COMPARISON BETWEEN CONCRETE-BLACK STEEL AND CONCRETE-GALVANIZED STEEL BOND VIA THE PULL-OUT TEST SUPPLIED WITH ACOUSTIC EMISSION

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ABSTRACT

This paper shows, in a comparative way, AE and mechanical results in the pull-out experiment to evaluate the concrete-steel bond, for two kinds of steel bars: black steel and hot-dip galvanized steel. We report here traditional parameters of AE and load-slip diagrams recorded along tests by using cubic samples of concrete centrally reinforced with ribbed bars. Several ages (7, 14, 21, 28 and 90 days) of concrete are considered to evaluate the bond for both kinds of steel. A comparison between mean values of bond tensile-force for concrete/black steel and concrete/galvanized steel systems is performed on a set of ten different concrete samples obtained with the same mixture. Results show a lower bond for galvanized steel than for black steel. Moreover, AE diagrams obtained during each monotonic pull-out test also show important differences for both types of steel.

1. Introduction

Concrete-steel bond, a key factor in beams reinforced with steel, has been carefully studied, specially in aspects connected with corrosion [1-2]. It is well known that the galvanized steel, used as reinforcement, improves the durability of the reinforced concrete structures in aggressive environments [1-2]. However, concerning concrete-steel bond, it could be lower than the one obtained with black steel. Some processes that take place at the concrete-galvanized steel interface could suggest the decrease of bond respecting the concrete–black steel system. Nevertheless, it has not yet been demonstrated that the bond between concrete and galvanized ribbed bars frame does not fit valid standards [3]. The main aim of our work is to advance in the evaluation of the bond between concrete and two types of steel for ribbed bars: black steel and hot-dip galvanized steel.

During the last decade, some papers have been published showing the capability of the AE technique to make understandable the concrete-steel bond phenomenon in pull-out tests [4-7]. Both traditional and quantitative processing has been applied to AE signals recorded. Sensors were placed at the lateral sides of concrete cubic specimens centrally reinforced and with a small bonded zone between the steel bar and concrete. In the same sense, in [4] and [5], mechanical and traditional acoustic emission results obtained in monotonic, cyclic, and long-term tests are discussed in terms of bond between both materials. In more recent papers as [6] and [7], the Moment Tensor Inversion Theory has been applied to recorded AE signals. Arrival times of acoustic waves had been previously asserted, which allowed the location of the damage in the concrete-steel interface, and to determine the fracture type and orientation of a fault, that was crack type. Especially important is the work performed by C.U. Grosse and collaborators from the University of Stuttgart and Otto-Graf-Institute, related with test setup and interpretation of both traditional and quantitative AE results.

However, the pull-out test with AE has never been applied to compare galvanized steel and black steel performance. For this reason, and keeping in mind the importance of evaluating bond in galvanized steel, we have developed a modest project to evaluate in a comparative way the concrete-steel adherence. This was done by analyzing at the same time the AE recorded by four sensors put on each lateral side of the concrete sample.

We report in the present paper the bond results together with AE results for several ages of concrete (7, 14, 21, 28 and 90 days), showing a very clear difference for both kinds of steel.

