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Research Article

The Cathodic Breakdown Test to Assess Chromic Acid Anodized Aluminum Alloys Corrosion Protection Performance, in Correlation with Salt Spray (Fog) Testing

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The corrosion protection performance of chromic acid anodized (CAA) coating, applied on aerospace aluminum sheets is determined by the Cathodic Breakdown Test (CBT). The results were compared to those obtained with the classical salt spray test using the standard ASTM B117. A clear experimental procedure was developed to describe this non-standardized test, leading to the conclusion that the CBT results correlate well with those of the salt spray tests. All the sealed samples, which fail in CBT test, also fail in salt spray. The CBT was not identified as a useful tool to differentiate different types of unsealed aluminum bare samples. The CBT failure criteria set was successfully used in the identification of sealed sample failures from salt spray tests. The sealing performance of the sample was correlated to the CBT test parameters. The CBT test lasted at least 2000 times less long than the salt spray test. Furthermore the utilization of a relevant experimental procedure of the CBT testing method is an interesting way to lower significantly the testing time of the evaluation of corrosion protection performance of sensitive coated aerospace materials in comparison to the salt spray method.

1. Introduction

The salt spray test based on the international standard ASTM B117 is one of the most widely used proof tests for evaluating corrosion protection provided by organic and inorganic coatings on metals. This test is frequently quoted in specifications as a quality control tool [1, 2].

Many benefits are offered by salt spray test, including standardized protocols for conducting the exposure, evaluating the results, and procedural simplicity. However, it has been strongly criticized, in the literature, for its lack of reproducibility from one test chamber to another, failure to predict service performance, results dependence to the operator, and its inability to provide easily a quantitative measure of corrosion damage [3].

Long-term salt spray tests are considered as the reference, regardless of their limitations and their time-consuming nature. In the end, they are the ultimate criterion in the aerospace industry.

On the other hand, the Cathodic Breakdown Test (CBT) is an electrochemical test, which involves—in its original form—a cathodic polarization to -1.6 V versus a saturated calomel electrode (SCE) for a period of 3 min in acidified sodium chloride (NaCl). The test was designed for anodized aluminum alloys because the alkali created at the large applied currents promotes the formation of corrosion spots on the defects in the anodized film [4, 5].

The CBT has been used in the aeronautical industry for about 15 years (from 1978 to 1993) on an informal basis to evaluate process shifts of chromic acid anodized aluminum coatings [6]. The collected CBT data appeared promising enough to evaluate the correlation between this test results and the salt spray data on a pass/fail basis. An experimental method was put in place to evaluate the corrosion resistance

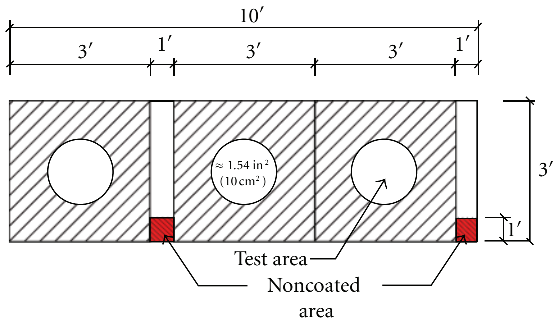

Figure 1: Samples dimensions and coating free area position used in the cathodic breakdown test. The numbres indicate the size in inches of each part of the samples.

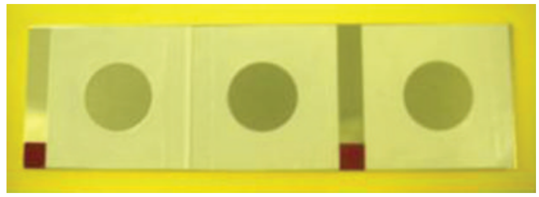

Figure 2: Image of the active sample including the maskholes and coating free areas used in the cathodic breakdown test.

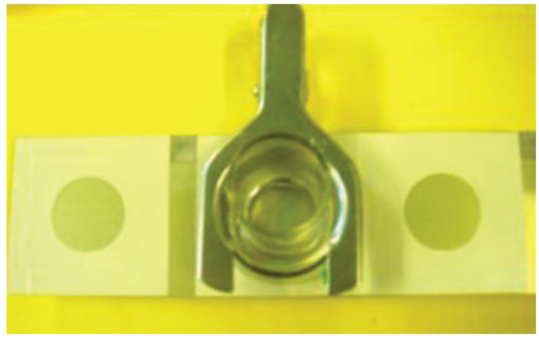

Figure 3: Image of the glass tube of the electrochemical cell clamped to the sample with O-ring seal.

performance of a typical chromic acid anodizing process. Sixteen variables were identified and arranged in a 2^{16-11} fractional factorial experiment, including sealing bath time. For each design point, 4 samples were tested in salt spray, and one equivalent sample was evaluated with CBT. At the end, 63 tests were conducted [7]. Two parameters of the CBT were used to establish the correlation: (1) the time to rapid current increase or "break time" (B_t) and (2) the time to reach $-250\,\mu$A for 0.62 inch diameter surface (T_{250}).

According to the reference procedure, the parameters to correlate CBT data with salt spray results were the break time B_t and T_{250}, and the salt spray score for a particular design point was the average failure time of the tested panels [7, 8]. The CBT is characterized by two parameters. B_t is the time in seconds of the rupture initiation. T_{250} is the time in seconds to get a current of -250 microamperes or $i = -128$ mA/cm^2. This last parameter is also known as the propagation rate of the rupture.

The correlation criteria were that all salt spray failures can be identified if $B_t < 15$ seconds (s) and $T_{250} < 55$ s or when the $\mathrm{CBT}_{\mathrm{combined}}$ (sec) < 15 s with $\mathrm{CBT}_{\mathrm{combined}}$ being a combination of the two parameters expressed by the following formula [7, 8]:

$$\mathrm{CBT}_{\mathrm{combined}} = 0.2 * T_{250} + 0.8 * B_t. \qquad (1)$$

Based on the 63 tests performed in [7], 10 of 10 samples which fail salt spray also fail CBT tests and from 53 samples which pass salt spray tests, 50 samples pass CBT tests, although three samples which pass salt sprays tests fail CBT tests. But all the samples which fail according to salt spray also fail CBT tests. But we may point out that some samples (3 in the case studies [7, 8] over 53) which pass salt spray tests fail from CBT tests.

