Acoustic emission during three-point bending test of corroded galvanized steel

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Keywords: Acoustic emission; Coatings; Galvanized steel; Corrosion; Bending test

Abstract

The present paper addresses to a specific important technological topic like the identification and evaluation of damage in corroded and not corroded galvanized steel, analyzing particularly the effect of corrosion on this kind of coatings. With this purpose, the behavior of hot dipped galvanized samples with different sizes and submitted to three-point bending tests was studied. Acoustic emission was measured with piezoelectric 150 kHz resonant sensors. After the tests, the AE signals were analyzed by considering the AE classical features and applying the Ib-value index. It was observed that just when the plastification of the samples occurs, the minimum Ib-value is obtained. The study compares galvanized and black steel, and galvanized steel with and without corrosion. The present paper is part of a program designed to evaluate the adherence of commercial galvanized coatings obtained under different conditions and then submitted to various corrosion processes, in order to understand coating features related to adherence and to establish criteria for improving the manufacturing process.

Introduction

Hot dip galvanizing is a surface treatment widely used to prevent oxidation and degradation of steel structures. Thus, an efficient solution to problems related to the durability of reinforced concrete beams is obtained by using a coating of Zn (galvanized steel) to protect steel reinforcement from corrosion. The use of this type of coating has nowadays been extended to different metallic applications. Although coating-substrate adherence is high due to creation of various Zn-Fe alloys during the coating forming process certain applications require a special quality control.

Previous work in our Group, referred to identification and evaluation by means of AE and Wavelet Transform (WT) of damage mechanisms in galvanized coatings, not corroded and corroded, during Scratch Test (ST), a typical adherence test [1-3].

In the present paper bending tests are performed, designed to evaluate the coating performance under more realistic situations, similar to those present during service of reinforced concrete structures.

AE signals are analyzed through the traditional parameters and the Ib value method, used by other authors to study the performance of concrete structures [4-8].
Experimental

Samples preparation

Galvanized steel and black steel samples were tested. Samples were galvanized in a process that included the following consecutive stages: degreasing bath at 80°C, elimination of iron oxide by immersion in an aqueous solution of 15% hydrochloric acid at 35°C bath containing aqueous ammonium chloride at 80°C, immersion in a Zn bath at 450°C and air cooling. The final stage consisted in homogenizing by spinning. This procedure conferred the samples a smoother appearance. Samples were then examined visually and the thickness of the coatings was assigned by the induced currents method.

Samples were prepared with two different dimensions: 400x30x12 mm³ (samples A) and 400x30x8 mm³ (samples B). The mean coating thickness was 270 µm for samples A and 210 µm for samples B. As shown in Table 1, three samples A were tested: A1 without the galvanization procedure (black steel); A2 Galvanized without corrosion; A3 Galvanized and corroded. For samples B, only a galvanized sample without corrosion was tested.

<table>
<thead>
<tr>
<th>Type</th>
<th>Test</th>
<th>Sample thickness</th>
<th>Steel</th>
<th>(L_Y): Yielding Load (kg)</th>
<th>(L_{AE}): AE Load (kg)</th>
<th>(L_{AE}) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>A1</td>
<td>12mm</td>
<td>Black steel</td>
<td>1506,31</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td></td>
<td>Galvanized steel</td>
<td>1583,72</td>
<td>430,730</td>
<td>27,1974</td>
</tr>
<tr>
<td></td>
<td>A3</td>
<td></td>
<td>Corroded galvanized steel</td>
<td>1539,37</td>
<td>237,408</td>
<td>15,4224</td>
</tr>
<tr>
<td>Type B</td>
<td>B1</td>
<td>8mm</td>
<td>Galvanized steel</td>
<td>762,85</td>
<td>203,424</td>
<td>26,6663</td>
</tr>
</tbody>
</table>

The sample A3 was introduced in a salt mist chamber during 816 h to simulate a marine environment. This procedure was done following the UNE-EN ISO 9227 standard, adapted from the International ISO9227:2006 standard. Afterwards, this sample was cleaned up with an ammonia hydroxide water solution (150/850 cm³). Before introducing it into the salt mist chamber and in order to concentrate the corrosion in a central region 8 cm long, the rest of the sample was covered with insulating tape, as shown in Figure 1.

Fig. 1. Photograph of sample A3 after cleaning and covered with insulating tape.

Bending tests

Figure 1 shows the set-up for three bending tests, the location of the supports (LS, RS), the point of application of load (Centre) and the location of AE sensors (S1 and S2). A monotonic test was carried out on each sample by means of a mechanical testing machine, keeping the displacement speed constant (0.5 mm/min).
AE Instrumentation

The ASMY-5 Vallen System was used to measure AE during tests. Two 150 kHz resonant AE sensors were placed on the samples as shown in Figure 2. The threshold of the AE sensors was set at 32.5 dB. The AE signals were amplified with a gain of 34 dB.

