Lap-Joint Corrosion Testing Of Precoated Steel Sheets

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In industry, and particularly in the building construction and automotive industries, lap-joint technology for precoated steel sheet assembly has undergone rapid development. However, the durability problems associated with joints of this type are well known, i.e., premature deterioration of protective coatings (metallic, organic) and accelerated metallic corrosion of the base steel by moisture retention in the joint, crevice corrosion, etc. The authors have been involved in researching lap-joint corrosion testing to learn the behavior of materials in these joints. The precoated steel sheet materials studied were divided into two groups according to their use in two well-defined industrial sectors: building (55% Al-Zn and hot-dip galvanized, painted and unpainted) and car manufacturing (electrogalvanized and galvanneal).

INTRODUCTION

Designs involving the use of lap-joints are becoming increasingly common in industry, particularly in the building construction and automotive industries. However, precoated steel sheets assembled by lap-joints are prone to suffer several corrosion processes, such as crevice corrosion, galvanic corrosion (in the case of unlike materials), premature degradation of protective coatings (metallic, organic), and accelerated metallic corrosion of the base steel by moisture retention in the joint, etc.

Much of the research effort related with this issue has been focused on the automotive industry. In automobiles, corrosion frequently starts inside some type of crevice, for instance in spot-welded joints or door hems, hood hems, etc. The crevice itself causes higher retention of moisture under prolonged periods and the probability of failure is increased in this type of joint. Corrosion is also accelerated in these zones because they are not completely protected by the paint system due to the insufficient penetrating power of the electrocoating and finish coatings to cover such areas. The corrosion failure on body panels is also dependent upon details of the total coating system, on the control and reliability of the manufacturing process, design of the structure, etc.

According to a survey conducted in Saudi Arabia,[1] of 5000 vehicles in service in coastal areas characterized by high temperature and humidity, 676 showed corrosion, with the main deterioration appearing in roofs (27.7%), door assembly (15.29%), and hoods (14.55%). The type and extent of corrosion varied from one component to the other, and it was usually localized in a specific area. For instance, the door damage was concentrated in the bottom (43%) and was associated with crevice and poultice corrosion accelerated by the high frequency of moisture entrapment in that area.[2]

The Swedish Corrosion Institute has performed an investigation looking at the corrosion attack inside crevices of spot-welded joints and hem flanges on cars of recent models. The investigation was carried out on 437 vehicles of 1994-1995 models and in total more than 2000 surfaces from various body parts were examined. The effects of design, metallic surface coatings, and

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Table 1—Characteristics of the Precoated Steel Materials Tested

		Coating			
		Metallic		Organic	
Industry	Code	Type	Thickness (μm)	Type Primer/Topcoat	Thickness (μm)
Building	A	55% Al-Zn (150 g m^{-2})	20	—	
	HDG	Hot-dip galvanized (225 g m^{-2})	20	—	
	CC1	Hot-dip galvanized (225 g m^{-2})	20	Polyurethane/ polyester	5/20
	CC2	Hot-dip galvanized (225 g m^{-2})	20	Polyurethane/ special polyester	5/20
	CC3	Hot-dip galvanized (225 g m^{-2})	20	Epoxy/ PVDF	5/20
	GP	55% Al-Zn (190 g m^{-2})	25	Epoxy/ polyester	5/30
Automotive	EG	Electrogalvanized (18 g m^{-2})	5	—	
	GA	Galvanneal (56 g m^{-2})	10	—	

treatment with antirust agents were studied.[3] The highest frequency of corrosion attack was observed on crevice surfaces at the spot-welded joints in the rocker panel and the rear wing/wheel well. Therefore, more than 10% (rocker panel) and 16% (rear wing/wheel well) of the inspected surfaces showed heavy corrosion. On the other hand, the open surfaces in the rocker panels were much easier to protect against corrosion compared to the crevice surfaces.

Researchers have considered a broad variety of experimental conditions and test specimens constructed by overlapping pairs of sheets which are then joined by spot welding,[4-6] rivets,[7] or screws.[8]

The tests used by the automotive industry to assess corrosion resistance have not been universally accepted.

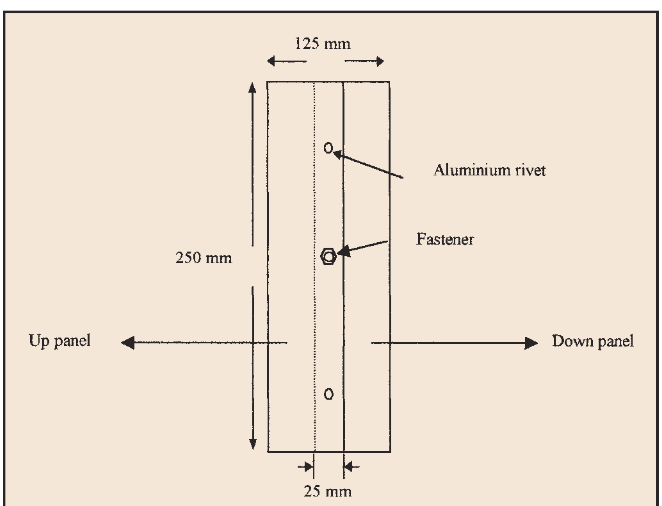

Figure 1—Lapped specimen used for atmospheric tests.

Roudabush and Dorsett[9] published a review in which they describe different methods used to assess corrosion in lapped areas with a recommended specimen type.[6] The tests described consist of exposure to a single environment (such as salt fog or immersion) or cyclic tests with exposure to two or more environments (salt fog, immersion, drying, humidity, ice, etc.).

Tests in climate cabinets are the most commonly used laboratory tests in the automotive industry, and the salt fog test (ASTM B117[10]) has been used almost exclusively for many years. However, there is controversy about the validity of this test, since the corrosion mechanisms that it triggers can differ from those which occur in practice.[11]

For years, the automotive industry's research was guided by the aforementioned ASTM standard B117[10] without obtaining realistic results. Therefore, since the 1980s, the industry has been carrying out different studies focused on developing tests that are more complex but are closer to the natural test,[12,13] i.e., cyclic corrosion tests (CCT), which more adequately simulate

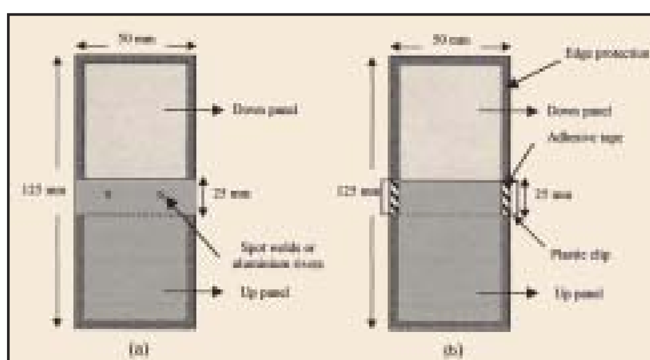

Figure 2—Lapped specimens used for accelerated tests.

