicknesses of the film [5].

Wet film thickness (WFT) can also be required to ensure that the subsequent thickness of the dry film is satisfied. The thickness of the wet film is measured using the instrument called „wet film comb“ (Figure 1). For a fast DFT calculation, WFT can be multiplied by 0,69.

Standard SRPS EN ISO 12944-5 [6] in its Appendix A gives different examples of color systems for certain corrosion categories, number of coating layers and dry film thickness values based on air-spray method of painting. When the paint is applied with a roller, brush, or other equipment, more layers are needed to obtain the appropriate thickness of the film.

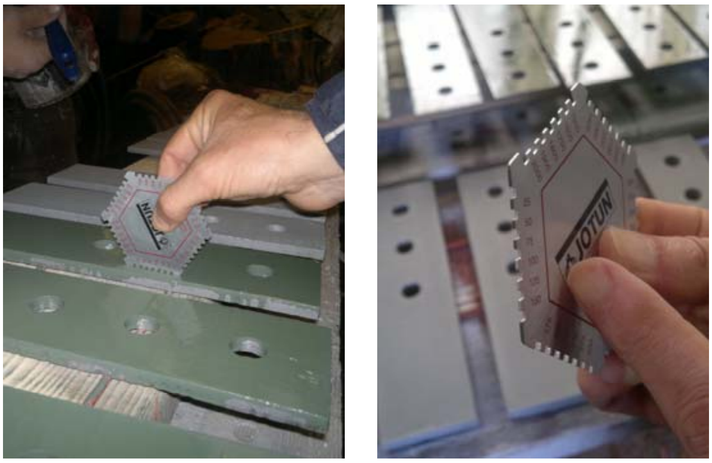

Figure 1 – Wet film comb usage [7]

4.2. PRINCIPLES AND APLICATION METHODS

Prior to selection of propriate protective painting system, investor defines the criteria that are of the greatest importance for him such as:

- warranty period and lifetime of the system,
- production technology,
- price and
- delivery speed.

Taking care of important criteria, SRPS EN ISO 12944-5 [6] standard can be used for selection of painting system. Standard specified painting systems by applying two basic principles:

- according to the binder used in the final coating, where the systems are given in the "sum table" - the usage is recommended when selecting the system based on the final coating, as well as to compare a lifetime of the color system for more than one category of corrosion , in case the category is not known
- according to the binder used for basic coating, where systems are shown only for one category of corrosion - it is suitable for the usage when the exact corrosion category of the medium to which the structure is exposed is known.

As an example a summary table for corrosivity category C2 is given (Table 8). The color systems shown in the table are just an example, since other systems with the same characteristics are also possible.

As a binder for basic and final coating can be used: AK - alkyd, AY - acrylic, PVC – polyvinyl-chloride, EP - epoxy, CR – chlorinated rubber and ESI – ethyl-silicate and PUR – polyurethane, aliphatic. Zinc (R) – zinc rich primer or misc – primers with miscellaneous types of anticorrosive pigment can be used for the base color type. If a zinc-rich color is used, the smallest content of zinc as a pigment in the non-volatile part of the paint must be 80% for both organic and inorganic binders. This quantity represents the basis for the life of basic colors with high zinc content.

Number of coating applications for each system and nominal thickness of dry film, which are defined by the standard, are shown in the Tabel 8.

Table 8 – Summary table for corrosivity category C2 [6]

Substrate: Low-alloy carbon steel Surface preparation: For Sa $2^1/_2$ from rust grade A, B or C only (see ISO 8501-1)										
System No.	Priming coat(s)				Subseq. coat(s)	Paint system		Expected durability		
	Binder type	Type of primer	No. of coats	NDFT [μm]	Binder type	No. of coats	NDFT [μm]	Low	Med	High
A.2.01	AK	Misc.	1	40	AK	2	80			
A.2.02	AK	Misc.	1-2	80	AK	2-3	120			
A.2.03	AK	Misc.	1-2	80	AK, AY PVC, CR	2-4	160			
A.2.04	AK	Misc.	1-2	100	-	1-2	100			
A.2.05	AY, PVC CR	Misc.	1-2	80	AY,PVC CR	2-4	160			
A.2.06	EP	Misc.	1-2	80	EP, PUR	2-3	120			
A.2.07	EP	Misc.	1-2	80	EP, PUR	2-4	160			
A.2.08	EP, PUR ESI	Misc.	1	60	-	1	60			