It was concluded that the CBT results correlate well with those of the salt spray. Furthermore, it was indicated that the CBT gives quantitative data within 10 min [8], whereas results from salt pray cannot be obtained before at least hundreds test hours have elapsed.

In the experiments in [7, 8], the tested samples were based on two different sealing times, 23 and 28 minutes. Unfortunately, the effect of the sealing time for each set of samples on the CBT results was not indicated and this difference of time in the sealing quality was considered as negligible.

This work is devoted to the systematic study of the correlation between the CBT and the salt spray results developed on industrial aerospace materials based on chromic acid anodized (CAA) coatings applied to aluminum with well-known high differences of sealing times (10 to 50 minutes) for each set of samples. A large range of sealing performances and times and two sealing procedures are evaluated.

The ultimate objective of this long-term project is the development of a new testing method based on CBT for the evaluation of the corrosion performance of aerospace materials because the method is less time-consuming than the salt spray method (10 minutes for CBT versus at least 336 hours for salt spray).

In this work, the correlation of CBT parameters (B_t and T_{250}) accuracy and their use as a combination parameter ($\mathrm{CBT}_{\mathrm{combined}}$) to determine the pass/fail mode in salt spray are presented. How this correlation could be reliable is also discussed.

The factors which affect the values of $\mathrm{CBT}_{\mathrm{combined}}$ and their correlation to salt spray pass or fail results (obtained with lots of 5 samples from the same category) will allow discussing the correlation between salt spray and CBT test results.

2. Experimental

2.1. Materials. Test panels were obtained from an approved aluminum supplier. The Al2024-T3 per SAE AMS QQ-a-250/4 and Al7075-T6 per SAE AMS QQ-A-250/12 panels were 3 inches by 10 inches by 0.040 inch thickness following

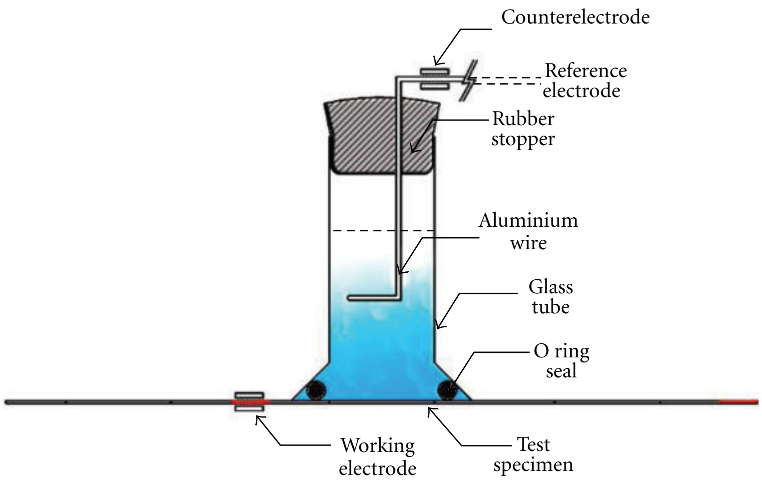

FIGURE 4: Electrochemical cell configuration for the determination of the cathodic break parameters. The different components including the working electrode (noncoated and coated sample) and the counterelectrode are shown.

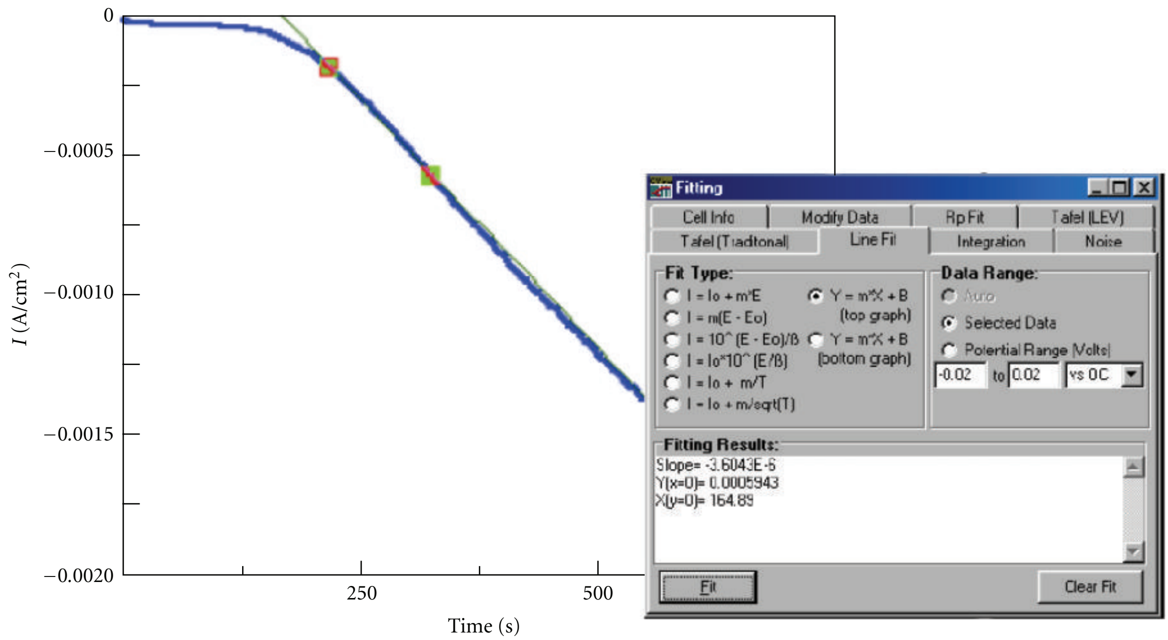

FIGURE 5: Typical current versus time of a sample analysed by CBT for the determination of the B_t. B_t is the slope of the curve.

Bombardier Aerospace specifications for corrosion testing. All the supplied panels were subjected to chromic acid anodizing coating, either without sealing or with different sealing performances and times. The coatings were applied by Bombardier Aerospace's surface treatment facility. The details on the anodizing chemistry and process of these panels are disclosed. Samples with obvious mechanical surface damages such as scratches or scuffs were not included in salt spray or CBT programs.

In order to obtain statistically reliable results, it was decided to divide the experiment in two major steps. The first step included tests on both Al2024-T3 bare and Al7075-T6 bare materials, with and without sealing, as described in Table 1. The sealing used in this step is "Diluted Chromate Sealing" and takes between 23 and 27 minutes. Each family of samples having the same characteristics is organized in five lots of 5 samples each. Thereby, for every lot tested in the salt spray chamber, the equivalent lot (i.e., similar material, sealing, production line, rack, and coating basin) of 5 samples is tested in CBT. For reproducibility studies, 5 lots of 5 samples per lot were tested in CBT and salt pray, respectively, for the same family of samples. This corresponds to a total number of 25 samples of the 5 lots for each of the different eight cases summarized in Table 1.