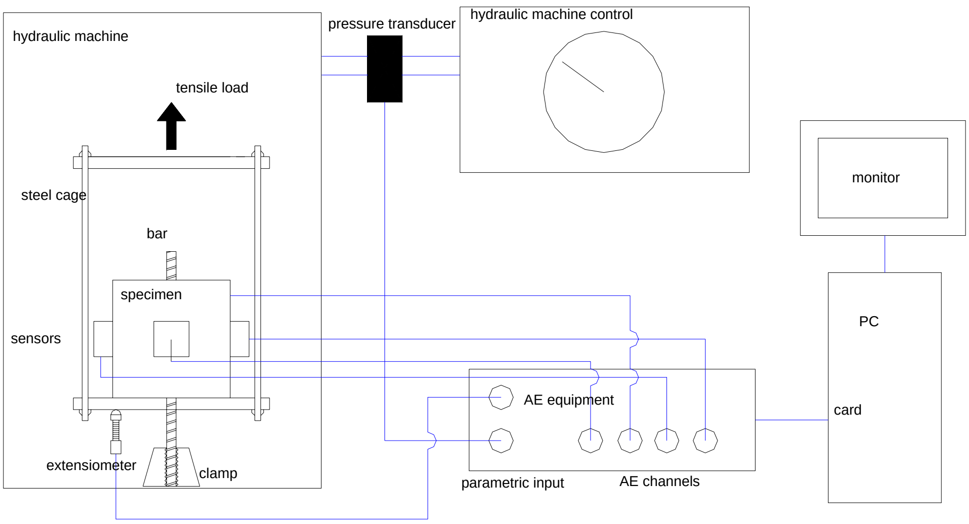

Figure 1: Diagram of the pull-out experiment with AE.

2. Experimental setup

The pull-out experiment with AE, schemed in Figure 1, was first applied at the University of Stuttgart and the Otto-Graf-Institute by Balázs, Grosse and collaborators [4-5]. Basically, it consists in putting the specimen (a piece of concrete with an embedded bar) with some AE sensors into a steel cage, which is inside a universal hydraulic machine. The bar embedded in the specimen, which crosses the cage via a small hole, is fixed to the machine with a clamp. When the machine is activated to work by tensile forces, the cage and the piece of concrete go up, thus producing a relative displacement between the bar and the concrete. During this load process, an extensiometer located at the inferior part of the cage allows to measure the displacement. This magnitude is recorded in the first parametric input of the AE device. At the same time, a pressure transducer located at the machine hydraulic circuit allows to record the load history as the second parametric input. During this process, the AE generated by the accumulated damage near the concrete-steel interface is captured by four sensors put on the specimen (one per each face). The detection system used was Vallen AMSY-5 from Vallen System. The piezoelectric sensors used were VS30-V (23-80kHz), with an integrated preamplifier AEP4H-ISTB (46dB of gain), both of Vallen System. Threshold was set at 40dB and the Vallen VisualAE software was used to after test AE parameters treatment.

Figure 2: Left: Specimen with bar. Right: Black and galvanized steel bars

3. Specimens description

Specimens under test were concrete cubes of 20x20x20cm, with a single central ribbed bar used as reinforcement. The diameter of the bar was 12mm, and the bond length was 5cm (1/4 of the total cube side), located in the middle line of the specimen (see Figure 2). The reinforcement was steel with a nominal strength of 500 N/mm^2. The minimum height of the rib was 0.85mm and the rib spacing was 16.14 mm. For comparison reasons, two kinds of specimens were tested: with black steel used as reinforcement (steel without coating) and with hot-dip galvanized steel (with a coating of Zn) as reinforcement. This second kind of reinforcement was obtained by galvanizing black steel in EUROTEGA S.A. (Spain), in a process that included successive stages. They were: degreasing bath at 80º C, elimination of iron oxide by immersion in a water solution of 15% chloridric acid at 35º C, bath in water diluted ammonium chloride at 80º C, immersion in a Zn bath at 450°C and air cooling. Figure 2 shows the specimen and the two kinds of bars used.

Concrete was obtained by mixing together Portland cement, fine aggregate (0/4 mm), coarse aggregate (4/12.5 mm) and the superplasticizer additive CONPLAST SP-337 in weight proportions: $1:3.42:2.78:5.8\cdot10^{-3}$. The water-cement ratio was 0.54. Specimens were prepared on a table specially built for this experiment (see Figure 3), where concrete can easily be prepared and vibrated in a few seconds. Finally, specimens were fog-cured at a constant temperature of 20^0C in a damp room. Five curing times, then steel ages, were considered in our study for each kind of steel, in order to investigate the evolution of the concrete-steel bond: 7, 14, 21, 28 and 90 days. For each age and kind of steel, ten tests were carried out, in order to obtain mean bond values from a high number of tests. Moreover, the compressive strength of concrete was measured on cylindrical samples (15cm of diameter and 30cm high), equivalent to the 10 samples used in each test, thus obtaining a mean value for each age. These results are shown in Figure 4. We can see in this Figure how the compressive strength increases with age, and asymptotically tends to a constant value.