It is important to keep in mind that applied coatings within a single system must be compatible. It is not mandatory to have all coatings of one system from same origin, but as a precautionary measure, all coatings should be obtained from one manufacturer, whose recommendations need to be followed. It is necessary to choose either a coating system that would correspond to the degree of preparation that could be achieved, or the degree of preparation that corresponds to the purpose and type of the coating system.

For each system, it is defined the lifetime in relation to the category of corrosivity. The lifetime is the time that goes from coating to the first next major renewal. The term "lifetime" of the paint protection system should not be mixed with the warranty period. The warranty period is, as a rule, shorter than the lifetime, and it is defined in the administrative part of the contract. The prescribed lifetime can be short, medium and long, as shown in Table 9.

Table 9 – Lifetime of coating systems

Lifetime	Years	Label
Short	2 - 5	L
Medium	5 - 15	M
Long	> 15	H

5. CONCLUSIONS

One of the basic preconditions for achieving the required durability of steel structures is the adequate protection against corrosion. The technical regulations related to this subject are at a very high level and it can be said that all aspects of coating usage as a steel structure corrosion protection are covered by the applicable standards. On the other hand, there is a great number of experiences in practice where, as a result of ignorance of the standards, contractors easily accept the obligations to perform corrosion protection with a guaranteed lifetime which is not possible to achieve. This is especially pronounced in the case of the reconstruction and rehabilitation of existing structures where the surface is prepared "in situ", most often by hand tools. Although in such cases the best surface preparation is obtained by using sandblasting, this method is usually abandoned due to the high cost of protection that should prevent the spread of quartz in urban areas. As a consequence of this approach, corrosion occurs significantly before the expiration of the warranty period, which introduces the participants into the long and painstaking work of the continuous repair of the applied coating system. Also, coating systems can cost significantly depending of type, number and thickness of layers in the prescribed system. Contactor are very often forced to change their suppliers to provide compatibility of all layers in coating system so this must be taken in to account during the calculation of prices.

ACKNOWLEDGMENT

The authors of this paper are grateful to the management and all employees of "Jadran" company from Belgrade (Republic of Serbia) for their hospitality during the company visit, for given literature and selfless help in collecting the data necessary for writing this paper.

REFERENCES

[1] SRPS EN ISO 12944-2: *Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 2: Classification of environments (ISO 12944-2:2017)*

[2] SRPS EN ISO 8501-1: *Preparation of steel substrates before application of paints and related products - Visual assessment of surface cleanliness - Part 1: Rust grades and preparation grades of uncoated steel substrates and of steel substrates after overall removal of previous coatings (ISO 8501-1:2007)*

[3] Radovanović D.: *Sistemi antikorozivne zaštite čeličnih konstrukcija sa primerom primene na industrijskom objektu*, MSc Thesis, University of Belgrade, 2018.

[4] SRPS EN ISO 8501-2: *Preparation of steel substrates before application of paints and related products - Visual assessment of surface cleanliness - Part 2: preparation grades of previously coated steel substrates after localized removal of previous coatings (ISO 8501-2:1994)*

[5] SRPS EN ISO 12944-7: *Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 7: Execution and supervision of paint work (ISO 12944-7:2017)*

[6] SRPS EN ISO 12944-5: *Paints and varnishes - Corrosion protection of steel structures by protective paint systems - Part 5: Protective paint systems (ISO 12944-5:2018)*

[7] Fric N.: *Theoretical and experimental research of losses of pretension force in high strength bolts,* PhD Dissertation, University of Beograde, 2015.