

Use of zinc-rich primers co-pigmented with phosphates applied on rusty steel surfaces contaminated with soluble salts

D. de la Fuente*, B. Chico* y M. Morcillo*

Abstract

Zinc-rich primers (ZRP) offer good anti-corrosive behaviour, and are an ecologically acceptable solution, when applied on carbon steel substrates that are rusted and contaminated with soluble salts (chlorides and sulphates), provided certain critical contamination thresholds are not exceeded. The use of phosphate-type co-pigments in ZRP formulations, could lead to an increase in tolerable critical levels for soluble salts. This work discusses the results of a comparative study carried out with ZRP and non-ZRP systems incorporating various types of co-pigments in several concentrations, applied on substrates contaminated with different chloride and sulphate levels. The study considers the results of atmospheric exposure test (24 months in Madrid atmosphere) and of accelerated humidity condensation tests.

Keywords

Rusty steel. Soluble salts. Zinc rich primers. Pigments. Osmotic blistering.

Empleo de imprimaciones ricas en zinc co-pigmentadas con fosfatos aplicadas sobre superficies de acero herrumbrado contaminado con sales solubles

Resumen

Las imprimaciones ricas en zinc (IRZ) ofrecen un buen comportamiento, además de ser una solución ecológicamente aceptable, cuando se aplican sobre sustratos de acero al carbono herrumbrado y contaminado con sales solubles (cloruros y sulfatos), siempre que no se superen ciertos umbrales críticos de contaminación. El empleo en la formulación de las IRZ de copigmentos de tipo fosfato podría suponer un aumento en los niveles críticos tolerables de sales solubles. En el presente trabajo se discuten los resultados del estudio comparativo llevado a cabo con sistemas IRZ y no IRZ con diferentes tipos de estos copigmentos en varias proporciones, aplicados sobre sustratos contaminados con distintos niveles de cloruros y sulfatos. El estudio incluye los resultados tanto del ensayo de exposición atmosférica (24 meses en la atmósfera de Madrid) como el ensayo acelerado de condensación de humedad.

Palabras clave

Acero herrumbrado. Sales solubles. Imprimaciones ricas en zinc. Pigmentos. Ampollamiento osmótico

1. INTRODUCTION

One of the most frequent causes of premature failure of anticorrosive paint coatings applied on steel structures is the presence of soluble salts, mainly chlorides and sulphates, at the metal/paint interface.

These salts are found among the steel corrosion products and have their origin in the exposure of the steel, prior to its painting, in environments containing these aggressive species. The rapid deterioration of the paint system is shown by the early appearance of blistering of the film. This

cause-effect relationship was first reported by Mayne in 1959^[1].

The blistering phenomenon is a consequence of the verification of osmotic processes through the paint membrane, due to the existence of soluble compounds at the interface, and of accelerated corrosion of the steel below the organic coating, caused by the aggressive ions (Cl^- and SO_4^{2-}). The problem appears mainly when the paint is applied on rusted steel.

Painting technology for the application of paints on rust has traditionally turned to lead orthoplumbate base pigments (red lead oxide) in oil type vehicles,

(* National Centre for Metallurgical Research. CENIM (CSIC). Avda. Gregorio del Amo, 8. 28040-Madrid (Spain).

with a good wetting power, with fairly acceptable results. However, ecological considerations now rule out the use of lead base pigments.

The alternatives currently available for this situation are:

- a) Use of very thick coatings (mastics) that impede the entry of water and oxygen molecules through them. They present the disadvantage of their high cost and complicated application.
- b) Use of inerting pigments. The inerting of the aggressive species of rust (Cl^- and SO_4^{2-}) can be achieved by different mechanisms: (i) the formation of insoluble compounds by chemical reaction of the pigment with the saline species^[2-5] and (ii) the use of zinc-rich paints (ZRP)^[6-8].

The first studies of the use of inerting pigments^[2-5] were published some time ago, and though promising did not lead to the development of commercial products. Nowadays, ecological criteria make it impossible to use the pigments tested in these early studies, since they contained Cd, Ba and Cr. However, there are other pigments, such as calcium phosphate, zinc phosphate and zinc-iron phosphate, which do not present these limitations and whose use as co-pigments in ZRPs may improve the anticorrosive behaviour of the latter, permitting an increase in the allowable critical levels of Cl^- and SO_4^{2-} at the metal/paint interface.