Table 2—Results of the Atmospheric Exposure Tests after Two Years of Exposure Time in Madrid and Avilés Test Sites

Test Site	Material	Codes	Nonlapped Zone	Lapped Zone
Madrid	55% Al-Zn	A	Loss of shine and generalized darkening	Without significant alteration
	Hot-dip galvanized	HDG	Loss of shine and generalized darkening	Darkening of the surface (80%). White corrosion of isolated zones of the surface.
	Painted hot-dip galvanized	CC1	Without significant defects	Without significant defects
	Painted hot-dip galvanized	CC2	Without significant defects	Without significant defects
	Painted hot-dip galvanized	CC3	Without significant defects	Without significant defects
	Painted 55% Al-Zn	GP	Without significant defects	Without significant defects
	Electrogalvanized	EG	Generalized darkening. Slight rusting at edges	Darkening of the surface (80%). White corrosion of isolated zones of the surface.
	Galvanneal	GA	Generalized darkening	Darkening of the surface (90%). White corrosion (less than in EG) of isolated zones of the surface.
Avilés	55% Al-Zn	A	Loss of shine and generalized darkening	—
	Hot-dip galvanized	HDG	Loss of shine and generalized darkening	—
	Painted hot-dip galvanized	CC1	Without significant defects	Without significant defects Adhered soiling
	Painted hot-dip galvanized	CC2	Without significant defects	Without significant defects Adhered soiling
	Painted hot-dip galvanized	CC3	Without significant defects	Without significant defects Adhered soiling
	Painted 55% Al-Zn	GP	Without significant defects	Without significant defects Adhered soiling
	Electrogalvanized	EG	Darkening. Corrosion at edges, which increases with time Generalized rusting	Darkening. White corrosion on isolated zones of the surface.
	Galvanneal	GA	Darkening. Corrosion at edges (less than in EG)	Darkening. White corrosion on isolated zones (less than EG)

natural aging. Thus, each automobile company has developed its own "multifunction" corrosion cycle,[14] and the current tendency is to replace salt fog tests with this type of cyclic test. These tests incorporate salt fog exposure periods, according to ASTM B117,[10] high humidity stages, and high temperature drying periods. Most CCTs start with exposure to salt fog, for a time that can vary from 10 min to two, four, six, and 24 hr, followed by periods of high humidity (95-100%) at high temperature (50°C), and finally a drying cycle in which the humidity is lowered to 30% and the temperature is raised to 60°C. The exact details vary from one CCT to another, but all are based on the same principle of salt fog, humidity, and drying cycles.

Under confined conditions, it has been shown that three important corrosion testing parameters, the wet-dry time ratio, the amount of salt dosage, and the temperature, have significant influence on the corrosion performance of zinc-coated steel.[15] During the wet-dry periodic exposure with a short drying phase (less than 11 hr), a highly alkaline environment is formed in the confined area, resulting in a high rate of dissolution of zinc.[16] An increase in the drying time leads to the neutralization of the alkalinity in the confined area and consequently to the formation of protective layers. A comparison between the results from field exposures and those from laboratory exposures has shown that a cyclic corrosion test with a longer drying phase can better simulate the field exposure that leads to perforation corrosion.[15] It is extremely important to allow the crevice to dry thoroughly when cyclic corrosion tests for the perforation corrosion evaluation of precoated steels are designed. On the other hand, a higher temperature leads to a much lower degree of macro-wetness during the drying phase, but to a higher corrosion rate during the humid phase.[15]

The authors of this work have previously carried out a study of the factors that influence the corrosion behavior of precoated steel sheets in lapped areas.[17-19] By using conventional accelerated tests,[17,18] the response obtained showed a delay in the deterioration of the lapped area compared with the nonlapped area, a result that is not in keeping with what really happens in aggressive atmospheres and other real situations, a fact that is recognized in the literature.[20] In this article, the results obtained by applying the Prohesion test to lapped speci-