During the second step, only Al2024-T3 bare samples were tested. Five lots of 5 samples, each one with a specific

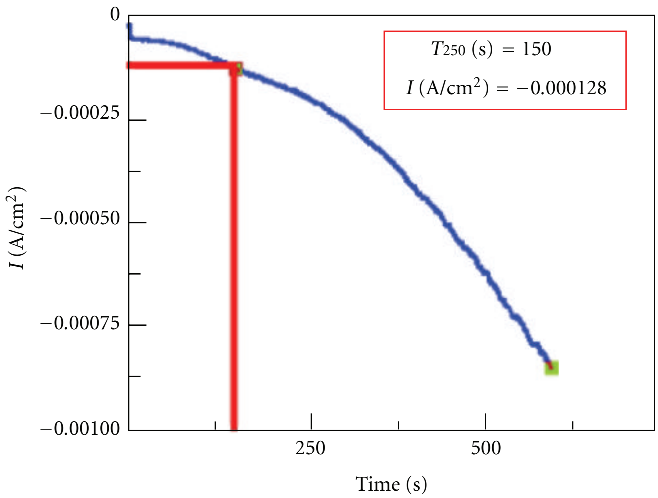

Figure 6: Variation of the current density at −950 mV with time and the determination of T_{250} the T_{250} is the time to reach $i = -128$ mA for a sample of 1.55 square inches.

Table 1: Step 1. The different testing conditions in salt spray or by cathodic breakdown (CBT) method of AL2024 bare and AL7075 bare, sealed and unsealed.

Testing conditions ⟶	Salt spray		CBT	
Sealing type ⟶	Sealed	Unsealed	Sealed	Unsealed
AL 2024-T3 bare	25 samples/5 lots	25 samples/5 lots	25 samples/5 lots	25 samples/5 lots
AL 7075-T6 bare	25 samples/5 lots	25 samples/5 lots	25 samples/5 lots	25 samples/5 lots

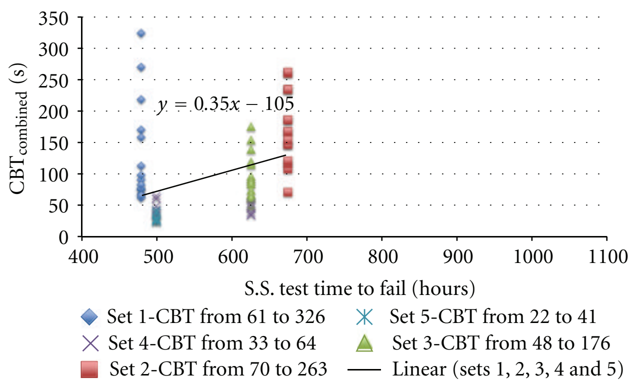

Figure 7: The variations of the CBT$_{\text{combined}}$ versus the salt spray results for AL2024-T3-CAA-step 1 sealing.

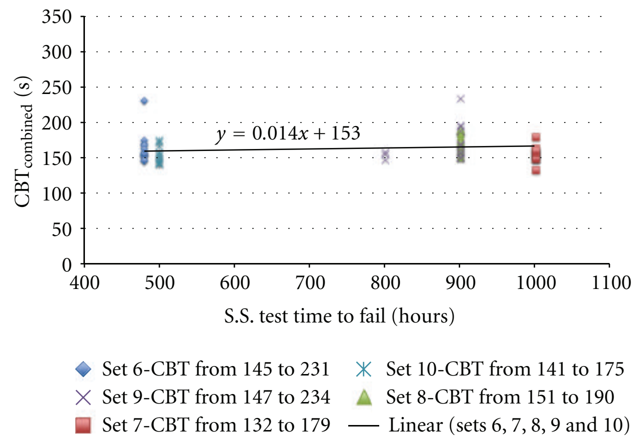

Figure 8: The variations of the CBT$_{\text{combined}}$ versus the salt spray results for AL7075-T6-CAA-step 1 sealing.

sealing performance (dipping time), were subject to salt spray testing. Another type of sealing was used in this step, "Dichromate sealing," and five similar lots were subject to CBT testing. Using different sealing times (10 to 50 minutes) would allow studying the sensitivity of CBT to sealing performances. Sample quantity and sealing times are described in Table 2.

For CBT samples, commercial masks were used in order to define a 10 cm^2 sample surface area for electrochemical testing. In addition, two other areas were free of coating as indicated in Figures 1 and 2. Because anodizing coatings are not drivers, these areas will help provide the necessary electrical contact. The position of these zones was determined taking into account the masks dimensions.

2.2. Test Methods

2.2.1. Neutral Salt Spray. Basically, the salt spray test method involves the spraying of a salt solution onto the samples being tested. This is done inside a temperature-controlled chamber. Typically, the electrolyte is a neutral 5% salt (sodium

Table 2: Step 2. Number of AL2024 bare samples with different sealing times.

Test	Salt spray					CBT				
Sealing time (minute)	10	20	30	40	50	10	20	30	40	50
AL 2024-T3 bare Number of samples	5	5	5	5	5	5	5	5	5	5

Table 3: Summary of the correlation results (pass/fail) between the salt spray and the CBT tests.

		CBT					
		Fail			Pass		
		Measurements	Samples	%	Measurements	Samples	%
Salt spray	Fail	155	52	100	55	18	25
	Pass	0	0	0	165	55	75
Total		155	52	100	220	73	100

chloride) solution. The samples being tested are inserted into the chamber and then the salt-containing solution is sprayed as a very fine fog mist over the samples. The temperature within the chamber is maintained constant. Since the spray is continual, the samples are constantly wet and, thus, constantly subject to corrosion. Through the years, there have been some new twists added to better simulate special environmental conditions, but the most common procedure by far in North America is the test described in ASTM B 117 Standard Practice for Operating Salt Spray (Fog) Apparatus. However, this test can unfortunately eliminate grades which can be used for an application. It can also lead to a nonappropriate modification of the classification of grades, as a result of creating different mechanism of corrosion.