2. EXPERIMENTAL PROCEDURE

In practice, soluble salts are found heterogeneously distributed in the steel corrosion products layer, and frequently located at the base steel/rust layer interface. However, in the studies carried out by most researchers in relation with this issue, with the aim of establishing critical concentration levels or other considerations, the specimens have been prepared by dosing the saline contaminant in a uniform way across unruined steel surfaces. This situation is rather different to what actually occurs in practice, and is a problem that has already been pointed out by Bayliss and Chandler^[9].

In order to resolve this problem, an attempt has been made to reproduce the atmospheric corrosion process of steel in environments contaminated with SO_2 and Cl^- , using a salt fog cabinet for the case of chlorides and a Kesternich type cabinet for sulphates.

In both cases, specimens of 12.5×8 cm were cut from carbon steel plate and degreased with acetone.

2.1. Contamination of specimens in a salt fog cabinet

After degreasing, the specimens were placed in the cabinet and subjected to salt fog testing according to DIN standard 50021^[10]. Specimens were withdrawn from the cabinet after different exposure times and kept in the laboratory for 2 weeks, during which time a rust layer formed on the specimen surfaces.

2.2. Contamination of specimens in a Kesternich cabinet

In the Kesternich cabinet, DIN 50018^[11], the specimens are suspended vertically from a plastic bar. At the bottom of the cabinet a resistor heats a water bath to 40 °C. A volume of SO_2 is introduced in the interior of the cabinet. The amount of SO_2 introduced was selected as the test variable. A certain volume of SO_2 was introduced and after two and a half hours of exposure the test was stopped, and the specimens were removed and kept for 2 weeks in the laboratory.

2.3. Automatic brushing to remove non-adherent rust

To remove non-adherent rust from the specimens contaminated with chlorides and sulphates, their surfaces were automatically brushed using a brush with stainless steel bristles of 0.3 mm diameter and 15 mm length. The specimens were placed on a support and the brush automatically acted on them horizontally (10 passes in both directions). The specimens were then turned around 180°, with the same side facing upwards, and the brushing process was repeated. Once brushed, the specimens were stored in plastic bags in the laboratory until their painting.

2.4. Extraction and analysis of chloride and sulphate ion contents

Three specimens per withdrawal were used to measure the amount of chlorides and sulphates present, following extraction according to the Mayne method^[1]. The specimens were separately

immersed in boiling distilled water for 60 min, after which the solutions were filtered and brought to a constant volume for their subsequent analysis.

- Analysis of chlorides: The chloride ions in solution were analysed using the ion selective electrode technique. This technique is based on measuring the change in potential through an ion selective membrane. The magnitude of the change in potential is converted into units of chloride concentration in solution by means of a previously calibrated analyser.
- Analysis of sulphates: The sulphate ions were analysed using the turbidimetric method. This determination is based on ASTM standard D516^[12]. The sulphate in solution is transformed into barium sulphate in suspension by the addition of barium chloride in controlled conditions. Using a spectrophotometer the absorbency of the solution is measured in the ultraviolet range (indirect measurement of the degree of turbidity), which is linear with the initial concentration of the sulphate ion in solution. The absorbency readings are compared with a calibration curve previously determined with standard sulphate solutions.

Table I displays the chloride and sulphate levels chosen for the application of the different paint systems to be studied (Table II).

The paint systems were applied according to their manufacturers' specifications, with thicknesses between 40-60 µm. Once the paints had been applied the edges of the specimens were protected and a scribe was made, according to DIN 53167^[13], on the lower part of those to be exposed in the atmosphere. Table III shows the corrosivity data of the Madrid testing station. Another series of specimens was subjected to cyclic humidity condensation-drying accelerated testing (144 h humidity condensation +24 h drying) in a Cleveland type humidity condensation cabinet, maintaining the temperature between 35-40 °C.

3. RESULTS

3.1. Atmospheric exposure

Tables IV and V show the degree of blistering of the paint systems after 3, 6, 12 and 24 months of exposure. The values of the size and frequency of blisters, according to ASTM standard D-714^[15], have been converted into numeric values using the Keane conversion table^[16].