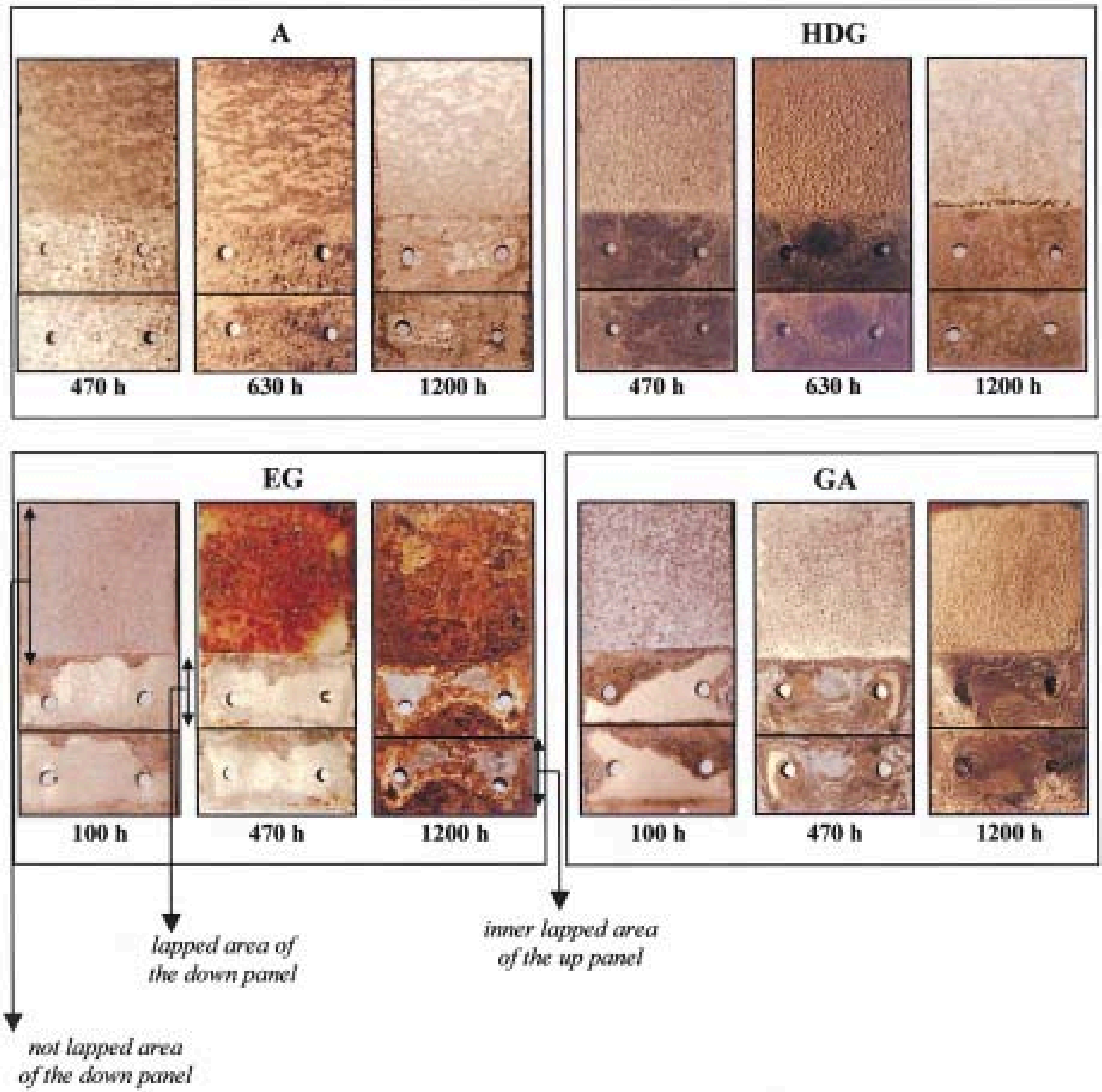

Figure 3—Aspect of metallic coatings, in lapped and nonlapped areas (after dismantling of lap-joint), following withdrawal from Prohesion test after different times.

mens are included. It is shown that conventional accelerated corrosion tests do not adequately simulate the relatively rapid corrosion failure of lap-joints. Likewise, for comparison purposes, data of atmospheric exposure are also presented. However, the testing sites, Madrid and Avilés (in Spain), were not aggressive enough, and the deterioration caused on the materials was insufficient to obtain real exposure data.

In order to reproduce in the laboratory the sequence of phenomena that occurs in practice and which leads to an acceleration of the attack of the material inside the lap-joint, the following cyclic test was carried out: (a) filling the lap crevice with water, as occurs, e.g., during an episode of rain or dew, or humidity capillary condensation due to the crevice itself, by exposing specimens in a humidity condensation cabinet; (b) contaminating the water retained inside the crevice with chloride ions by exposing specimens in a salt fog cabinet; (c) retention of the liquid in the crevice for a long time depending on the relative humidity and ambient temperature, by placing the specimens inside a climate cabinet; and (d) drying period, leaving the specimens to the laboratory atmosphere.

The cyclic test is presented in this article with the aim of adequately simulating what occurs in practice in this type of joint. By applying this test, premature deterioration in the lapped area compared with the nonlapped area is obtained.

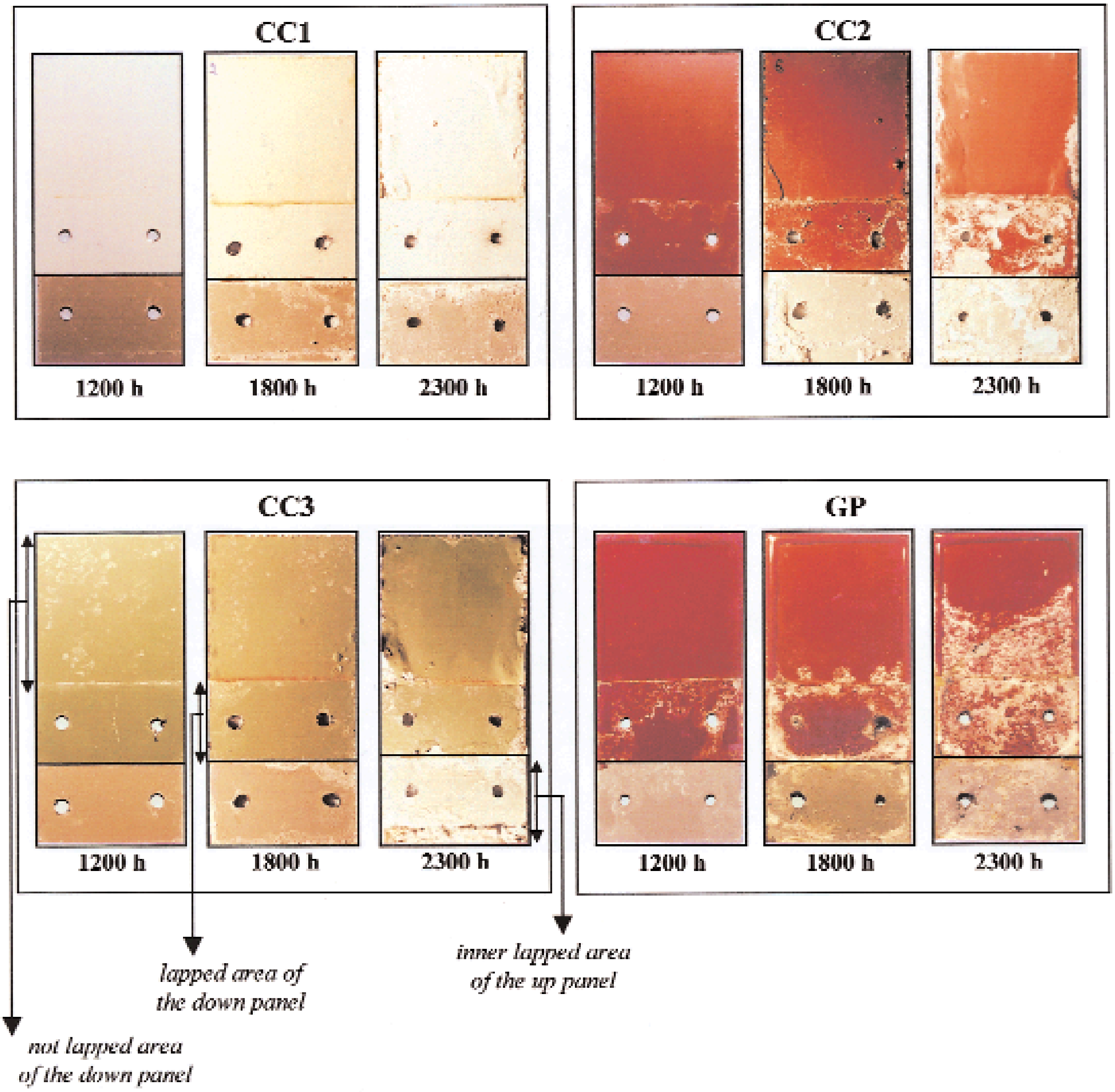

Figure 4—Aspect of mixed (metallic + organic) coatings, in lapped and nonlapped areas (after dismantling of lap-joint), following withdrawal from Prohesion test after different times.