In this work, salt spray testing was conducted according to ASTM B117 [9, 10], which specifies exposure in an enclosed chamber at 95°F (35°C) to fog generated from 5% sodium chloride (NaCl) solution. One salt spray chamber was used for the testing of all panels to avoid variation between chambers. Samples were hung inside the testing chamber using plastic strings in a free standing mode to ensure that all sides of specimens got sprayed uniformly. All salt spray tests were conducted at Bombardier Aerospace's Materials and Processes Laboratory (BAMPEL). The test panels were placed in the salt spray chamber by lots of 5 specimen panels and checked every day by removing them, rinsing them with distilled water, and counting the pits. Panels that did not fail the test were returned to the test chamber. The salt spray results, time of failure, and pits were compared to the CBT data to determine whether CBT correlated with salt spray pass/fail results.

Panels condition was compared against the Bombardier Aerospace Process Specification (BAPS) 160-010 "Chromic Acid Anodizing" (CAA) performance criterion, which states: "The specimens shall show no more than a total of 15 isolated spots or pits, none larger than 1/32 inch in diameter, in a total of 150 square inches of test area grouped from five or more test pieces; nor more than 5 isolated spots or pits none larger than 1/32 inch in diameter, in a total of 30 square inches except those areas within 1/4 inch from the panel edge, 1/16 inches from identification markings and electrode contact marks remaining after processing." If this criterion is met after 336 hours of testing for CAA coating, the lot of five specimen panels passes the test. However, for the test panels covered by the present study, salt spray testing time was extended to failure.

2.2.2. Cathodic Breakdown Test (CBT). The baseline test procedure used for conducting the CBT, as described in the reference [7], indicates that it is only necessary to specify the test voltage, the polarity, the medium, the counterelectrode, and the testing time. No separate reference electrode is used. For chromic acid anodizing, the voltage applied was −950 mV, and the specimen was cathodic (electron donor). The electrolyte was 5 mL of a 5% sodium chloride solution meeting the requirements of ASTM B117 standard. The counterelectrode was 0.030 in diameter, 99.7% minimum purity aluminum wire. Test time was 10 minutes or the time to reach 3000 μA, whichever came first, and the surface diameter was 0.62 in (1.57 cm).

The CBT experimental procedure of the present work is based on the above previous conditions. However, many changes (a commercial electrochemical cell, a 10 cm^2 testing electrode, a more pure counterelectrode, a potentiostat was used for the polarization) were added including a detailed procedure developed for clarity and reproducibility purposes.

The experiment was conducted using a Princeton Applied Research (PAR) Model 273 potentiostat, and a commercial electrochemical cell, "The PTC1 Paint Test Cell" from GAMRY instruments (Figure 3). The Port Holes Electrochemical Sample Masks were used with the cell to define a 10 cm^2 (1.55 square inches) sample surface area. The counterelectrode was an aluminum wire of 0.032 in diameter and 99.999% purity supplied by Puratronic (Figure 4).

The sample was mounted as the working electrode. The electrolyte was 25 mL of a 5% NaCl solution. To minimize variables, the same solution used in the salt spray cabinet was used for the CBT testing. Each measurement took 10 minutes

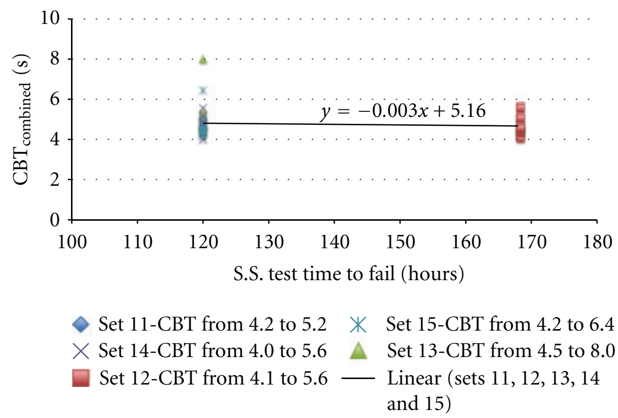

FIGURE 9: The variations of the CBT$_{combined}$ versus the salt spray results for AL2024-T3-unsealed.

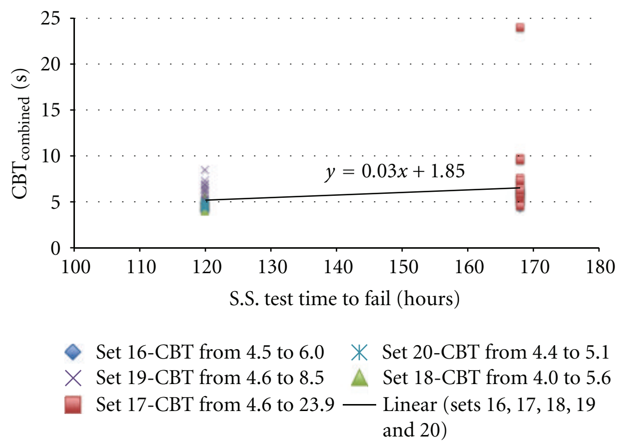

FIGURE 10: The variations of the CBT$_{combined}$ versus the salt spray results for AL7075-T6-unsealed.

and the voltage applied was −950 mV. A time versus current curve was plotted as the main result.

In this work, it was decided to take 3 measurements (10 minutes per measurement) by sample, resulting in three values of CBT$_{combined}$ by sample. Thus, for every lot of 5 samples, with the same material and coating, 15 values of CBT$_{combined}$ are obtained.

3. Results and Discussion

3.1. Salt Spray Test Results. The results of the salt spray obtained in this work were based on criteria (number of pits (pit of certain sizes indicated above in the salt spray method description) on a sample and on the total specified number of samples) well accepted by the aerospace community. The testing time (lasted number of hours of each chamber in the salt spray chamber) to fail is the key parameter of the sample performance against corrosion. This testing time is correlated to the number of pits and the time corresponding to the failure (when the number of pits corresponds to the failure of the specimen according to the industry). The failure time depends of course on the sample and coating specifications and the sealing time. The time to the failure from a salt spray test of the sealed samples studied here can last from hundreds to thousands of hours. Several attributes of the salt spray testing made the results especially suitable for a correlation study. First, panels always failed by pitting. Second, a large sample population was available: two materials, sealed or not sealed, or with different sealing performances.

3.2. CBT Results and Curve Analysis. Figures 5 and 6 show the current versus time for the determination of the B_t, and T_{250}, respectively. The rupture time B_t : B_t is the slope: $= -(b_2 - b_1)/(a_2 - a_1)$.