Table I. Chloride and sulphate levels chosen

Tabla I. Niveles seleccionados de cloruros y sulfatos

| Chlorides (mg/m ²) | Sulphates (mg/m ²) |
|--------------------------------|--------------------------------|
| 0 | 0 |
| 50-100 | 500 |
| 100-200 | 1500 |
| 200-300 | 2500 |
| 900 | 4000 |

Table III. Corrosivity data of the testing station

Tabla III. Datos de corrosividad de la estación de ensayo

| | |
|---|-------|
| Time of wetness (annual fraction) | 0.155 |
| Chloride deposition rate (mg · m ⁻² · d ⁻¹) | 0.9 |
| SO ₂ deposition rate (mg · m ⁻² · d ⁻¹) | 36.6 |
| ISO Corrosivity category* | C2 |
| Mild steel corrosion rate (µm · y ⁻¹) | 18.5 |
| Zinc corrosion rate (µm · y ⁻¹) | 0.40 |

* ISO 9223^[14]

Table II. Applied Primers

Tabla II. Imprimaciones aplicadas

| Systems | | | |
|-----------------|--------------------------|-----------------------|--------------------------|
| Vehicle | Pigment | Vehicle | Pigment |
| Oil (reference) | Red lead oxide | Epoxy-ZRP (reference) | – |
| Epoxy-non ZRP | Calcium phosphate 10 % | Epoxy-ZRP | Calcium phosphate 5 % |
| | Calcium phosphate 20 % | | Calcium phosphate 10 % |
| | Zinc-iron phosphate 10 % | | Zinc-iron phosphate 5 % |
| | Zinc-iron phosphate 20 % | | Zinc-iron phosphate 10 % |
| | Zinc phosphate 10 % | | Zinc phosphate 5 % |
| | Zinc phosphate 20 % | | Zinc phosphate 10 % |

Table IV. Degree of blistering after 3, 6, 12 y 24 months of exposure in the Madrid atmosphere for specimens contaminated with known levels of sulphates

Tabla IV. Grado de ampollamiento exhibido por las muestras contaminadas con niveles conocidos de sulfatos tras 3, 6, 12 y 24 meses de exposición en la atmósfera de Madrid

| Systems | | Level 0 | | | | Sulphates level | | | | | | | | | | | | | | | |
|------------------|-------------------------|----------|----------|-----------|-----------|-----------------|----------|-----------|-----------|----------|----------|-----------|-----------|----------|----------|-----------|-----------|----------|----------|-----------|-----------|
| Vehicle | Pigment | 3 months | 6 months | 12 months | 24 months | S500 | | | | S1500 | | | | S2500 | | | | S400 | | | |
| | | | | | | 3 months | 6 months | 12 months | 24 months | 3 months | 6 months | 12 months | 24 months | 3 months | 6 months | 12 months | 24 months | 3 months | 6 months | 12 months | 24 months |
| Oil (ref) | red lead oxide | - | - | - | - | 7 | 6 | 6 | 4 | 4(s) | 2 | W | W | 2(s) | 0 | W | W | 2(s) | 0 | W | W |
| | Calcium phosphate 10% | - | 7(s) | 6(s) | 6(s) | 5(s) | 2 | W | W | d(s) | 0 | W | W | 5(s) | 0 | W | W | n.t. | n.t. | n.t. | n.t. |
| | Calcium phosphate 20% | - | 9(s) | 6(s) | 4(s) | - | 7(s) | 2(s) | 2(s) | d(s) | 0 | W | W | 5(s) | 0 | W | W | n.t. | n.t. | n.t. | n.t. |
| EXPOSI-NON PRZ | Zinc-iron phosphate 10% | - | - | - | - | 9(s) | 7(s) | 4(s) | 4(s) | 3 | 0 | W | W | 3(s) | 0 | W | W | 2(s) | 0 | W | W |
| | Zinc-iron phosphate 20% | - | 8(s) | 7(s) | 6(s) | 7(s) | 5 | W | W | 2(s) | 0 | W | W | 5(s) | 0 | W | W | 3(s) | 0 | W | W |
| | Zinc phosphate 10% | - | - | 7(s) | 7(s) | 9(s) | 8(s) | 5(s) | 5(s) | d(s) | 0 | W | W | 3(s) | 0 | W | W | n.t. | n.t. | n.t. | n.t. |
| | Zinc phosphate 20% | - | 8(s) | 6(s) | 6(s) | - | 8(s) | 4(s) | 0(s) | 6(s) | 0 | W | W | 3(s) | 0 | W | W | 3(s) | 0 | W | W |
| EXPOSI-PRZ (ref) | - | 5(s) | 5(s) | 5(s) | 5(s) | - | 6(E) | 2(E) | 2(E) | d | W | W | W | d | W | W | W | d | W | W | W |
| | Calcium phosphate 5% | - | - | - | - | - | 6(E) | 4 | 2 | - | d | W | W | 9(s) | d | W | W | n.t. | n.t. | n.t. | n.t. |
| | Calcium phosphate 10% | - | - | - | - | - | 6 | 5 | 5 | 5 | 5 | W | W | 4 | 0 | W | W | n.t. | n.t. | n.t. | n.t. |
| EXPOSI-PRZ | Zinc-iron phosphate 5% | - | - | - | - | - | 6(E) | d(E) | d(E) | 8(s) | d | W | W | 8(s) | d | W | W | n.t. | n.t. | n.t. | n.t. |
| | Zinc-iron phosphate 10% | - | - | - | - | - | 2 | W | W | - | d | W | W | - | d | W | W | 6(s) | d | W | W |
| | Zinc phosphate 5% | - | - | - | - | 6(s) | 0 | W | W | 7(s) | d | W | W | - | d | W | W | n.t. | n.t. | n.t. | n.t. |
| | Zinc phosphate 10% | - | - | - | - | - | 6(E) | 3(E) | 2(E) | 0 | d | W | W | 8(s) | d | W | W | n.t. | n.t. | n.t. | n.t. |

