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Development of a flash test for fast qualification of the durability of painted galvanised steel sheets used for roofing in equatorial/ tropical environment.

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Abstract :

An ultrasonic flash test is developed in order to characterize the toughness of the paint /metal interface of manufactured prepainted galvanized steel sheet used for roofing in the Caribbean area. The morphologies and kinetics of damage processes of the painted surfaces generated by the ultrasonic solicitations, are quantitatively followed and correlated to long term efficiency of the tested anticorrosion treatments.

Keywords : ultrasounds, cavitation, wet adhesion

Introduction :

Galvanised steel sheets are extensively used in the Caribbean area for the roofing of houses. Due to the high aggressiveness of the tropical/equatorial climate, the protection against corrosion of such materials must be strongly reinforced in order to increase their durability.

A classical low cost process of protection of non stainless steel consists of application of galvanization coatings. In order to reinforce the efficiency and for aesthetic purpose, such galvanized materials can be covered by various organic coatings such as paints. These coatings are supposed to enhance the protection effect by addition of corrosion inhibitors in the primary layer and to reduce the intrusion of water to the interface by a barrier effect of the finishing layer.

The main problem which has to be solved is the evaluation of the durability and/or long term efficiency of such treatments. Up to now, the classical procedure used to evaluate these properties is the exposure in severe environmental conditions in order to accelerate the damage processes. This is done in stands where UV, moisture, temperature mechanical stresses can be applied simultaneously in a controlled manner. Such procedures need however long time experiments (up to ten years in natural exposure). Some shorter tests (scratch test, friction test, pilling test…) are also used to evaluate some mechanical or adhesive properties of the coatings which can have significant influences on the durability of the materials.

In this work a flash test (few minutes experiment) based on ultrasonic solicitations is developed [1] in order to qualify the adhesion of organic coatings used for corrosion protection of metallic substrates.

The behaviour of various samples during the flash test (stripping kinetic, morphology of the stripping) is deeply investigated and the quantitative results are correlated to the long term behaviour of the same samples in natural exposure on a C5 class stand in Cayenne.

Some relevant quantitative parameters are used in order to classify long term efficiency of such coatings.

Materials

The studied materials are composite coatings made of four layers deposited on steel substrates as described in the schematic cross-section presented in figure 1 [2].

The galvanization treatment, consisting of covering steel with a zinc-based alloy, is the first protection layer against corrosion. The second layer enhances the adhesion between the metal and the organic coating. The first paint layer (primary layer) is composed of a polymer containing corrosion inhibitors. The second paint layer (finishing layer) containing pigments and UV stabilizers operates as a barrier [3-4] to avoid diffusion of chemical species (water, oxygen...) to the organic/metal interface.

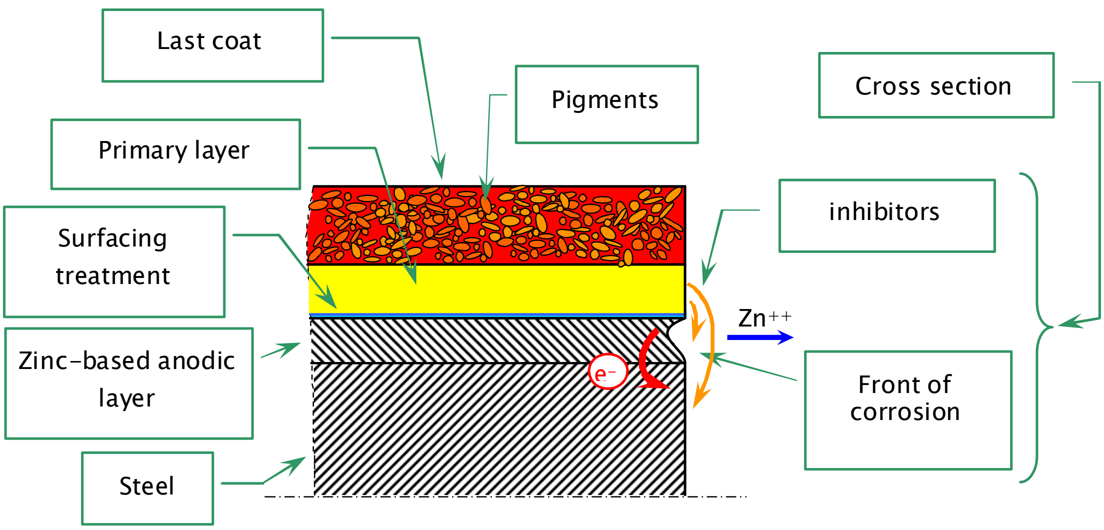

Figure 1 : Schematic representation of the different layers used for the protection of the steel sheets [2]

Classical "natural exposure test" for the qualification of the system of paint

Pieces of the samples of interest were exposed according to standard ECCA T19 on the stand located in Cayenne (French Guyana, figure 2a) during four years from 1998 to 2002. The environmental stand parameters over one year were readily stable during the four years of exposure, with a monthly sunshine light of 200 hours, monthly averages temperatures between 26 and 28 °C, relative humidity between 82 and 92 %, annual rainfall of 3000 millimetres mainly between December and July. These parameters lead to a C5 classification of the stand according to ISO 9223-1992 [5].