The T_{250} is the time to reach $i = -128$ mA for a sample of 1.55 square inches.

From the time versus current plots similar to Figures 5 and 6 for a series of sample, the two parameters (B_t and T_{250}) are extracted from each series of measurements. The T_{250} values indicate the severity of the corrosion and the values of B_t indicate the increase in its rate. The high values of these parameters are related to a low corrosion attack and small values are indication of high rates of corrosion.

Initially the T_{250} represents the time to reach $-250\,\mu$A for a surface of 0.62-inch diameter. In this work the current density is expressed in μA per cm^2 to be −1.28 because the area used 1.55 square inches. Thus, it is only necessary to point out the time on the curve necessary to reach this value. The break time, B_t, is less straightforward, since it is not related to a constant current density and is specific for each curve. Though, it is the time of rapid current increase.

There are four possible cases for the analysis of the B_t and T_{250} values: $B_t > 15$ s (acceptable or pass), $B_t < 15$ s (unacceptable or fail), $T_{250} > 55$ s (acceptable or pass), and $T_{250} < 55$ s (unacceptable or fail). Accordingly, the four possible cases and their significance have some effect on the sample resistance to the corrosion attack. The combination of these four parameters in the combined CBT reduces the four cases to two cases. Accordingly, the correlation criteria were that all salt spray failures can be identified if $B_t <$ 15 seconds (s) and $T_{250} < 55$ s or for the combined CBT when the CBT$_{combined}$ (sec) $<$ 15 s. with CBT$_{combined}$ being a combination of the two parameters expressed in (1).

The experimental results obtained from Figures 5 and 6 on various lots were used to calculate the corresponding CBT$_{combined}$ values. The variations of the CBT$_{combined}$ versus the salt spray results for various types of samples and sealing conditions are shown in Figures 7 to 13. These correlations are shown in Section 3.2.1. In (Section 3.2.2), the correlations between B_t and T_{250} for various types of samples in view to analyze the effect the sample and sealing type on the coating performance.

3.2.1. Relationship between CBT and Salt Spray Test Results. Figures 7 and 8 show the variation of the CBT$_{combined}$ with the salt spray test (SST) time to fail for sealed AL2024-T3 and AL7075-T6, respectively. The variation of the CBT$_{combined}$ and the salt spray test values depend of course on the sample

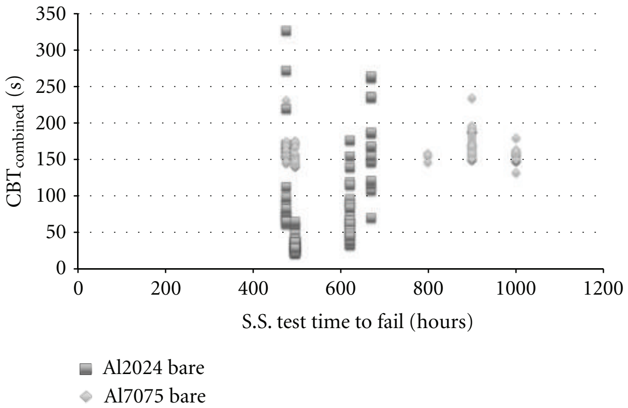

Figure 11: The variations of the CBT$_{combined}$ versus the salt spray results for AL2024-T3 and AL7075-T6-CAA sealed.

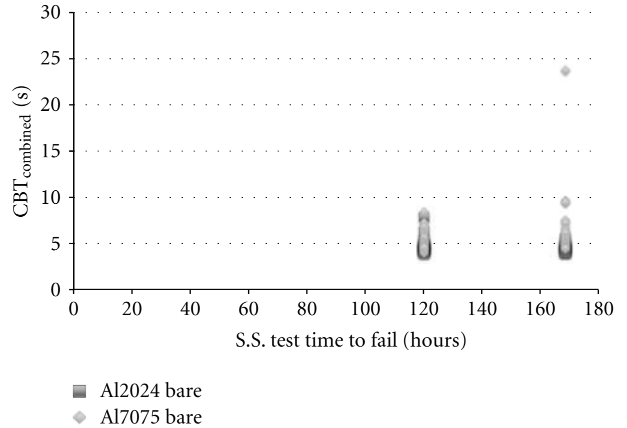

Figure 12: The variations of the CBT$_{combined}$ versus the salt spray results for AL2024-T3 and AL7075-T6-unsealed.

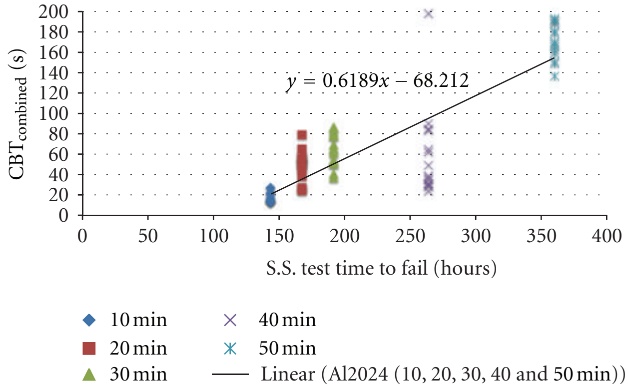

Figure 13: The variations of the CBT$_{combined}$ versus the salt spray results for AL2024-T3-10, 20, 30, 40, and 50 min sealing times.

and the sealing types. The AL2024-T3-CAA-step 1 sealing, samples exhibited CBT$_{combined}$ values in the range of 22 to 326 second and an SST time between 480 hours and 672 hours. In the case of the AL7075-T6-CAA-step 1 sealing the CBT$_{combined}$ values are different and lie in the range of 132–234 seconds and the SST is between 480 and 1000 hours. These values indicate that all these samples pass. In contrary the CBT$_{combined}$ times values of the AL2024-T3-T3-CAA-Step 1 unsealed (Figure 9) and the AL7075-T6 T6-CAA-step 1 (Figure 10) unsealed are in the range of 2 to 12 seconds and their SST times are in the range of 120 to 170 hours. Both CBT$_{combined}$ and SST time values of the unsealed samples, of course, fail the corrosion test.

From these results, Figure 7 shows also that, except for Set 1, whose data is more spread and dispersed, a relation between CBT$_{combined}$ parameter and the time passed in salt spray before failure can be noticed for the Al2024-T3 bare sealed. In fact, the more the set resists the corrosion attack in the salt spray cabinet, the bigger are the CBT$_{combined}$ values. The trend line slope of 0.35 confirms this conclusion.

