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Maintenance of corroded silos: A case study

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ABSTRACT

Silos used for storing fuels, foods, and chemicals are specialized structures designed to safely contain and dispense various types of chemicals commonly used in the construction industry, such as cement, aggregates, and additives. Most of the materials required for glass fiber reinforced concrete (GFRC) panel production are stored in silos. The required materials are taken from the silos with the help of pumps equipped with an automatic dosage system. Steel is prone to corrosion when exposed to moisture and oxygen in the air, resulting in the formation of rust. In the open air, especially in places with excessive humidity and rainfall, silos corrode faster over time. Therefore, punctured silos due to corrosion can lead to production stoppages and severe financial losses. Painting is one of the primary methods for protecting steel from corrosion as it creates a barrier between the metal surface and the environment, preventing direct contact with corrosive agents and extending the life of the steel structure. In this study, the maintenance work of two heavily corroded silos, which had been in use for 20 years by Fibrobeton GFRC company, was carried out step by step according to ASTM D3276, ISO 8501 and ISO 12944:2018 standards. Wet sandblasting was used to remove the paint from the surface, followed by cleaning of the oxide layer with a patented acid solution (TPE Patent Application No: 2017/11354) containing corrosion inhibitors, followed by the application of two coats of surface tolerant ($Zn_3(PO_4)_2$ based) epoxy paint and then acrylic paint with high UV resistance. During this maintenance process, attention was also drawn to the problems caused by not preparing the metal surface in accordance with the standards before painting.

Keywords: *Corrosion, silo, paint, maintenance, atmospheric corrosion*

Korozyona Uğramış Siloların Bakımı: Bir Vaka Çalışması

ÖZET

Yakıt, gıda ve kimyasalların depolanması için kullanılan silolar, inşaat sektöründe de yaygın olarak kullanılan çimento, agrega ve katkı maddeleri gibi çeşitli kimyasalları güvenli bir şekilde depolamak ve dağıtmak için tasarlanmış özel yapılardır. Cam elyaf takviyeli beton (GFRC) panel üretimi için gerekli malzemelerin çoğu silolarda depolanır. Gerekli malzemeler, otomatik dozaj sistemi ile donatılmış

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pompalar yardımıyla silolardan alınır. Havadaki nem ve oksijene maruz kalan siloların korozyona uğrayıp pas oluşturması yüksek ihtimaldir. Açık havada, özellikle aşırı nem ve yağış alan yerlerde silolar zamanla daha hızlı korozyona uğrar. Dolayısıyla korozyon nedeniyle delinen silolar üretimin durmasına ve ciddi mali kayıplara yol açabilir. Boyama, metal yüzey ile çevre arasında bir bariyer oluşturarak korozif maddelerle doğrudan teması önlediği ve çelik yapının ömrünü uzattığı için çeliği korozyondan korumanın başlıca yöntemlerinden biridir. Bu çalışmada, Fibrobeton GFRC şirketi tarafından 20 yıldır kullanılan ve ağır korozyona uğramış iki silonun bakım çalışmaları ASTM D3276, ISO 8501 ve ISO 12944:2018 standartlarına göre adım adım gerçekleştirilmiştir. Eski boyanın silo yüzeyinden uzaklaştırılması için sulu kumlama kullanılmış, ardından korozyon inhibitörleri içeren patentli bir asit çözeltisi (TPE Patent Başvuru No: 2017/11354) ile oksit tabakası temizlenmiş, ardından iki kat yüzey toleranslı ($Zn_3(PO_4)_2$ bazlı) epoksi boya ve ardından UV dayanımı yüksek akrilik boya uygulanmıştır. Bu çalışmada bakım işlemi sırasında metal yüzeyin boya öncesi standartlara uygun olarak hazırlanmamasından kaynaklanan sorunlara da dikkat çekilmiştir.

Anahtar Kelimeler: *Korozyon, silo, boya, bakım, atmosferik korozyon*

I. INTRODUCTION

Corrosion is the process by which a material loses its physical and mechanical properties over time by reacting with its environment through chemical or electrochemical processes. Corrosion causes serious economic losses in the construction industry as well as in many other industries [1].
Atmospheric corrosion was one of the first types of corrosion to be observed. This type of corrosion is commonly observed on metals in both indoor and outdoor environments. Steel silos are generally used in an open atmosphere. Steel silos used in different atmospheric conditions in different parts of the world are corroded by the effects of humidity / moisture, temperature, salt ions and industrial gases formed due to air pollution [2]. Due to industrialisation, there are many toxic, acidic and alkaline solids, liquids and gases in the environment and atmosphere [3]. Unless there is a specific reason (e.g. food and health), silos are made from plain carbon steels because they are easy to form and weld and are readily available and cheap. It is important to protect these metals, which are less resistant to corrosion than other metal alloys, especially from atmospheric corrosion [4].