To enable the classification of the systems of paint, and by the way to give an image of there durability, a few parameters are taken into account as it can be seen on figure 2b:

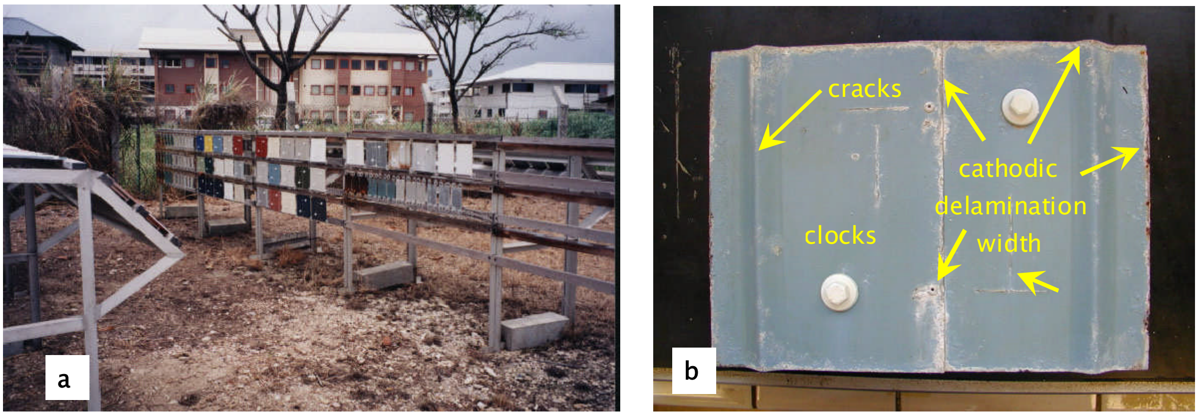

Figure 2 : Natural exposure in Cayenne (French Guiana)
a) the stand, b) Typical aspect of a 4 years exposed sample

width of cathodic delamination from the edges, presence or not of cracks on the folds, paint metal disbondment ...

Flash test

The test has been developed from published works of J. SCHULTZ [6] and H. HAIDARA [7] on metal thin films (a few nanometres thick) vapour deposited on polymer substrates.

The conditions of our test are described in figure 3. The samples are discs of 18 mm diameter obtained by stamping steel sheets of interest. Each sample is glued on the probe so that the painted face keeps in contact with the liquid (see figure 4). The samples are then submitted to ultrasonic solicitations (90W, 20kHz) by sequences of 30 sec to 1 min depending on the behaviour of the coating. After each sequence, a digitized picture of the painted surface is recorded. At the end of the test (total stripping of the paint layers) computerised analyses of the digitized pictures allow us to quantitatively evaluate the surface fraction still covered by the paint (non stripped area fraction).

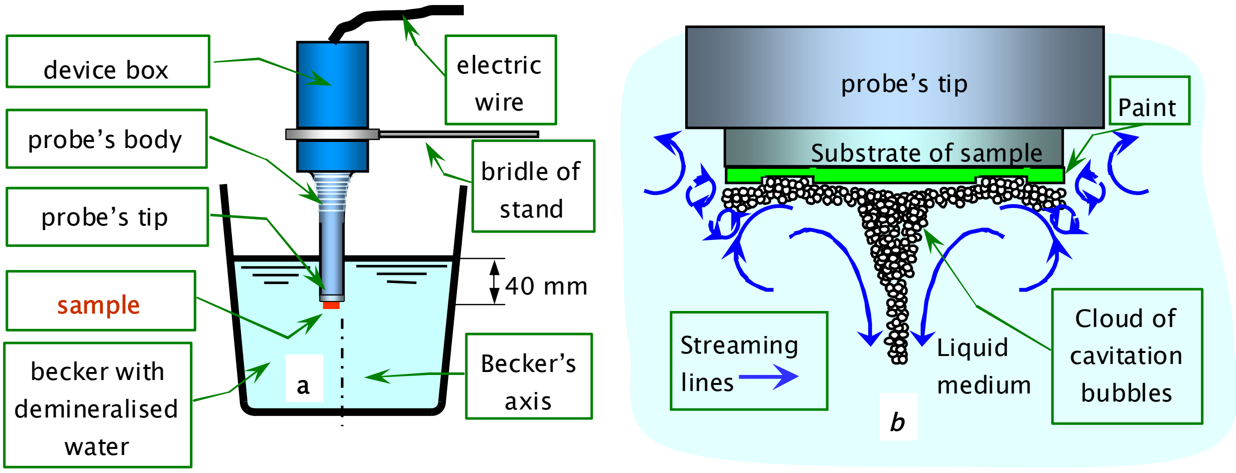

Figure 3 : device used for the test using ultrasounds generator : a) experimental design, b) detail of the sample during the test