For comparison purposes, the cyclic test was also carried out with the VDA 621-415 cycle,[21] a specification based on accelerated aging tests for anticorrosive coatings in the automotive industry that also uses a specimen design which includes a lapped area.

EXPERIMENTAL

Materials

Table 1 indicates the characteristics of the coatings employed and their identification codes. Both protective metallic and mixed (metallic + organic) coatings on steel substrates were evaluated: 55% Al-Zn (A), hot-dip galvanized (HDG), electrogalvanized (EG), galvanneal (GA), prepainted galvanized (CC1, CC2, and CC3) and prepainted 55% Al-Zn (GP).

Panels were evaluated using two methods: atmospheric exposure and accelerated laboratory tests.

Panel Design

OUTDOOR EXPOSURE TEST*:* For this type of test the lapped panel designs shown in *Figure* 1 were used. Initially, test specimens were obtained in the form of single 75 × 250 mm panels. Lapped specimens were assembled by vertically overlapping pairs of panels by 25

Table 3—Summary of the Results Obtained in the Prohesion Test for the Metallic Coatings

Material	Zone	A	B	C
EG	NL	<24 hr	200 hr	200-268 hr
	L	<100 hr	300-470 hr	470 hr
GA	NL	<24 hr	1500 hr	1700 hr
	L	<100 hr	>1800 hr	
HDG	NL	<24 hr	1200 hr	>1800 hr
	L	<100 hr	1800 hr	>1800 hr
A	NL	~300 hr	>2300 hr	
	L	~470 hr	2300 hr	

NL: nonlapped area; L: lapped area
A: appearance of white corrosion; B: appearance of first points of rust; C: consistent rust

mm. Lapped pairs were joined by spot welding or aluminum rivets and fasteners, for automotive or building materials, respectively. The specimens were exposed to the atmosphere with the overlap running vertically, with the left part over the right, following the criteria of the European Coil Coating Association (ECCA).[22]

Accelerated Tests: The lapped panel design used to carry out the accelerated tests is illustrated in *Figure* 2.

Specimens of 125 × 50 mm were formed by lapping single plates of 75 × 50 mm taken from coils manufactured by continuous strip processes, leaving a lap length of 25 mm (lapped/nonlapped area ratio of 0.25). Lapped pairs were joined by spot-welding (automotive materials) or aluminum rivets (building materials) spaced at 30 mm intervals (*Figure* 2a). In the case of mixed coatings (metallic + organic), the two parts of the specimen were lapped in such a way that the topcoat paint layer of one part was in contact with the primer paint layer of the other.

Another series of panels was prepared in order to assess the attack of the materials in the presence of a crevice of a known width inside the lap-joint (with spot-welding and riveting, the lap separation is theoretically 0 mm). The crevice width was established by applying lengths of adhesive tape at the side edges of the lap, and the lapped panels were fastened together by means of plastic clips (*Figure* 2b). The tested crevice width was 200 µm. The use of plastic clips allowed the rapid assembly and disassembly of the lap-joint in order to monitor the evolution of deterioration inside the crevice and to determine the most suitable specimen withdrawal times in the accelerated test.

The specimen design used in the Prohesion test was like that shown in *Figure* 2a, but without protection at the edges, as happens in practice. Specimens with a controlled crevice width were not used in this accelerated test.

The specimens were placed in the testing cabinets with the lap in horizontal position and the lap opening facing upwards, favoring the penetration of aggressive agents from the medium into the lap-joint crevice.

Methodology

Atmospheric Corrosion Tests: The tests were carried out in the test sites of Madrid (corrosivity category according to ISO 9223: C2) and Avilés (corrosivity category according to ISO 9223: C4). The exposure tests were carried out according to ISO 8565.2. The test specimens were exposed for two years.

Prohesion Test: The methodology consisted of cycles of one hour of salt fog projection followed by one hour of drying. The cabinet temperature was 30 ± 5ºC. The saline solution contained 4 g/l $(NH_4)_2SO_4$ and 0.5 g/l NaCl.

New Cyclic Tests: A series of preliminary tests was carried out, using an electrogalvanized material whose low zinc coating thickness gave the earliest appearance of rust due to consumption of the metallic coating and corrosion of the base steel. The preliminary tests also included a study of the effect of the crevice width: 0 µm (in contact); 100 µm; and 200 µm, on the corrosion process inside the lap-joint.

The preliminary weekly cycles consisted of: (a) four, eight, or 24 hr of salt fog; (b) humidity: remaining time up to five days. In a constant humidity condensation cabinet or in a climate cabinet (20ºC and 95% RH); and (c) drying: two days in laboratory conditions.

Another preliminary cycle was tested, changing the sequence of the different stages so that the first stage was 24 hr of constant humidity condensation, in order to favor the complete penetration of water throughout the lap-joint before the salt fog stage.

In view of the preliminary results, a specific accelerated corrosion test was carried out to reproduce what normally occurs in practice, i.e., premature degradation of the material inside the lap-joint. The weekly test consisted of: (a) one day of constant humidity condensation according to ASTM D 4585[23]; (b) eight hours of salt fog according to ASTM B117[10]; (c) 88 hr in a climate cabinet at 20ºC and 95% RH; and (d) two days at room temperature and RH.

VDA Cycle: The tests were carried out in parallel with the VDA 621-415 cyclic test,[21] modified slightly to avoid visiting the laboratory during the weekend. The weekly cycles consisted of: (a) one day of salt fog according to ASTM B117[10]; (b) four days of humidity condensation according to KFW DIN 50017.[24] Each day consisted of eight hours of heating with the cabinet door closed (humidity stage), followed by 16 hr without heating and with the cabinet door open (drying stage). The final day consisted of four hours of drying instead of the 16 hr indicated by the standard; and (c) 2.5 days of drying in laboratory conditions, instead of the two days indicated by the standard.