Figure 3: Special table to prepare 20x20x20cm and 10x10x10cm specimens.

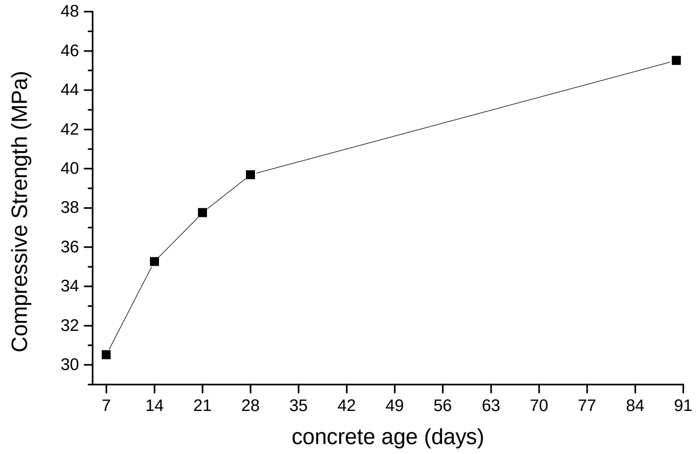

Figure 4: Compressive strength versus age of concrete used in tests.

4. Results

For shortness reasons, only AE results of two tests on black and galvanized steel with a specimen age of 28 days are presented here. Results obtained with other tests present a similar behaviour. Figures 5 and 6 show results of the first test with black and galvanized steel, respectively, while Figures 7 and 8 show the results of the second test. In each case, the Figure a) shows the relative bar-concrete displacement in mm versus time in seconds. The duration of each experiment was about 5 minutes. We can see from these figures that there exists an initial stage where the slip varies nonlinearly, followed by a second stage where the slip increases linearly (the relative speed is constant), until a certain point, just when the bond tensile-force is reached (the load is maximum), at which the slip increases very fast and nonlinearly. This behaviour is similar in both kinds of steel and in all tests, which justifies the validity of our comparison. The Figure b) shows the load-slip diagram. From these diagrams we can measure the bond tensile-force, which is clearly lower for galvanized steel (Figures 6-b and 8-b) than for black steel (Figures 5-b and 7-b), in both tests. This bond tensile-force is between 34 kN and 38 kN for black steel and 29 kN and 30 kN for galvanized steel. We can also see the similarity of these diagrams for both kinds of steels and tests. The Figure c) shows the number of hits of AE recorded in channel 1 along the experiment, versus time in seconds. The load history has been plotted superposed, in order to correlate it with the generated AE that represents the accumulated damage. Finally, Figure d) shows the peak amplitude of the AE signals recorded in the same channel as that of Figure c), versus time and superposed, the load history. We can see that the behaviour of both traditional AE parameters, number of hits and peak amplitude, is very similar.

For black steel the higher AE was registered around the highest bond force zone, just when the applied load started to decrease. However, just before the maximum force developed, the AE activity was clearly smaller. In clear contrast, the AE recorded for the galvanized steel is different. After having grown in a continuous and progressive way from the test beginning until a certain applied load, which is quite lower than the maximum load, it holds constant and at very high values. These features take place before and after the maximum load is reached. So, there exists a great difference between AE for each type of steel, which implies that different adherence mechanisms are involved in each case. Thus, while for black steel the maximum energy produced by damage at the concrete-steel interface is concentrated mainly just passing the maximum load, for galvanized steel the zone of maximum interfacial damage is more extended and it starts earlier than the maximum load is reached. This fact could indicate chemical adherence mechanisms present in the concrete-galvanized steel system. However this result is not evident from slip-load diagrams, which are quite similar for both steels. This is the reason why the AE technique shows up as a better alternative for auscultation tests.