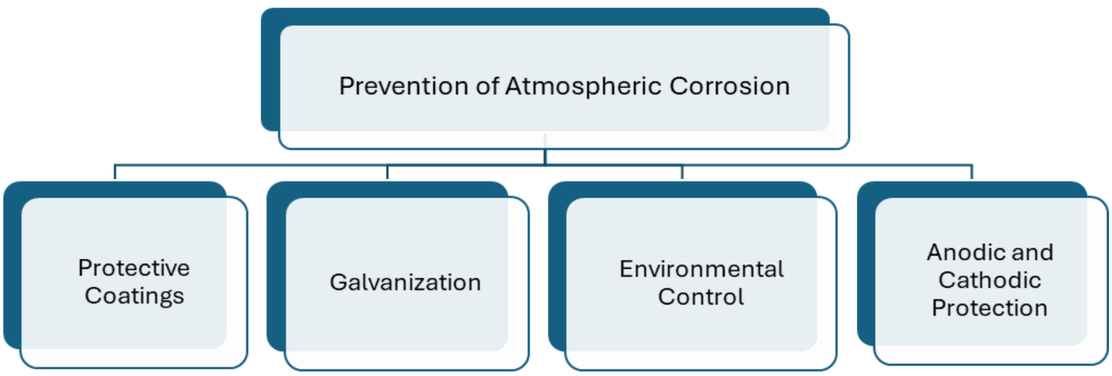

Figure 1. *Preventing atmospheric corrosion*

By applying the preventive measures shown in Figure 1, it is possible to effectively reduce the potential damage from atmospheric corrosion and thus extend the life of metallic materials exposed to the external environment. Steel silos have many auxiliary parts and equipment. Welding is a commonly used process in the manufacture of these parts. The welding process significantly affects not only the mechanical properties but also the corrosion properties of various types of metallic materials due to microstructural changes [5-8]. The weld areas are the most exposed and damaged areas to corrosion. Coatings are the

basic methods of protecting metals from corrosion. Metallic materials are successfully protected against corrosion for a long time thanks to coating methods based on the logic of creating a barrier by preventing the diffusion of water, oxygen and other factors [9,10].
Zinc is a typical metal coating widely used in anti-corrosion coatings. Zinc provides both cathodic protection and barrier protection [11,12]. Zinc-rich paints are used in various harsh environments [13]. Depending on the type of paint, zinc-rich coatings are divided into organic and inorganic coatings [14]. The most common organic binders are epoxy/polyamine-amide, vinyl resins, chlorinated rubbers, unsaturated polymers, etc. [15]. Paints containing corrosion inhibitors [16] have also become widely used.

In this study, two cement silos were cleaned of old paint and corrosion products by wet blasting. After sandblasting, the silos were washed with a patented corrosion inhibitor and prepared for painting. After two coats of a resin-based primer, the process was completed with a polyurethane-based topcoat. The problems experienced during all these processes and the experiences gained are presented in this study as a case study to shed light on future applications.

II. MATERIAL and METHOD

A. Surface Preparation Before Painting

Although the two 70 tonne silos, which have been in service for around 20 years, had undergone general maintenance on several occasions, it was found that the protective properties of the paint had been compromised due to under-shell corrosion (Figures 2 and 3).

Figure 2. *First state of silos*

Figure 3. *Condition of silos before painting*

Since the roof of the Fibrobeton Yapı Elemanları San.İnş.Tic.A.Ş. [17] factory is covered with solar panels to ensure energy and resource efficiency and reduce carbon emissions, wet blasting was preferred to remove the existing blistered old paint on the surface of the silos (Figure 4).

Figure 4. *Wet blasting process*

Aqueous blasting was carried out at a pressure of 300 bar using silica sand with a grain diameter of 0.125 mm-1.0 mm. Immediately after aqueous blasting, an oxide film was formed on the surface of the silos due to corrosion (Figure 5).