RESULTS

Outdoor Exposure Tests

Table 2 indicates a brief summary of the results obtained in the atmospheric tests. Given the moderate aggressiveness of the atmospheres where the study was carried out, two years of exposure was an insufficient amount of time to cause an important level of degradation of the materials tested and, consequently, to reach definitive conclusions about their behavior in lap-joints.

Prohesion Test

The tests had a total duration of 2300 hr. *Figure* 3 displays photographs showing the state of the metallic coatings after different testing times. *Table* 3 presents a summary of the results obtained for the metallic coatings, indicating the times taken for white corrosion and rust to appear, differentiating between observations in the lapped (L) and nonlapped (NL) areas.

As can be seen in *Figure* 3, there was a certain delay in the deterioration of the lapped area compared with the nonlapped area. The deterioration of the material in the lapped area was not uniform. It was common to observe zones in the lapped area that remained intact at the end of the tests, without any attack being initiated. The attack that occurred in the lapped area was initiated in peripheral zones, and in time, progressed towards the interior in the form of ripple mark waves.

Figure 4 illustrates the state of the different mixed (metallic + organic) materials after different exposure times to the Prohesion test. *Table* 4 presents a summary of the results obtained for the mixed coatings (cross-sections of the material were prepared and SEM observations were made).[17]

With both prepainted galvanized (CC1, CC2, CC3) and prepainted 55% Al-Zn (GP) materials, deterioration was first initiated in the lapped area of the plate treated only with primer paint (inner zone of the top panel in

Table 4—Summary of the Results Obtained in the Prohesion Test for the Mixed Coatings

Material	Zone		Exposure time, hr: 1800	2300
CC1	Primer side	NL	—	
		L	Corrosion of the metallic coating which promotes blistering of the paint layer, which may fracture and cause detachments of the organic coatings	Corrosion progresses in intensity and extension as testing time increases. After this time, consumption of the galvanized coating has occured and the organic coatings is detached
	Fully painted side	NL	This zone is presented in a good state, except for the edges which were not protected in which delaminations of the paint system appear	
		L	Without significant defects	Slight corrosion of the galvanized coating giving rise to detachments of the film
CC2	Primer side	NL	—	
		L	Notable attack of the galvanized coating and detachment of the paint coating	Great attack of the galvanized coating which causes a total deterioration of the paint coating
	Fully painted side	NL	This zone is presented in a good state, except for the edges which were not protected, in which delaminations of the paint system appear.	
		L	Corrosion of the galvanized coating on isolated zones which promotes slight blistering of the organic coating	Great attack of the galvanized coating which causes a total deterioration of the paint coating
CC3	Primer side	NL	—	
		L	Corrosion of the metallic coating which promotes blistering of the paint layer	Great attack of the galvanized coating which causes a total deterioration of the paint coating
	Fully painted side	NL	This zone is presented in a good state, except for the edges which were not protected, in which delaminations of the paint system appear	
		L	Blistering of the organic coating on isolated zones	Better behavior than the panel treated only with primer although detachments of the organic coating have also occurred
GP	Primer side	NL	—	
		L	Great attack which had already begun after 470 hr	Deterioration is initiated in the lap zone and extends below the organic coating, affecting the nonlapped zone to a great extent. The attack is concentrated in the interdendritic regions, reaching the base steel
	Fully painted side	NL	Without significant defects	Deterioration on a great extent
		L	Deterioration on isolated zones	Blistering of the organic coating giving rise to detachment of the film

NL: nonlapped area; L: lapped area.