W: Withdrawn; (s): scribe; (E): Edge; d: delamination; n.t.: non tested

Table V. Degree of blistering after 3, 6, 12 y 24 months of exposure in the Madrid atmosphere for specimens contaminated with known levels of chlorides

Tabla V. Grado de ampollamiento exhibido por las muestras contaminadas con niveles conocidos de cloruros tras 3, 6, 12 y 24 meses de exposición en la atmósfera de Madrid

| Systems | | Level 0 | | | | Chlorides level | | | | | | | | | | | | | | | |
|------------------|-------------------------|----------|----------|-----------|-----------|-----------------|----------|-----------|-----------|----------|----------|-----------|-----------|----------|----------|-----------|-----------|----------|----------|-----------|-----------|
| Vehicle | Pigment | 3 months | 6 months | 12 months | 24 months | C50-100 | | | | C100-200 | | | | C200-300 | | | | C900 | | | |
| | | | | | | 3 months | 6 months | 12 months | 24 months | 3 months | 6 months | 12 months | 24 months | 3 months | 6 months | 12 months | 24 months | 3 months | 6 months | 12 months | 24 months |
| Oil (ref) | red lead oxide | - | - | - | - | - | 9 | 9 | 9 | - | 9 | 8 | 8 | 9 | 8 | 8 | 7 | 8 | 6 | 6 | 6 |
| | Calcium phosphate 10% | - | 7(s) | 6(s) | 6(s) | - | - | - | 9 | n.t. | n.t. | n.t. | n.t. | 9 | 7 | 7 | 7 | n.t. | n.t. | n.t. | n.t. |
| | Calcium phosphate 20% | - | 9(s) | 6(s) | 4(s) | - | 9(s) | 9(s) | 8(s) | n.t. | n.t. | n.t. | n.t. | 9 | 6 | 6 | 6 | n.t. | n.t. | n.t. | n.t. |
| EXPOSI-NON PRZ | Zinc-iron phosphate 10% | - | - | - | - | - | - | 9 | 9 | - | 8 | 7 | 7 | - | 6 | 6 | 6 | 7 | 5 | 5 | W |
| | Zinc-iron phosphate 20% | - | 8(s) | 7(s) | 6(s) | - | 9 | 9 | 9/7(s) | n.t. | n.t. | n.t. | n.t. | - | 7 | 7 | 6 | 7 | 5 | 5 | W |
| | Zinc phosphate 10% | - | - | 7(s) | 7(s) | - | - | - | 9(s) | n.t. | n.t. | n.t. | n.t. | - | 7 | 7 | 6 | n.t. | n.t. | n.t. | n.t. |
| | Zinc phosphate 20% | - | 8(s) | 6(s) | 6(s) | - | - | - | - | n.t. | n.t. | n.t. | n.t. | 9(s) | 7 | 6 | 6 | 9 | 5 | 4 | 2 |
| EXPOSI-PRZ (ref) | - | 5(s) | 5(s) | 5(s) | 5(s) | 9 | 9 | 9 | 9 | n.t. | n.t. | n.t. | n.t. | 7 | 7 | 7 | 7 | 7(E) | 5(E) | 8/5(E) | 7/5(E) |
| | Calcium phosphate 5% | - | - | - | - | - | - | - | - | n.t. | n.t. | n.t. | n.t. | - | - | - | - | n.t. | n.t. | n.t. | n.t. |
| | Calcium phosphate 10% | - | - | - | - | - | - | - | - | n.t. | n.t. | n.t. | n.t. | - | 9 | 9 | 9 | n.t. | n.t. | n.t. | n.t. |
| EXPOSI-PRZ | Zinc-iron phosphate 5% | - | - | - | - | - | - | - | - | - | - | 9 | 9 | - | 9 | 9 | 9 | n.t. | n.t. | n.t. | n.t. |
| | Zinc-iron phosphate 10% | - | - | - | - | - | 9 | 9 | 9 | n.t. | n.t. | n.t. | n.t. | - | - | 9 | 9 | - | - | - | - |
| | Zinc phosphate 5% | - | - | - | - | - | - | - | - | n.t. | n.t. | n.t. | n.t. | - | - | - | 9 | n.t. | n.t. | n.t. | n.t. |
| | Zinc phosphate 10% | - | - | - | - | - | - | - | - | n.t. | n.t. | n.t. | n.t. | - | - | - | - | n.t. | n.t. | n.t. | n.t. |