Figure 5. *General view of silos after wet blasting*

The removal of this oxide layer before painting is as important as the quality of the paint [18]. According to the Association for Material Protection and Performance (AMPP) [19] and ISO 8501 standards, chemical solutions can be used to clean the oxide film shown in Figure 5 [20].

This oxide film on the surface of the silos was cleaned with a patented solution (TPE Patent Application No: 2017/11354) previously tested by Coskun et al. [21]. As the solution has a density that can be applied with a high-pressure cleaner, the oxide film on the surface of the silos was removed by washing 3 times in a very short time (Figure 6).

Figure 6. *Washing process with chemical solution*

Figure 7. *After washing with chemical solution*

Figure 8. *After washing with chemical solution and wiping the silos with a car brush*

After washing with the chemical solution, a light grey layer was formed on the metal (Figure 7). In order not to leave dust on the surface, the silos were wiped with a brush and made ready for painting (Figure 8).

B. Preparation and Application of Paint

After the application of the chemical solution, two coats of primer and one coat of topcoat were applied respectively. After each paint application, paint thicknesses were measured with Elcometer thickness gauge device.

The primer paint used in the study was obtained from Kanat Boya company (15550 KANEPOX MASTICOAT). The primer paint used in the study is a resin-based two-component product cured with polyamine hardener, containing anticorrosive zinc phosphate pigments and low organic volatile matter, as specified in the product description form in Table 1.

Table 1. *Technical specifications of the primer*

Density (gr/ml)	1.50±0.10
Colour	Oxide Red
Theoretical spread rate (m^2/lt)	8.40
Flash point	43 °C
Volatile organic compounds (gr/lt)	132
Mixing ratio (by volume)	16 units "A" component + 4 units "B" component
Solid matter in the mixture (%)	84±2

The topcoat used was also supplied by Kanat Boya (37850 KANPOLY ACR ENAMEL DTM). It consists of a high solid, anti-corrosive, glossy acrylic polyurethane resin topcoat with zinc phosphate pigments. It has high adhesion, colour and gloss resistance, elasticity and mechanical resistance. The UV resistance has been tested by COT according to ISO 16474-3. Technical specifications of the topcoat are given in Table 2.

Table 2. *Technical specifications of the topcoat*

Density (gr/ml)	1.62±0.10
Colour	Grey
Theoretical spread rate (m^2/lt)	11.67
Flash point	39 °C
Volatile organic compounds (gr/lt)	270
Mixing ratio (by volume)	16 units "A" component + 2 units "B" component
Solid matter in the mixture (%)	70±2

The recommended dry paint film thickness for atmospheric corrosion categories in accordance with ISO 12944:2018 is shown in Table 3.

Table 3. *Guide values of coating thickness required in silos*

First coat of primer paint (µm)	Second coat of primer paint (µm)	Top coat paint (µm)
120	120	60

Thickness measurements were taken after the application of the first and second coats of primer and the top coat (Figures 9, 10, 11 and 12).

Figure 9. *First coat primer application*

Figure 10. *Measurement of primer paint thickness of silos*

Figure 11. *Second coat primer paint application of silos*

Figure 12. *Topcoat paint application of silos*

III. RESULTS and DISCUSSION

Research shows that most paint failures are caused by application errors. According to the ASTM D3276 standard, the relative humidity of the environment in which the paint is applied, the temperature of the metal surface and the proper preparation of the metal surface are extremely important. Unfortunately, the days chosen for painting were the days with the highest relative humidity. As the cranes were not allocated on time, the painting process took quite a long time. The thicknesses of silos numbered one and two were measured 3 (three) times from 8 points which were determined to be always on the same line and the average thickness values are shown in Table 4. As can be seen, higher thickness values were read where the first coat of primer should be 120µm. For example, at the fourth point the thickness doubled to 240 microns.

As can be seen in Table 4, the thickness of the first primer coating in silo number one was measured to be 70-90 µm higher. In high thickness paint applications, especially in the substrate, expansion and contraction may occur with temperature changes, which may lead to cracking and peeling of the paint over time. Excessively thick coatings can also cause sagging and dripping problems when applied to vertical surfaces. This situation will undoubtedly make it difficult to achieve a uniform appearance on the painted surface and will also increase the cost of protection.