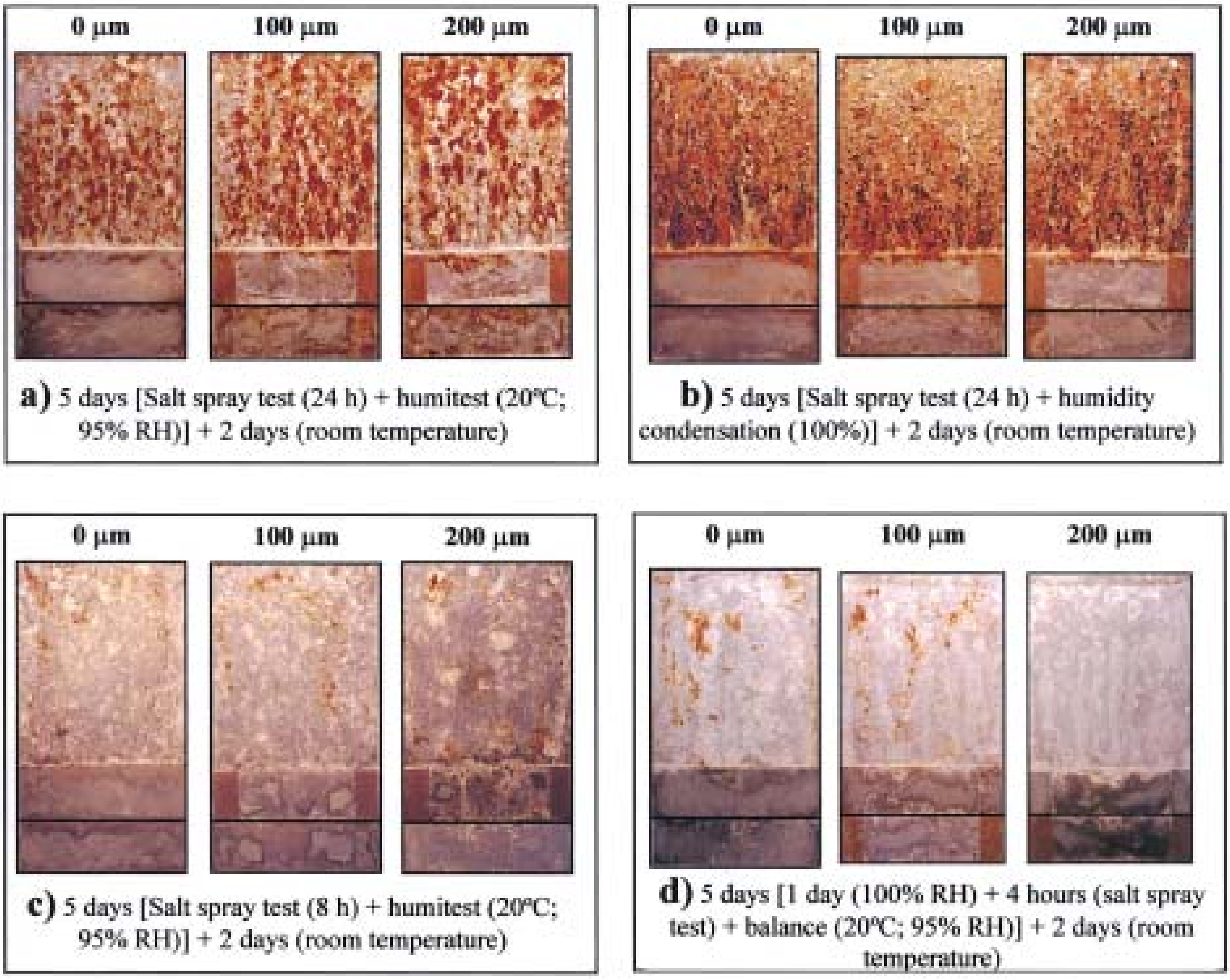

Figure 5—Aspect of electrogalvanized steel lap-joint exposed for two cycles to four (a, b, c, and d) different cyclic test configurations after dismantling of lap-joint.

Figure 4) and took the form of corrosion of the metallic coating, promoting the blistering of the paint layer, and in turn, its fracturing and detachment. The attack initiated in the lapped area, advanced towards the nonlapped area, and progressed below the paint film.

The panel treated with the complete paint system showed a better behavior. Nevertheless, after longer testing times (2300 hr) this can also deteriorate, giving rise to detachments of the film.

The nonlapped zone in CC1, CC2, and CC3 materials is presented in a good state, except for the edges which were not protected, in which delaminations of the paint system appeared.

New Cyclic Tests

Preliminary Tests: *Figure* 5 presents a summary of the results obtained after two preliminary weekly testing cycles:

(1) In *Figures* 5a and b it can be seen that 24 hr of salt fog was an excessive time and that the greatest attack appeared in the nonlapped area.

(2) The attack in the lapped area seemed to be more intense with the climate cabinet humidity stage at 20°C and 95% RH (*Figure* 5a) than in constant humidity condensation (*Figure* 5b).

(3) A reduction in the fog time from 24 to eight hours (*Figure* 5c) confirmed this supposition. However, observation of the lap-joint showed that numerous zones of the metallic coating continued to be intact, as the electrolyte had not reached the entire interior of the crevice.

(4) In a new cycle, the sequence of the different stages was changed to make the first stage 24 hours of constant humidity condensation, in order to achieve complete penetration of water throughout the lap-joint before a second stage of four hours of salt fog (instead of eight hours). *Figure* 5d shows the intensification of the attack in the lap-joint with this cycle configuration.

New Cyclic Test and VDA Cycle: Two, four, and six cycles were carried out with the electrogalvanized (EG) and galvanneal (GA) materials, and 2, 4, 6, 10, and 20 cycles with the rest of the materials tested.[17] *Figure* 6 shows the state of the tested metallic coatings in lapped

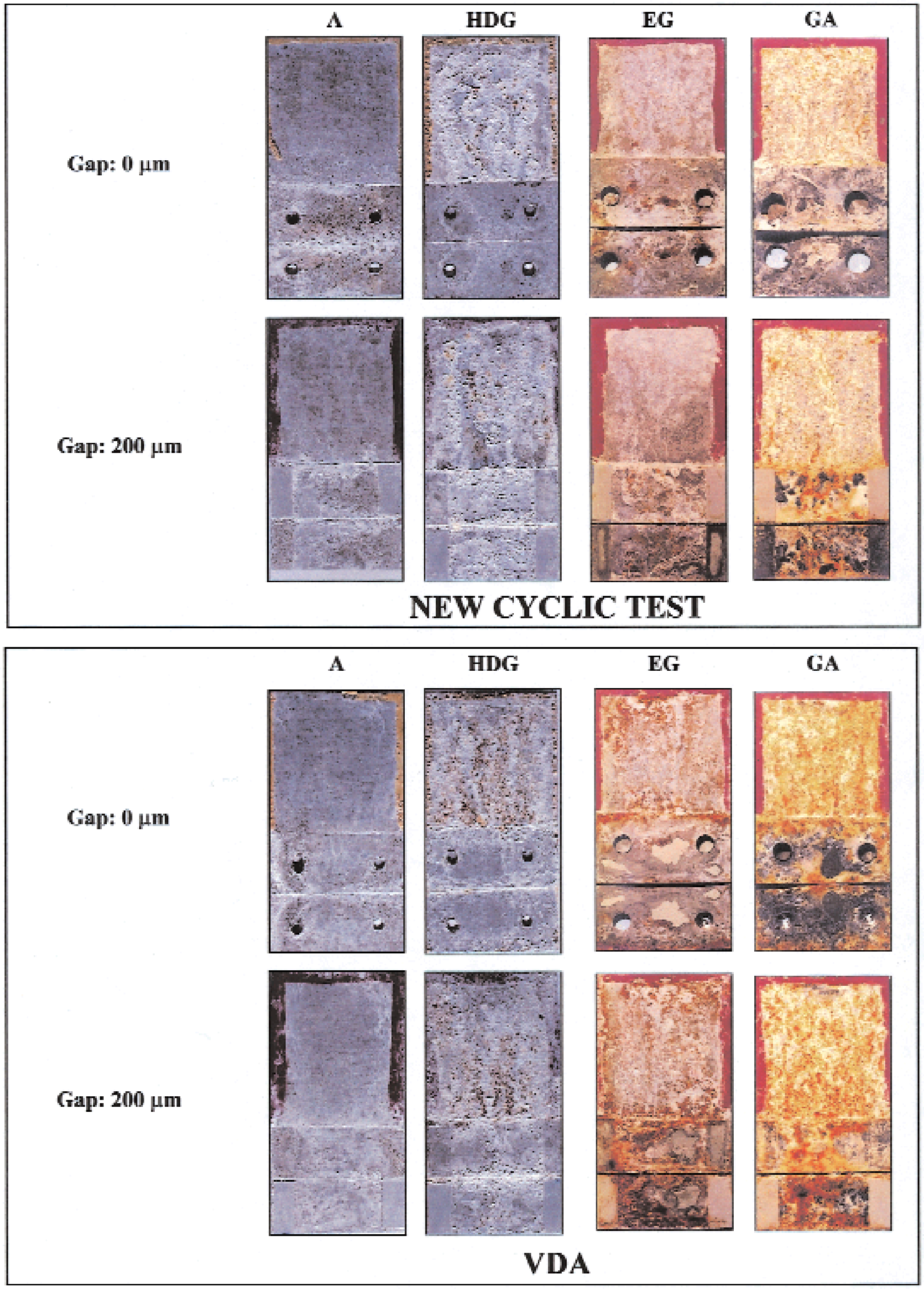

Figure 6—Aspect of metallic coatings, in lapped and nonlapped areas, after exposure to two (EG and GA) and 10 (A and HDG) cycles of the new and VDA cyclic tests, following dismantling of lap-joint.

and nonlapped areas after 10 new tests and VDA cycles (for EG and GA materials the state after two cycles is shown). *Figure* 7 shows the state of the mixed coatings after 10 cycles [prepainted galvanized (CC1, CC2, and CC3) and prepainted 55% Al-Zn (GP) materials].