Finally, by using the load history, the maximum bond tensile-force has been obtained for both kinds of steel, the five ages of concrete and the ten tests in each case. Figure 9 shows the results for the mean value over the ten tests carried out, versus age. This result shows a clear difference between both kinds of steel, with values clearly higher for the black steel for all age values: a 18% higher for 7 days, and a 30% for 90 days. As expected, bond increases with age, being this increase slower for higher ages.

5. Conclusions

A study of the concrete-steel bond by means of the pull-out test with acoustic emission for two steel types, black and galvanized, has been carried out. Results show that the AE diagrams could reveal some bond processes present at the galvanized steel-concrete interface, which produce a very high interfacial damage concentration much earlier the maximum bond force is reached. Differences in behavior between both steel types point out the convenience of black steel because a higher bond force is obtained. The study concerning concrete age reveals significant differences favoring black steel because of the increase of maximum bond force as age increases.

6. Bibliography

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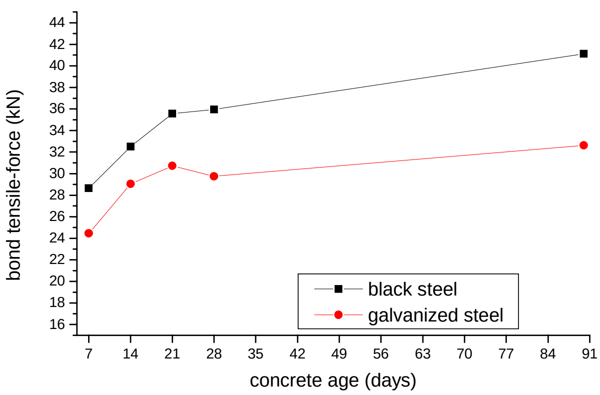

Figure 9: Bond tensile-force versus concrete age for black and galvanized steel. Each point in this Figure is a mean value of ten concrete tests with the same mixtures.