The results also show that for the Al7075-T6 bare sealed samples (Figure 8), the CBT$_{combined}$ values increase slightly, while the salt spray test time significantly changes from a set to another as seen in Figure 8. The trend line slope is about 0.01, indicating that the augmentation of salt spray test time with the CBT$_{combined}$ parameter is less important than the one noticed for the Al2024-T3 bare with sealing.

In Figure 9, the correlation between CBT$_{combined}$ and SST times on the Al2024-T3 bare unsealed does not show any notable changes in the CBT$_{combined}$ with the relative augmentation of salt spray time. In this case, the trend line slope is nearly inexistent.

Finally, the correlation between the CBT$_{combined}$ and SST times for the Al7075-T6 bare unsealed shows that the time to fail in the salt spray increases with the CBT$_{combined}$ values (Figure 10). The slope of straight line of the correlation is 0.03.

Although the increase of salt spray test time to fail with the CBT$_{combined}$ values is common in all the cases for sealed samples, this supports the existence of a correlation between the two parameters for sealed samples.

3.2.2. Comparison between Al2024-T3 and the Al 7075-T6 Performances. Figure 11 shows the variation of the CBT$_{combined}$ values with the SST times for *AL2024-T3 and AL7075-T6-CAA* sealed. The Al7075-T6 bare with CAA and step 1 sealing, shows better corrosion resistance properties in the salt spray cabinet (test time to fail between 480 and 1000 hours) in comparison with Al2024-T3 bare with step 1 sealing (test time to fail between 480 and 672 hours) as expected. This might be related to the difference in copper contents in the two alloys. However, the analysis of the CBT$_{combined}$ values does not indicate that the CBT$_{combined}$ values are sensitive to the copper content because there is a much wider dispersion of the CBT$_{combined}$ values for the Al2024-T3 sealed (from 22 to 326 seconds) than those of the Al7075-T6 sealed (from 132 to 234 seconds). However the test time for failing of the Al2024-T3 bare with step 1 sealing is included in those of Al7075-T6 bare with CAA and step 1 sealing. If the CBT$_{combined}$ values may be sensitive to the copper content, it may influence the sealing properties (which are probably affected by surface properties) leading

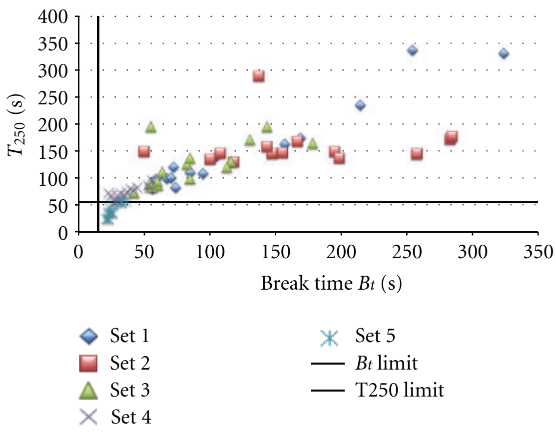

Figure 14: The variations of the T_{250} versus break time B_t for AL2024-T3-CAA-step 1 sealing.

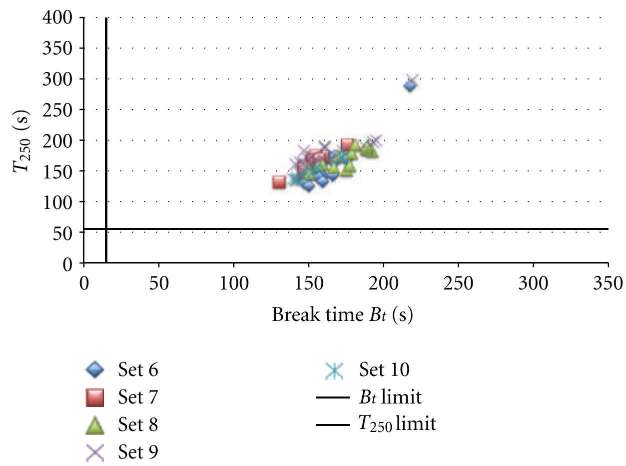

Figure 15: The variations of the T_{250} versus break time B_t for AL7075-T6-CAA-step 1 sealing.

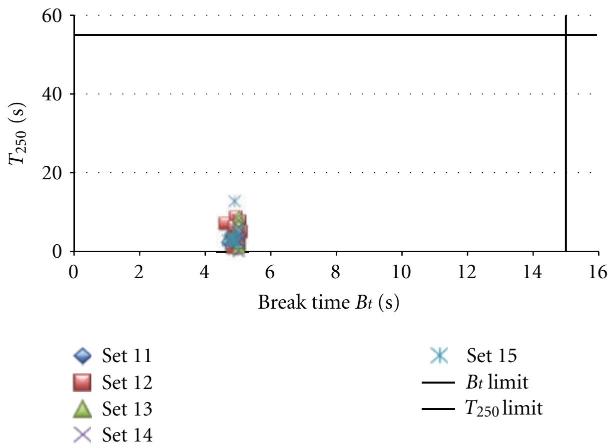

Figure 16: The variations of the T_{250} versus break time B_t for AL2024-T3-unsealed.

to a difference in the $\mathrm{CBT}_{\mathrm{combined}}$ and the SST times values. These findings apply only to sealed samples, as neither Al2024-T3 nor Al7075-T6 bare unsealed collected data indicates a major difference whether in terms of salt spray results or CBT's (Figure 12).

It may be pointed out that salt spray testing is usually performed primarily on Al2024-T3 as it represents the "worst case scenario because it exhibited the smallest and the lowest range of SST times values." Also, no significant difference in term of criteria used for the sample acceptance between Al2024-T3 and Al7075-T6 would be observed if the test was stopped after the mandatory 336 hours to pass.

3.2.3. Comparison between CBT Combined P Values and Salt Spray Test Times for Sets of Different Sealing Performances. Figure 13 shows the variation of the $\mathrm{CBT}_{\mathrm{combined}}$ values with the sealing time of the sample. The Figre shows clearly that the $\mathrm{CBT}_{\mathrm{combined}}$ values increase with sealing time or the sample performance against corrosion. The aim of this study is to determine the effect of the sealing time on the sample performance against corrosion. Consequently, it was decided to test in salt test chamber samples with different sealing time, for example, performances, and to correlate them to their $\mathrm{CBT}_{\mathrm{combined}}$ values (this has never been done before). Thus, the results in Figure 13 were obtained from five sets of Al2024-T3 bare specimens which were dipped in the same sealing tank for periods of 10, 20, 30, 40, and 50 minutes, respectively.