As can be seen in *Figure* 6, in the case of 55% Al-Zn (A) and hot-dip galvanized (HDG) materials, 10 testing cycles was a sufficient amount of time to evaluate their behavior. Both the new test and VDA cycle promoted a notable attack of the materials in the lapped area, more (A) or less (HDG) than in the nonlapped area.

For the EG and GA materials, two cycles was a sufficient amount of time to evaluate their behavior. However, the new cyclic test showed the differences in

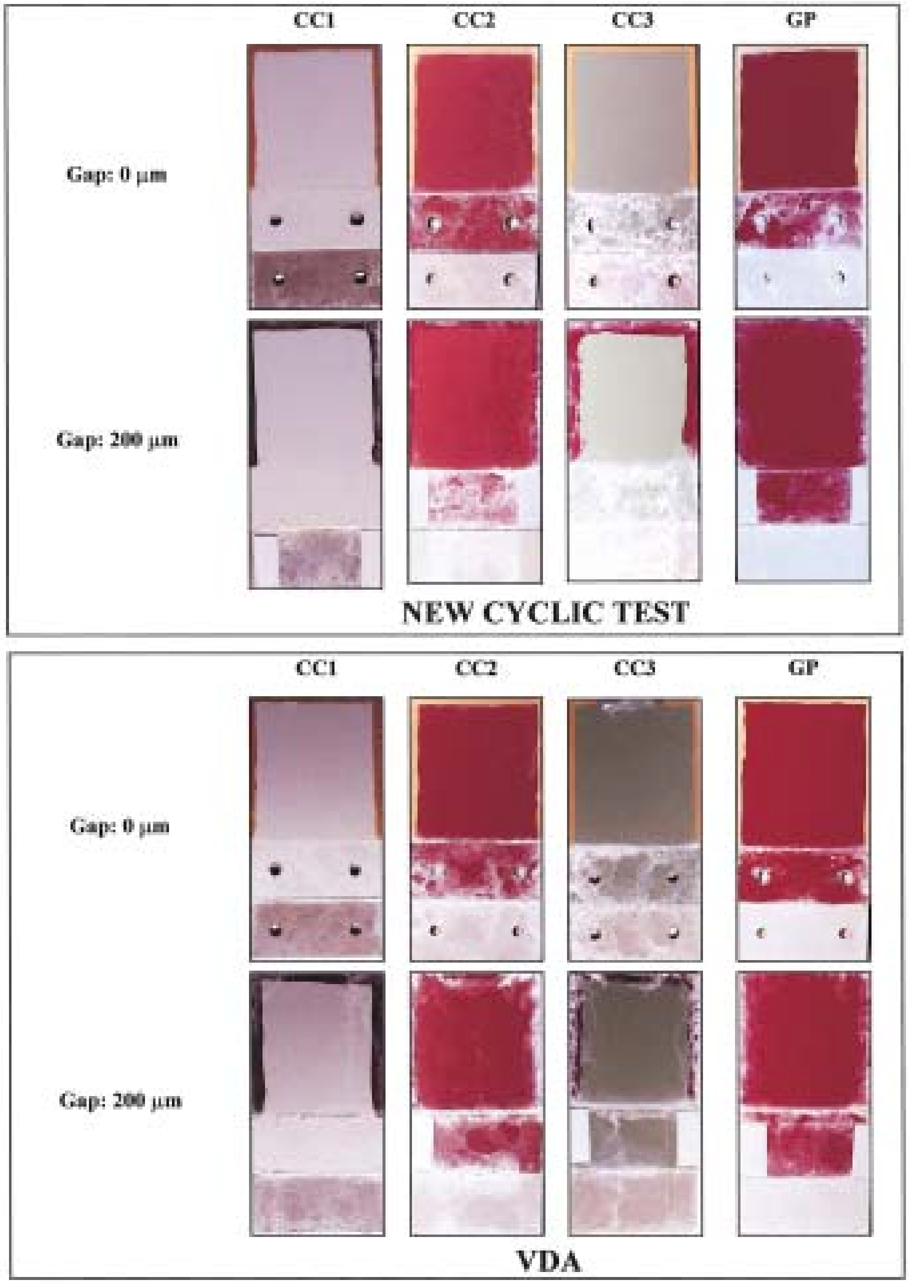

Figure 7—Aspect of mixed coatings, in lapped and nonlapped areas, after exposure to 10 cycles of the new and VDA cyclic tests, following dismantling of lap-joint.

behavior between lapped and nonlapped areas better than the VDA cycle, particularly with the electrogalvanized material.

For the mixed coatings, both cycles also promoted greater attack in the lapped area than in the nonlapped area, and 10 cycles was a sufficient amount of time to evaluate their behavior.

In general, a crevice width of 200 μm contributed to a greater attack of the material in the lapped area, particularly with the galvanized materials [painted (CC1, CC2, CC3) or unpainted (HDG)]. With the 55% Al-Zn material [painted (GP) or unpainted (A)], deterioration in the lap zone was accelerated when the panels were in contact by means of riveting.

DISCUSSION

In the outdoor exposure test, two years was an insufficient amount of time to cause an important level of degradation of the materials, although, in general, the degradation of the coatings was greater in the lapped zone than in the nonlapped zone, the attack being initiated in the lapped zone in the vicinity of the lap openings. In the case of the metallic coatings, the best behavior was observed with the 55% Al-Zn material. This material appeared unaltered after two years, conserving its initial shine. In the case of mixed coatings, the materials tested were seen to be without significant defects, with two years having been an insufficient amount of time for significant differences to be observed between the different coatings.