W: Withdrawn; (s): scribe; (E): Edge; d: delamination; n.t.: non tested

For the case of sulphates it was not possible to obtain relevant results at comparative level, either between the ZRP and non-ZRP systems or between the co-pigmented systems and reference systems. This is due to the fact that after 1500 mg/m² all the primers presented an important degree of blistering and undercutting after only 3 months of exposure, above all in the proximity of the scribe and at the edges. This undercutting, which started at the edges and at the scribe, evolved to complete delamination of the paint coating on most specimens after this level, and for this reason they were withdrawn after 6 months. None of the primers tested seems to tolerate the level of 500 mg/m² either. Though complete delamination of the coating was not observed, all the primers present significant blistering and in some cases undercutting at the edges and at the scribe. Furthermore, in the case of the ZRPs, some points of rust are already perceptible on the surface after 6 months of exposure.

However, for the case of chlorides certain differences have been found between the different systems. In the case of the ZRPs differences are observed, for all the tested levels, between the co-pigmented systems and the reference system. Up to the level of 200-300 mg/m², and even for the only system tested at the level of 900 mg/m², the co-pigmented ZRP systems did not present significant deterioration, unlike the ZRP reference system. The co-pigments permit an increase in the critical chloride levels tolerated. Among them, the best behaviour is provided by zinc phosphate and calcium phosphate.

This does not occur with the non-ZRP systems, where the behaviour of the co-pigmented primers is very similar to that of the red lead primer, selected as reference, presenting notable problems after the level of 200-300 mg/m². Despite this, the best behaviour in the non-ZRP systems is also offered by the zinc phosphate and calcium phosphate pigments.

3.2. Accelerated humidity condensation test

Tables VI and VII indicate the degree of blistering of the paint systems after different numbers of condensation cycles. The values of the size and frequency of blisters, according to ASTM standard D-714^[15], have been converted into numeric values using the Keane conversion table^[16].

In general, worse behaviour is seen with the non-ZRP systems than with the ZRP systems, and there is a notable improvement in the case of the latter with the co-pigmented systems compared to the ZRP reference system. Also in this case the best behaviour is provided by the zinc phosphate and calcium phosphate pigments, though in the latter case rust stains appear on the exposed surface at many levels, especially in the conditions of maximum pigment concentration.