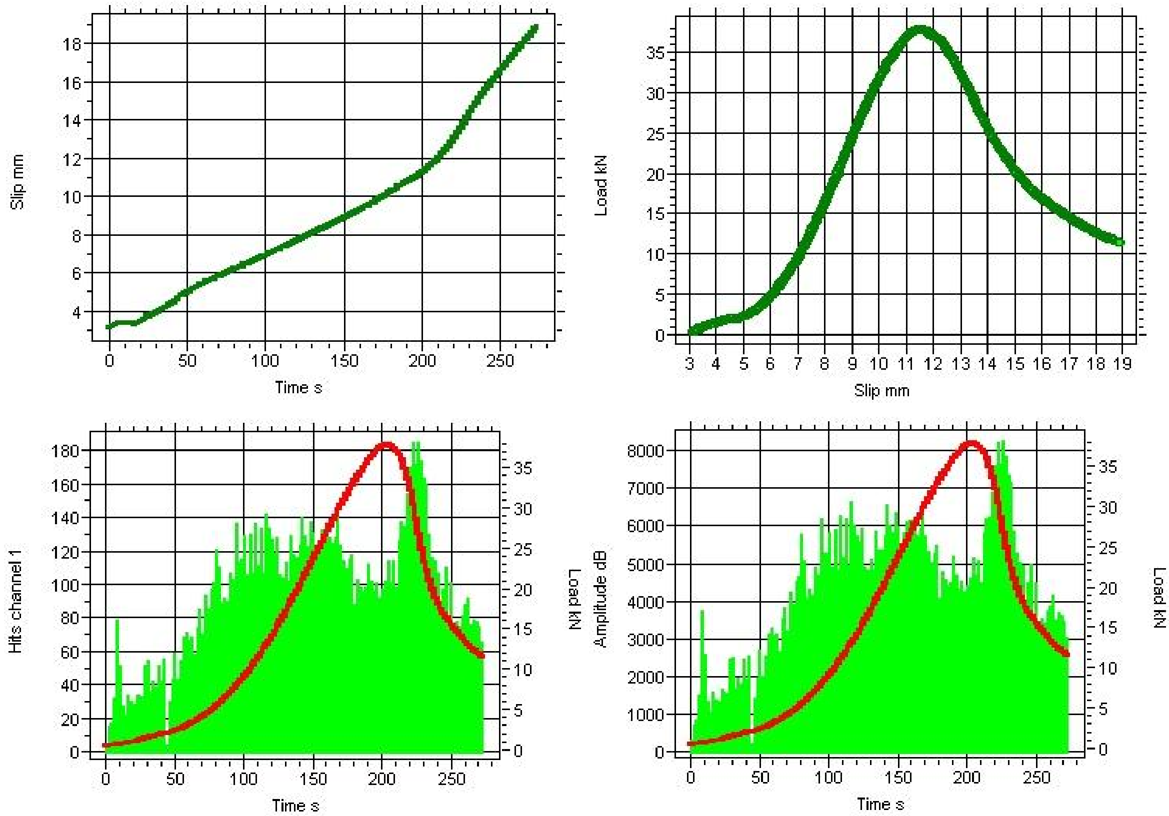

Figure 5. First test with black steel (age: 28 days): a) Up-left: Slip versus time; b) Up-right: Applied load versus slip; c) Down-left: Number of AE hits in channel 1 (bars) and load applied (continuous line) versus time; d) Down-right: AE Peak Amplitude (bars) and applied load (continuous line) versus time.