In the Prohesion test, it was observed with regard to the metallic coatings that in general these materials were attacked more often and earlier in the freely exposed zone (nonlapped area) than in the lapped area. The delay in the attack of the material in the lap-joint crevice was due to two main causes: (a) excessive attack of the coating on the surface freely exposed to the aggressive medium of the testing cabinet as a result of the aggression of the medium, and (b) blocking of the lap openings due to the accumulation of corrosion products from the attack of the coating in the freely exposed area and at the unprotected edges of the test specimen.

Thus, it was of technological interest for the testing of materials in lap-joints to develop an accelerated laboratory test for lap-joints which reproduces what normally occurs in practice, i.e., premature degradation of the material in the lap-joint, both for metallic coatings and for mixed coatings (metallic and organic).

The philosophy that inspired the development of this test on lap-joint corrosion was based on the following premises: (a) the test should promote an acceleration of the attack of the material in the interior of the crevice formed by the lap-joint; (b) the test should be sufficiently aggressive and should not cause an excessive delay in the degradation of the material in the lapped area compared with the deterioration in the nonlapped area; and (c) the test should be applicable to a wide range of coating materials.

Thus, an attempt was made to reproduce in the laboratory the sequence of phenomena that occurs in practice and which leads to an acceleration of the attack of the material inside the lap-joint: (a) filling the lap crevice with water, as occurs, for example, during an episode of rain or dew or humidity capillary condensation due to the crevice itself; (b) retention of the liquid in the crevice for a long time, depending on the relative humidity and ambient temperature; and (c) a drying period. A study carried out by the authors[25] has determined the influence of the crevice dimensions and environmental conditions on the time of wetness after each period of time that the crevices remain active after being saturated with electrolyte. According to this study, moisture retention inside the 100-300 µm crevices may range from days or even weeks (RH 95%) to just a few hours (RH 60%), depending on the environmental RH. The retention of moisture inside the lap is the main cause of the premature deterioration of materials in this type of joint. In humid atmospheres, the electrolyte is maintained for a much longer time in the interior of the crevices than outside them, allowing corrosion processes to take place, at times for months, after each wetting. Consequently, the corrosion processes are initiated earlier and are much faster on occluded surfaces than on those outside the lap.[26,27]

To the previous sequence of stages, a second stage of salt fog was added with the aim of increasing the aggressiveness of the solution in the crevice (in the case of marine atmospheres). An appropriate balance of the duration of these four stages should produce the desired results.

Thus, the test cycles determined had the following basic configuration:

(a) Filling the lap with distilled water, by exposure of the specimens for one day in a humidity condensation cabinet.

(b) Sodium chloride contamination of the water retained in the lap crevice. This was achieved by exposing the specimens in a salt fog cabinet. The duration of this stage can be critical in terms of anticipating the attack of the material in the lapped area. The optimum duration was between four and eight hours. A longer duration of this stage, one day in the case of the VDA cycle used for comparative purposes, led to early deterioration of the material in the nonlapped area, contrary to the desired effect, and slightly accelerated the aggressiveness of the test.

(c) Prolonged retention of the saline solution in the lap crevice. This was achieved by placing the specimens inside a climate cabinet and maintaining the temperature and relative humidity at 20°C and 95% RH, respectively.

(d) Drying of the lap by exposing the specimens over the weekend to the laboratory atmosphere (23°C, 50% RH).

The new cyclic test, thus designed, gave highly satisfactory results. In comparison with the reference cycle (VDA 621-415),[21] which follows a similar configuration, it presents the following advantages and disadvantages:

(1) Both tests are considered suitable for simulating in the laboratory the behavior of materials in lapped areas.

(2) The VDA test is slightly more aggressive than the new cyclic test (even though the former triples the salt fog time of the latter), making it somewhat more accelerated, though this does not suppose an important reduction in the number of cycles necessary to evaluate the behavior of materials in lap-joints. At the same time, and as a disadvantage, it leads to the situation where the differences in behavior between the lapped and nonlapped areas of the different materials are not so clearly shown as in the new cyclic test.

(3) A possible disadvantage of the new cyclic test compared with the VDA test is that the former requires three cabinets while the latter needs only two.

With regard to the shape and dimensions of the test specimens used in this experimentation, these are considered to have been adequate. As will be remembered, the specimens of 125 × 50 mm (*Figure* 2) were formed by lapping single plates of 75 × 50 mm taken from coils manufactured by continuous strip processes, leaving a lap length of 25 mm (lapped/nonlapped area ratio of 0.25).

It is imperative to protect the edges of the specimens in the nonlapped regions. The lap configuration obviously makes it impossible to protect the edges of the lapped region. Failure to protect the specimen edges implies the following adverse effects on the test: (a) early corrosion of the coating and/or the base steel at the specimen edges, detachment of the corrosion products, and staining of the nonlapped surface of the specimens causes the blocking of the lap openings, hindering (or preventing) the entrance of the aggressive medium, and, thus, delaying (or impeding) the deterioration of the material inside the lap-joint, and (b) premature delay of the coating in the proximity of the edges, which can affect a large percentage of the testing surface, also making it difficult to evaluate the behavior of the material in the lapped region.

The attack of the material inside the lap increases with the lap separation. A crevice width of 200 µm can be sufficient for this purpose. The crevice width can be established by sticking lengths of adhesive tape at the side edges of the lap and securing the lap-joint by means of plastic clips (*Figure* 2). In the case of passive materials (aluminum and its alloys, stainless steel, etc.) it is not advisable to increase the crevice thickness if one wishes to cause their failure. In these cases, spot welding or riveting is preferable, as these facilitate the deoxygenating of the crevice and promote the deterioration of the material in the lapped area.

CONCLUSIONS

A weekly cyclic test which adequately simulates the negative effect presented in practice by lap-joints in aggressive atmospheres is appointed. This test presents the following four-stage configuration: (a) constant humidity condensation, for 24 hr; (b) sodium chloride contamination of water retained in the lap for eight hours; (c) retention of saline solution in the lap for 88 hr (20ºC and 95% RH); and (d) drying of the specimens by exposure to the laboratory atmosphere (23ºC and 50% RH) over the weekend.

The VDA test is slightly more aggressive and, thus, more accelerated than the new cyclic test. The differences in behavior between the lapped and nonlapped areas of the different materials are more clearly shown in the new cyclic test than in the VDA test.

A lap separation of 200 µm contributes to a greater attack of the material in the lapped area compared with spot-welded joints (lap separation 0 µm). On the other hand, for the 55% Al-Zn material, deterioration in the lap zone is accelerated when the panels are placed in contact by means of riveting.

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