For the case of chlorides, the co-pigmented ZRPs do not present important blistering problems for levels below 200-300 mg/m², or with the only system tested at the level of 900 mg/m², at least up to 7 cycles or even up to 16 cycles in some cases.

For the case of sulphates, it is also the ZRPs co-pigmented with zinc and calcium phosphate that show the best behaviour, in most cases improving on the behaviour of the reference system. After the level of 2500 mg/m² all the systems show signs of deterioration during the first test cycles. The non-ZRP systems do not offer a significantly worse behaviour than the ZRP systems, though the specimens of the system co-pigmented with zinc phosphate offer better results than the rest, including the reference red lead.

4. CONCLUSIONS

- It is possible to achieve the laboratory contamination of specimens with predetermined chloride and sulphate levels using salt fog and Kesternich type cabinets, obtaining a more similar distribution of contaminants on the rust to that which takes place in the atmosphere.
- ZRPs are an acceptable solution, both from the point of view of anticorrosive protection and from the ecological standpoint, when applied on rusted steel substrates contaminated with up to certain levels of chlorides and sulphates.
- The addition of phosphate type co-pigments improves the behaviour of ZRPs, especially in the case of zinc phosphate, and thus makes it possible to increase critical saline contamination levels. The worst behaviour was provided by zinc-iron phosphate, while calcium phosphate showed intermediate results.
- With regard to co-pigment concentration, the best results were obtained at the maximum concentration tested, which was 10 %, especially in the case of zinc phosphate.

Table VI. Degree of blistering after different number of humidity condensation cycles for specimens contaminated with known levels of sulphates

Tabla VI. Grado de ampollamiento exhibido por las muestras contaminadas con niveles conocidos de sulfatos tras diferente número de ciclos de condensación de humedad

| Systems | Sulphates level | | | | | | | | | | | | | | | | | |
|-------------------------|-----------------|---------|----------|-----------|-----------|---------|----------|-----------|-----------|---------|----------|-----------|-----------|---------|----------|-----------|-----------|--|
| | 0 | | | S500 | | | S1500 | | | S2500 | | | S400 | | | | | |
| | cycles | 1 cycle | 5 cycles | 10 cycles | 16 cycles | 1 cycle | 5 cycles | 10 cycles | 16 cycles | 1 cycle | 5 cycles | 10 cycles | 16 cycles | 1 cycle | 5 cycles | 10 cycles | 16 cycles | |
| Oil (ref) | 6 | 7 | W | W | W | 5 | W | W | W | 4 | W | W | W | 2 | W | W | W | |
| Calcium phosphate 10% | 9 | 5 | W | W | W | 6 | W | W | W | 5 | W | W | W | n.t. | n.t. | n.t. | n.t. | |
| Calcium phosphate 20% | 9 | 5 | W | W | W | 6 | W | W | W | 5 | W | W | W | n.t. | n.t. | n.t. | n.t. | |
| Zinc-iron phosphate 10% | 9 | 7 | W | W | W | 8 | W | W | W | 5 | W | W | W | 6 | W | W | W | |
| Zinc-iron phosphate 20% | 9 | 6 | W | W | W | 7 | W | W | W | 6 | W | W | W | 4 | W | W | W | |
| Zinc phosphate 10% | - | 8 | 6 | W | W | 8 | 7 | W | W | 7 | W | W | W | n.t. | n.t. | n.t. | n.t. | |
| Zinc phosphate 20% | - | 8 | 7 | W | W | 9 | 8 | W | W | 7 | W | W | W | 6 | W | W | W | |
| EXPOSI-PRZ (ref) | - | - | 7 | 6 | 6 | - | 1 | W | W | - | 7 | W | W | 6 | 6 | W | W | |
| Calcium phosphate 5% | - | 8 | 6 | 4 | 4 | 9 | 2(E) | 1(E) | 1(E) | - | 3 | W | W | n.t. | n.t. | n.t. | n.t. | |
| Calcium phosphate 10% | oxide | 8 | 8 | 8 | 6 | oxide | 8 | 7 | 6 | oxide | oxide | oxide | W | oxide | 1 | W | W | |
| Zinc-iron phosphate 5% | - | 3 | 3 | 3 | 3 | 9 | 9 | 6 | 6 | - | 5 | W | W | n.t. | n.t. | n.t. | n.t. | |
| Zinc-iron phosphate 10% | - | 7 | 3 | 3 | 3 | - | 9 | 8 | 8 | - | 4 | W | W | - | 4 | W | W | |
| Zinc phosphate 5% | - | 9 | 8 | 8 | 8 | - | 8 | 6 | 6 | - | 3 | 3 | 3 | n.t. | n.t. | n.t. | n.t. | |
| Zinc phosphate 10% | - | 9 | 9 | 8 | 8 | 9 | 9 | 6 | 6 | - | 6 | 6 | 6 | n.t. | n.t. | n.t. | n.t. | |