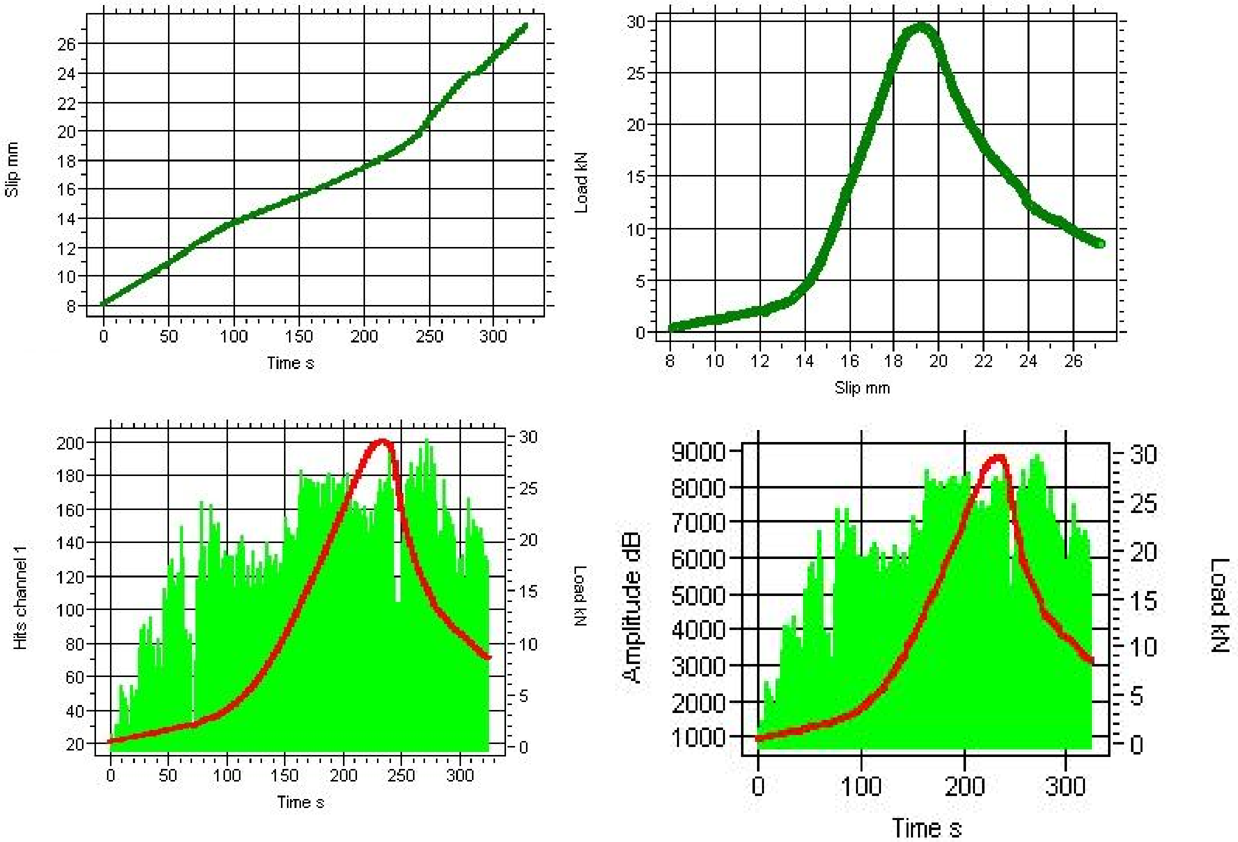

Figure 6. First test with galvanized steel (age: 28 days): a) Up-left: Slip versus time; b) Up-rigth: Applied load versus slip; c) Down-left: Number of AE hits in channel 1 (bars) and applied load (continuous line) versus time; d) Down-right: AE Peak Amplitude (bars) and applied load (continuous line) versus time.

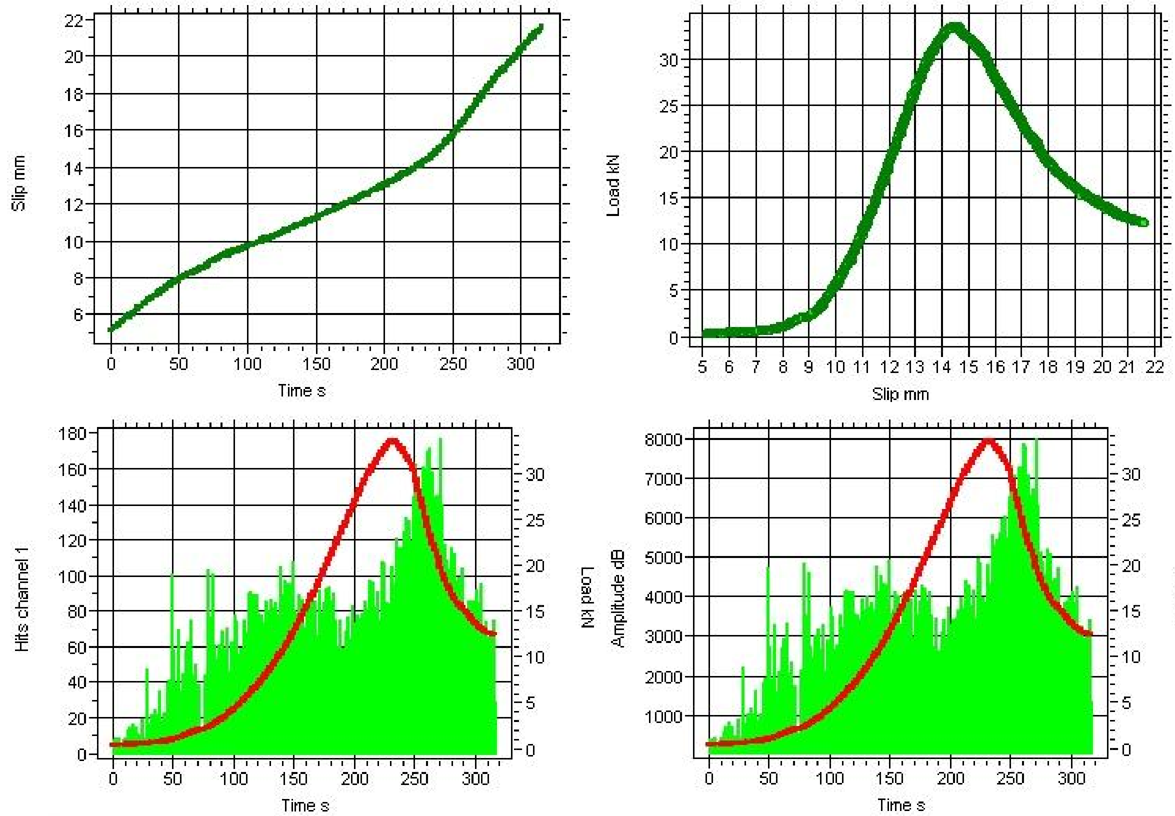

Figure 7. Second test with black steel (age: 28 days): a) Up-left: Slip versus time; b) Up-right: Applied load versus slip; c) Down-left: Number of AE hits in channel 1 (bars) and applied load (continuous line) versus time; d) Down-right: AE Peak Amplitude (bars) and applied load (continuous line) versus time.