The successive results obtained by salt spray testing show clearly their sensitivity to the sealing performance variation. Indeed, 10-minute sealing time samples have passed 140 hours in the cabinet before reaching the fail criteria, directly followed by the 20-minutes sealing time samples with a test time to fail of 168 hours. The 30 minutes of sealing time coupons, for their part, fail at 192 hours, and the 40 minutes sealed coupons at 264 hours. In last case, the 50-minute sealing time set reaches 360 hours of test time in salt spray cabinet before failing. This last set is the only one to go beyond the 336 hours limit to pass the salt spray test. Thereby, the time spent in the salt spray cabinet by the samples before failing increases with the sealing time or quality.

This trend is also noticed regarding the $\mathrm{CBT}_{\mathrm{combined}}$ parameter. In fact, the smallest the sealing time is, the lowest the $\mathrm{CBT}_{\mathrm{combined}}$ value is. For example, the $\mathrm{CBT}_{\mathrm{combined}}$ value is comprised between 11 and 17 seconds for the coupons sealed during 10 minutes, while it is between 23 and 78 for the 20 minutes, indicating clearly the increase of the $\mathrm{CBT}_{\mathrm{combined}}$ value with the sealing time (Figure 13).

3.2.4. Correlations between CBT Basic Parameters (B_t and T_{250}) and Relations to the Reference Criteria. The $\mathrm{CBT}_{\mathrm{combined}}$ values were involved in the above correlation with the salt spray test times. These $\mathrm{CBT}_{\mathrm{combined}}$ values are determined as combination of the B_t which is the time in seconds of the rupture initiation and T_{250} which is the time in seconds to get a current of -250 microamperes or $i = -128\,\mathrm{mA/cm^2}$. The salt spray failures can be identified as $B_t < 15$ seconds (s) and $T_{250} < 55\,\mathrm{s}$. How the correlation between T_{250} and B_t can be used to meet the criteria of corrosion performance

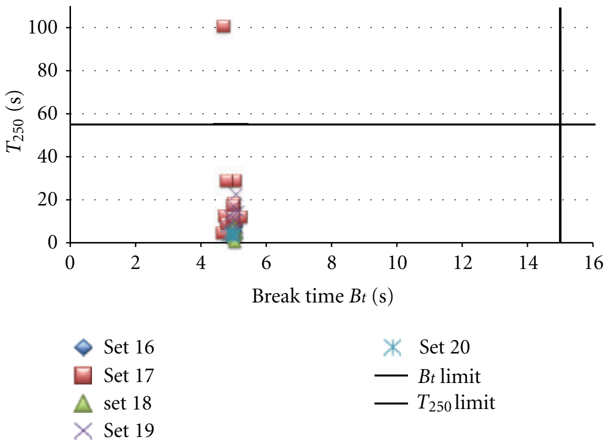

FIGURE 17: The variations of the T_{250} versus break time B_t for AL7075-T6-unsealed.

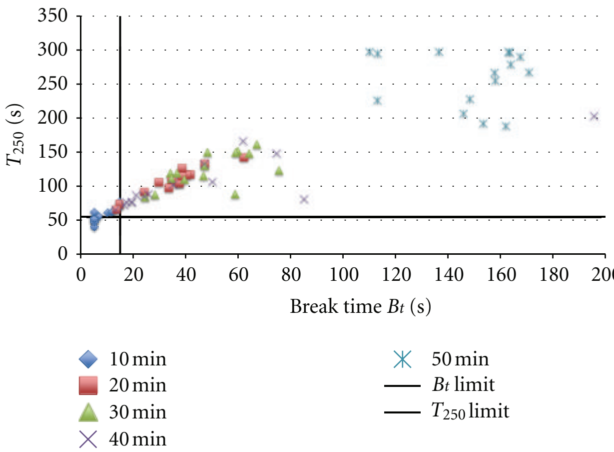

FIGURE 18: The variations of the T_{250} versus break time B_t for AL2024-T3 bare with different sealing performances.

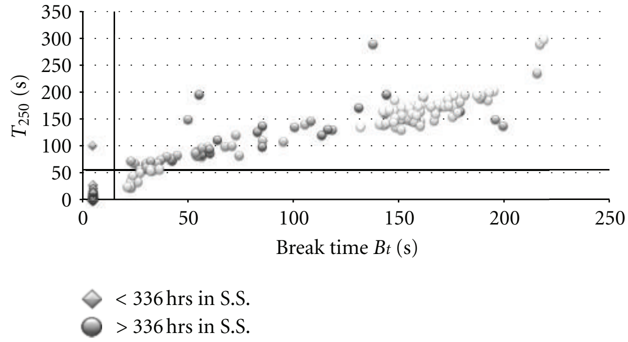

FIGURE 19: The variations of the T_{250} versus break time B_t for all AL2024-T3 and AL7075-T6 sets sealed, unsealed and different sealing performances.

of the sealing is analysed in the following. Figure 14 shows the variation between T_{250} and B_t. All Al2024-T3 bare sealed samples passed the 336 hours limit in salt spray and all the CBT measurements (through the values of T_{250} and B_t) related to these succeeded to predict it. Similarly, in Figure 15, the Al7075-T6 bare sealed samples which pass the salt spray test are correctly predicted by the CBT (through the values of T_{250} and B_t).

Similar correlations between T_{250} and B_t were made for the unsealed samples and it was found that all failures predicted by CBT (through the values of T_{250} and B_t) for the Al2024-T3 bare (Figure 16) are also predicted by the results obtained from the salt spray test method. In the case of the unsealed Al7075-T6 bare, the CBT (through the values of T_{250} and B_t) tests predicted the failures of 14 samples over the 15 failures predicted by sat spray test (Figure 17). Accordingly, if one sample failed from CBT tests measurement, it will fail from salt spray measurements.

On the other hand, samples with different sealing times (10, 20, 30, 40, and 50 minutes) or performances were submitted to the same analysis. It resulted that only 6 CBT measurements over 60 spread over four sets that failed the salt spray test. Note that all of the 6 measurements are part of the first set with 10-minute sealing time. Figure 18 shows clearly that the samples less than 5 minutes exhibit T_{250} and B_t values which are in the failed region ($B_t < 15$ seconds (s) and $T_{250} < 55$ s.) On the other hand, all the sample which pass the salt spray tets were predicted by the CBT, in particular those of the 50-minute sealing time set (Figure 18).