W: Withdrawn; (E): Edge; n.t.: non tested

Table VII. Degree of blistering after different number of humidity condensation cycles for specimens contaminated with known levels of chlorides

Tabla VII. Grado de ampollamiento exhibido por las muestras contaminadas con niveles conocidos de cloruros tras diferente número de ciclos de condensación de humedad

| Systems | | Chlorides level | | | | | | | | | | | | | | |
|------------------|-------------------------|-----------------|---------|-----------|---------|----------|-----------|----------|----------|-----------|----------|----------|-----------|---------|----------|----------|
| | | 0 | | | C50-100 | | | C100-200 | | | C200-300 | | | C900 | | |
| Vehicle | Pigment | 10 cycles | 1 cycle | 10 cycles | 1 cycle | 7 cycles | 16 cycles | 1 cycle | 7 cycles | 16 cycles | 1 cycle | 7 cycles | 16 cycles | 1 cycle | 5 cycles | 7 cycles |
| Oil (ref) | red lead oxide | 6 | 6 | W | 6 | W | W | 6 | W | W | 6 | W | W | 6 | W | W |
| | Calcium phosphate 10% | 9 | 6 | W | n.t. | n.t. | n.t. | n.t. | W | W | 4 | W | W | n.t. | n.t. | n.t. |
| | Calcium phosphate 20% | 9 | 6 | W | n.t. | n.t. | n.t. | n.t. | W | W | 4 | W | W | n.t. | n.t. | n.t. |
| EXPOSI-NON PRZ | Zinc-iron phosphate 10% | 9 | 6 | W | 6 | W | W | 6 | W | W | 6 | W | W | 4 | W | W |
| | Zinc-iron phosphate 20% | 9 | 6 | W | n.t. | n.t. | n.t. | n.t. | W | W | 6 | W | W | 4 | W | W |
| | Zinc phosphate 10% | - | 6 | W | n.t. | n.t. | n.t. | n.t. | W | W | 6 | W | W | n.t. | n.t. | n.t. |
| | Zinc phosphate 20% | - | - | 6 | n.t. | n.t. | n.t. | n.t. | W | W | 6 | W | W | 4 | W | W |
| EXPOSI-PRZ (ref) | - | - | - | 8 | n.t. | n.t. | n.t. | n.t. | W | W | 2 | W | W | 5 | W | W |
| | Calcium phosphate 5% | - | - | - | n.t. | n.t. | n.t. | n.t. | W | W | 9 | W | W | n.t. | n.t. | n.t. |
| | Calcium phosphate 10% | oxide | - | oxide | n.t. | n.t. | n.t. | n.t. | oxide | oxide | oxide | oxide | oxide | n.t. | n.t. | n.t. |
| EXPOSI-PRZ | Zinc-iron phosphate 5% | - | - | - | 5 | 5 | W | 6 | 6 | W | 6 | 6 | W | - | 9 | 9 |
| | Zinc-iron phosphate 10% | - | - | 8 | n.t. | n.t. | n.t. | n.t. | - | 9 | - | - | 9 | n.t. | n.t. | n.t. |
| | Zinc phosphate 5% | - | - | 8 | n.t. | n.t. | n.t. | n.t. | 7 | W | 7 | 7 | W | n.t. | n.t. | n.t. |
| | Zinc phosphate 10% | - | - | - | n.t. | n.t. | n.t. | n.t. | - | - | - | - | - | n.t. | n.t. | n.t. |

W: Withdrawn; n.t.: non tested

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