Mechanical effects of ultrasounds

Due to the high velocity of the probe's tip surface, bubbles of water vapour appear near the tip as soon as the test runs (figure 3b). In the same time, whirlpool streams of the liquid medium take place in the becker [8, 9].

It is well known that ultrasounds make the liquid medium unstable and produce in a very short time the evaporation of the liquid into small bubbles (cavitation bubbles) of different sizes. It has been demonstrated [9], solving the motion equation of a bubble frontier in a high powered ultrasound field, that mainly two kinds of bubbles exist : stationary and transitory cavitation bubbles.

The stationary cavitation bubbles oscillate in the field of ultrasounds at there own rhythm. Their volume periodically varies inducing an alternative pumping effect on the paint able to initiate disbondment at the paint metal interface (fatigue phenomenon) and periodic intrusion of water at the interface (figure 4a, *b)*. These effects can lead to the stripping of large flakes (figure 4c*)*.

The transitory cavitation bubbles oscillate at the rhythm of ultrasound waves and collapse, after one or two oscillations, generating locally very high pressures. In addition, when such bubble collapses near a solid surface, a phenomenon described by PLESSET [10] (illustrated in figure 4*d*) occurs. In its collapse motion, the bubble changes its shape so that a water jet appears opposite to the substrate and hit the solid surface as a real hammer (pressure range of about 100 MPa). One can easily imagine that the jet produces high superficial stresses leading to local damages (pitting) of the solid material (figure 4 *e, f*).

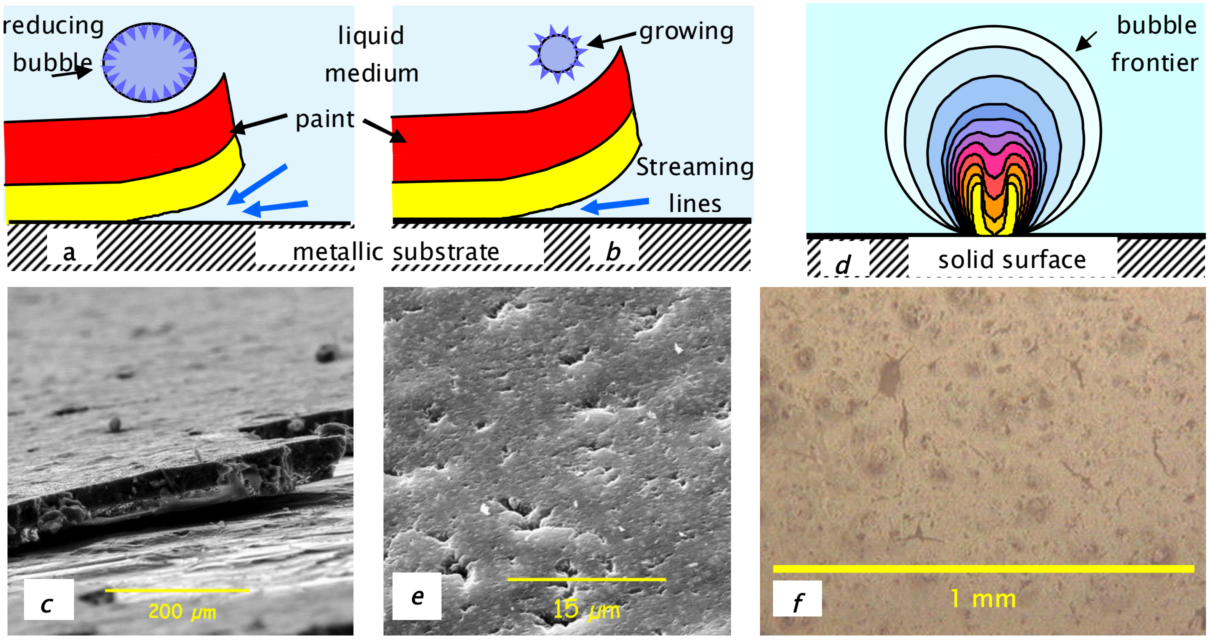

*Figure 4 : mechanical effects of ultrasounds : **a)** and **b)** disbondment occur by the way of oscillations of stationary cavitation bubbles, **c)** ASEM view of a sample after 3 minutes of ultrasonic solicitations. **d)** Different steps of the collapse motion of a transitory cavitation bubble near a solid boundary by M. S. PLESSET [10]. **e)** ASEM view and **f)** optical micrograph picture of surfaces damaged by pitting resulting from cavitation bubble collapses*