Information of time and load provided by the test machine was recorded by the AE system through a parametric input. Moreover, in order to remove or reduce the sources of spurious friction noises, teflon films were placed between the sample and the contact of the bend test. Vacuum grease LR (high vacuum silicon grease) was used as a coupling between the sample and the sensors. Before mounting the sensors, its surface was cleaned in order to guarantee the maximum coupling adhesion. The applied coupling layer was thin; so, it could fill the gaps caused by the surface roughness and eliminate air gaps to ensure good acoustic transmission. The sensors were firmly held to the test specimen.

Results

AE traditional parameters

Figure 3 shows load versus displacement recorded during the test B1; the yielding point has been marked. As it can be seen, a good linearity was obtained just before this point. Similar results were obtained in the other tests. The load at the yielding point for all tests is shown in Table 1. As expected, the yielding load is lower for samples B than for samples A. Moreover, it can be seen that corrosion produces a slight reduction of the elastic zone of the material.

A two sensors AE linear location was done using the event builder and locator of the Vallen VisualAE software, using 486 cm/ms as velocity of propagation of the wave in the material and 1 ms as first-hit discrimination time. Figure 4 shows the position of the AE events versus time throughout the test. Moreover, the load has been superposed in these figures. The horizontal lines indicate the supports position, and the long vertical line indicates the yielding point. The short vertical line indicates the start of significant AE. As it can be seen, AE begins in the centre of
samples, just where the load is applied, and it extends from the centre to the supports as the test proceeds.

Figure 5 shows a scheme explaining cracks evolution according to what was observed in the laboratory. The initial fracture is produced in the centre of the sample and, while the test advances, the zone of transversal fractures moves toward the supports. The noticeable fact is that when the yielding point is reached, the whole zone between supports is already cracked.

Table 1 also shows the yielding load of each test, \(L_Y\), and the load at with the AE starts to be significant, \(L_{AE}\) (point marked in Figure 4). Both loads were related by means of the index \(L_{AE}(\%)\), defined as:

\[
L_{AE}(\%) = 100 \cdot \frac{L_{AE}}{L_Y}
\]

As mentioned previously, the yielding load is lower for samples B than for samples A. Note that the yielding load of samples A is approximately constant. Moreover, it can be seen that the corrosion produces a little reduction of the elastic zone of the material.

Figure 6 shows accumulated AE events versus time for tests B1 and A2. The vertical line indicates the yielding point in each test. As it can be seen in both cases, a clear change of trend is produced at the yielding point of steel, with a linear increase of the number of events versus time.
Figure 7 shows the amplitude versus the linear location of AE events for tests A1 (black steel) and A2 (galvanized steel). Note that clearly the number of registered hits is significantly lower for black steel. Moreover, the AE events recorded during test A1 have lower amplitude. This is a clear indication AE provides basically from the fracture of the galvanized coating.

**Ib-value analysis**

The b-value index is defined as the “log-linear slope of the frequency-magnitude distribution of AE”. It represents the “scaling of magnitude distribution” of AE, and is a measure of the relative numbers of small and large AE intensities which are signatures of localized failures in materials under stress. It is important to specify the method used for determining Ib-value, since the selection of the amplitude or magnitude limits of the “linear range” of the cumulative frequency distribution data of AE is critical. An “improved” Ib-value was proposed and applied to the evaluation of slope failure by Shiotani et al [6]. The Ib-value was defined as:

\[
I_b = \frac{\log_{10}(\frac{N(\mu - \alpha_1 \sigma)}{- \log_{10}(\frac{N(\mu + \alpha_2 \sigma)}{(\alpha_1 + \alpha_2) \sigma}))}}
\]

where \(\mu\) is the mean amplitude; \(\sigma\) the standard deviation; \(\alpha_1\) and \(\alpha_2\) the user-defined constants which would represent coefficients of lower and upper limits of the amplitude range to yield a proper straight line. In general N=200 was chosen, but in the first part of the test N=60 was conveniently chosen, in order to avoid the late occurrence of the first Ib-value. The parameters \(\alpha_1\) and \(\alpha_2\) were adjusted for each test, checking that they were between 0 and 1.5.

Figure 7 shows the Ib-value obtained during three tests together with the registered load and a vertical line indicating the yielding point. It can be seen that in all the tests the minimum value of the Ib-value was obtained just close to the yielding point.
Conclusions

1. AE begins at a certain moment in the centre of the sample, point of application of the load, and then it advances toward the supports. When the yielding point is reached, the whole zone between supports is cracked.

2. The relationship between the load at which AE starts and the yielding point is conveniently assessed by the parameter $L_{AE} (%)$ which takes characteristic values depending on the type of steel (i.e. galvanized steel). It decreases for corroded galvanized steel.

3. Observing accumulated the AE events versus time curve, a clear change of trend is observed after the yielding point of steel with a linear increase of number of events versus time, results obtained both in samples A and B.

4. AE registered during the three point bending test is lower for black steel than for galvanized steel, both in quantity and in amplitude of hits.

5. Temporal coincidence is observed between the Ib-value minimum and the yielding point.

Acknowledgements

This work was partially supported by the Spanish I+D National Plan DPI 2006-02970 Project. Hot-dip galvanization was performed at Galvanizados, S.A., Madrid.
References