Table 4. *Thickness measurements of paint applied to silo number one*

Measurement Point	1st primer paint (µm)		2nd primer paint (µm) + Topcoat paint (µm)		Total deviation compared to method
	Measurements	**Average**	**Measurements**	**Average**	
1	245, 178, 205	209	272, 326, 334	310	10 µm more
2	270, 196, 230	232	334, 313, 353	333	33 µm more
3	202, 270, 236	236	380, 414, 363	385	85 µm more
4	248, 242, 230	240	387, 401, 380	389	89 µm more
5	236, 220, 204	220	413, 368, 398	393	93 µm more
6	198, 176, 200	192	395, 321, 390	368	68 µm more
7	156, 118, 133	135	321, 314, 261	298	2 µm less
8	200, 193, 205	199	373, 328, 358	353	53 µm more

In silo number two, on the contrary, Table 5 shows that the first coat of primer is approximately 5-55 µm less. The curvature of the silos, due to their geometrical structure, prevented a homogeneous distribution of the paint thicknesses. As it was more difficult to work on the parts of the silos facing the factory wall due to the lack of space, the paint thicknesses in these areas were sometimes less than the first primer coat value as planned in Table 3. As it was not clear how much solvent was being used, the possibility of the technical staff using more solvent than necessary during the paint preparation process, particularly when preparing the paint required for silo number two, was also not considered. In addition, the average paint thickness after the second coat and the main coat varied between 215-393 µm in both silos for the reasons mentioned above.

Table 5. *Thickness measurements of paint applied to silo number two*

Measurement Point	1st primer paint (µm)		2nd primer paint (µm) + Topcoat paint (µm)		Total deviation compared to method
	Measurements	**Average**	**Measurements**	**Average**	
1	57, 78, 85	74	226, 244, 236	235	65 µm less
2	115, 82, 118	105	244, 270, 282	265	35 µm less
3	118, 73, 76	89	278, 241, 285	268	32 µm less
4	142, 83, 117	114	287, 192, 257	245	55 µm less
5	76, 72, 82	77	232, 225, 265	240	60 µm less
6	66, 60, 70	65	303, 282, 235	273	27 µm less
7	62, 70, 74	69	232, 218, 228	226	74 µm less
8	68, 107, 70	82	216, 227, 204	215	85 µm less

In the ISO 12944:2018 standard, the atmospheric corrosion classification is classified as C1 and C2 for atmospheres with high and low corrosion rates, respectively. In this context, it can be seen that the average total paint thickness of the silo (Silo 2) given in Table 5 is 108 µm less than the average total thickness of Silo 1. Therefore, it is 120 µm more than the recommended paint thickness for both silos for Class C1 and C2 atmospheres for corrosion protection. In this context, both silos have been coated according to the relevant standard to provide protection for more than 25 years [22, 23].

IV. CONCLUSIONS

This study summarises the experience and results obtained during the maintenance of two silos subjected to severe atmospheric corrosion.

1) The method used to remove old paint is important. The water molecules pulverised during the wet blasting process reacted with the metal and caused corrosion.
2) Homogeneous corrosion products formed on the metal surface can be successfully removed from the metal surface using chemical solutions. Care should be taken to ensure that the product selected for this process does not contain chemicals that are harmful to the environment and human health.
3) Weather conditions must be taken into account in the pre-coating design. A successful finish can only be achieved in favourable weather conditions.
4) Surface preparation is at least as important as the quality of the paint. Surfaces should be prepared in accordance with standards.
5) Applying excessive paint thickness to the metal surface does not mean better protection. Excess paint will only increase the cost.
6) Applying less primer than necessary to the metal surface will cause rust attack and rust spots (peak corrosion) on the surface of the painted material, depending on the conditions.
7) The primer and topcoat applied must be of compatible components. Otherwise, delamination will occur.
8) The solvent used in the preparation of the paint must be suitable for the paint and must be used in the required quantity.
9) It is expected that the painting process carried out in the atmospheric conditions of the two silos subject to this study will provide protection for more than 25 years according to the relevant standard.
10) This study has once again shown that the technical personnel involved in the process of preparing and painting the silo surface should receive all the necessary training. Technical personnel who do not have the necessary training and awareness may refuse to comply with the standards because they have difficulty understanding the importance of the work. In this context, the importance of institutions and organisations that provide vocational training has been confirmed by this study.

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