Quantification

The areas of the non stripped zones are quantitatively measured by means of image analyses based on a colour recognition software developed in the laboratory. For each curve, we can notice an horizontal step at the beginning followed by the decrease of the central non stripped area of paint, but if we calculate the average radius of this area, we notice that it decreases rather linearly (figure 5).

The two systems of paint of the figure 5 have opposite behaviours in natural exposure (left hand pictures on the graphs) and comparable duration in the flash test. So we must admit that the strongness/toughness of a system of paint in the flash test can not be directly related with its durability in natural conditions.

On the other hand, as it can be seen also on figure 5 (right hand pictures on the graphs) , there is two main kind of morphological aspect of the samples during the test, and it has been possible to relate this morphology of damages process with the sorting of the system of paint by their performances in natural exposure.

Then, assuming that the extraction process of large flakes of paint should lead to a larger dispersion of the stripping kinetic curves than the pitting process, we expressed a “flash test index” as the normalized area defined by the dispersion of the graphs obtained on six samples of the same system of paint (figure 5). The “flash test index” of eight systems of paint are reported in Table 1. A classification of efficiency is proposed on this criterion (greatest index corresponding to lowest efficiency, and smallest index to highest efficiency) and compared to the long term behaviour in natural exposure.

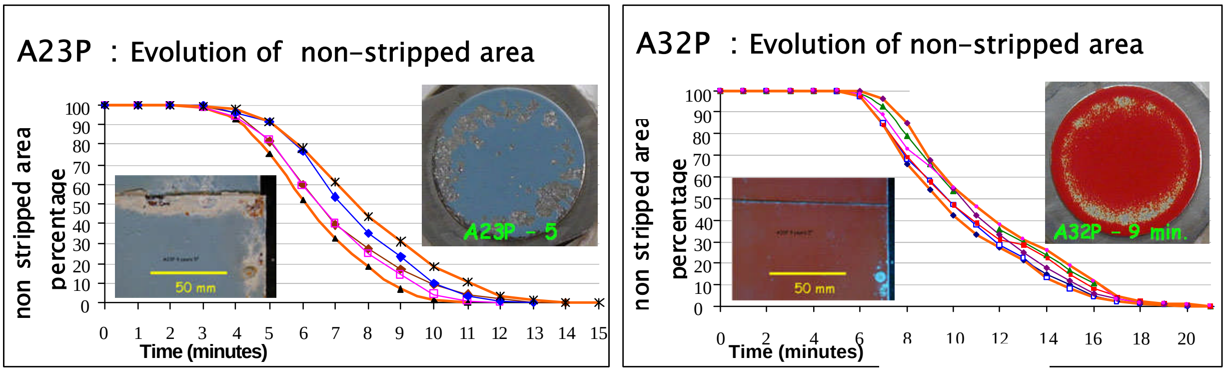

Figure 5 : graphs for six samples of two systems of paint. The flash test index is deduced from the area limited by the two extreme (red color) kinetic curves divided by the time of total stripping.

Table 1 : Efficiency classification : Comparison between flash test and four years natural exposure results.

system of paint	Flash test damage process	Flash test index	Flash test classification	four years natural exposure behaviour
A32P	pitting	6.5	1	very good
A24P	pitting	8.0	2	good
A15P	pitting	8.6	3	good
A26P	flakes stripping & pitting	9.0	4	bad
A16P	flakes stripping & pitting	9.1	5	medium
A22P	flakes stripping	11.3	6	medium
A23P	flakes stripping	12.3	7	bad
A20P	flakes stripping	14.5	8	bad

Conclusion

The flash test developed for this study, first designed for the monitoring of the quality stability of industrial materials, points out some specific parameters which can be interpreted and correlated to long term efficiency. Especially the morphology of the stripped particles and consequently the dispersion of stripping kinetic curves appear to be strongly dependent on the paint metal adhesion. This property strongly affects the long term behaviour of the manufactured material. These remarks induced the definition of a “flash test index” as the ratio of kinetic curve dispersion surface on experiment time. Measurements carried out on six specimens of the same system of paint allowed us to establish a paint/metal adhesion classification of eight systems. The correlation of this last one to long time natural exposure behaviour revealed a good agreement between the two types of results. This seems to show that the flash test could be a short time experiment for paint coating durability evaluation.

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