Table 3 summarizes the correlation results between the salt spray and the CBT tests. The results show that every time the CBT predicted a failure of a sample, the salt spray test will confirm this failure, and the majority of the tests which pass the salt spray were accurately identified.

In order to validate the correlation criteria set by the reference procedure, enunciating that all salt spray failures can be identified if $B_t < 15$ sec and $T_{250} < 55$ sec, we found it interesting to present graphs that show the designed experiment correlation between salt spray hours (≥336 hrs being a pass and <336 hrs a fail) and the 2 CBT parameters of B_t and T_{250}. Figure 19 shows this set of correlations between T_{250} and B_t for unsealed samples, various times or performances of sealing and type of samples. We know that the salt spray failures can be identified as <336 hrs or as $B_t < 15$ seconds (s) and $T_{250} < 55$ s. The samples which failed in salt spray test (<336 hrs) or from CBT ($B_t < 15$ seconds (s) and $T_{250} < 55$ s) are unsealed samples and/or samples sealed at less than 50 minutes. On the other hand all the samples which pass CBT tests ($B_t > 15$ seconds (s) and $T_{250} > 55$ s) lasted 336 hours in salt spray test measurements. This confirms the good correlation between CBT tests and salt spray test and indicates that the chromic acid anodized specification requires passing a 336-hour test.

4. Conclusions

Based on the results obtained in this work, the following can be concluded.

(1) The $CBT_{combined}$ parameter increases with the salt spray test time to fail. This trend was obtained among most cases but with different degrees of intensity.

(2) The CBT is not a useful tool to differentiate the unsealed Al2024-T3 bare from Al7075-T6 bare.

(3) The salt spray test was able to identify properly the corresponding sealed samples. This is an indication that the CBT test might be an appropriate method to characterize the sealing performances. However, the CBT was very responsive to the effect of the sealing time and performance.

(4) The comparison between the results obtained in this work, in terms of CBT correlation with salt spray on a fail/pass basis, concluded that using the CBT criteria set is successful in the identification of failures in salt spray tests. However, when it comes to the prediction of the sample which may pass, the discussed criterion was shown to be too optimistic.

(5) Finally, although no salt spray failures were identified as passes, some samples which pass salt spray tests were identified as failures by CBT tests. With this ability, the use of CBT could allow a considerable reduction of salt spray testing, deliver great time savings, and provide objective quantitative data analysis.

Future work will extend the work on the effect of the CBT parameters on the mechanism of the corrosion of the samples.

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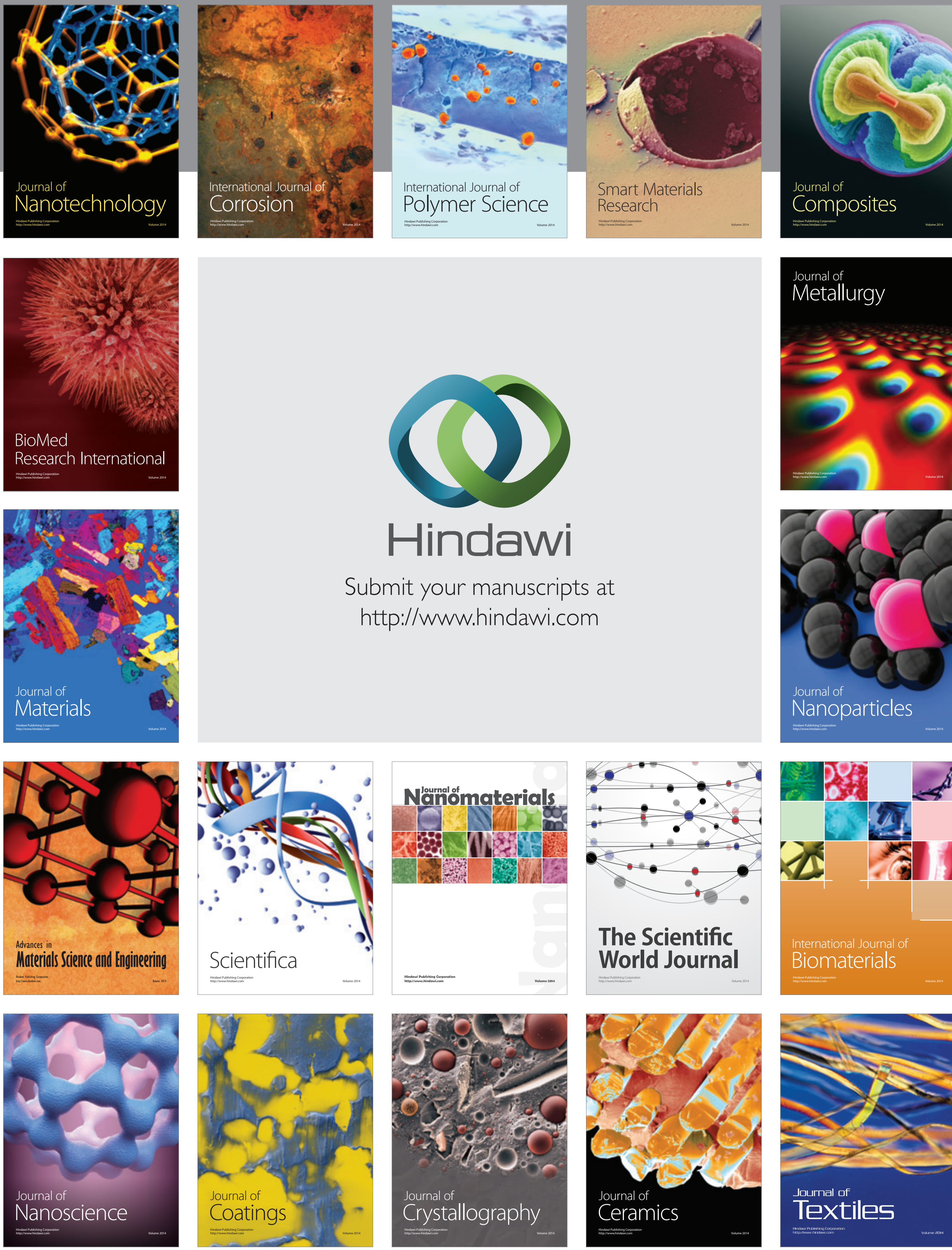
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