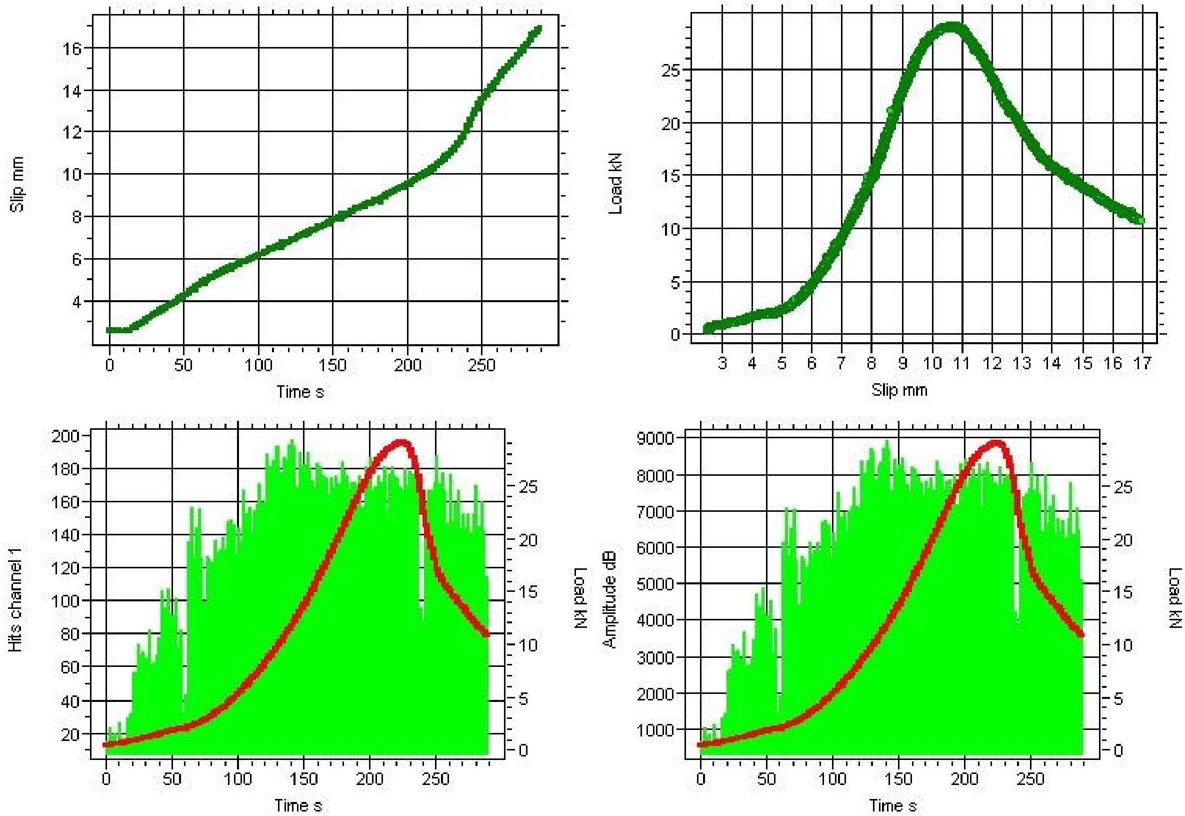

Figure 8. Second test with galvanized steel (age: 28days): a) Up-left: Slip versus time; b) Up-right: Applied load versus slip; c) Down-left: Number of AE hits in channel 1 (bars) and applied load (continuous line) versus time; d) Down-right: AE Peak Amplitude (bars) and applied load (continuous line) versus time.