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Deterioration in Fatigue Detected by Acoustic Emission Technique
Étude du comportement à la fatigue au moyen d'émissions acoustiques
Untersuchung des Ermüdungsverhaltens durch Schallemissionsmessungen

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SUMMARY

The acoustic emission technique was used to investigate the progress of local damage on steel-concrete interactions subjected to repeated loading. The accumulation of internal damages detected by this technique gives a clear indication on the failure process and the subsequent failure. The damage accumulation, defined as the cumulative acoustic emission amplitudes, resulted in a similar tendency to the cyclic creep of bond.

RÉSUMÉ

La technique d'émission acoustique est appliquée pour examiner l'évolution des dommages locaux au contact acier-béton causés par des charges répétées. L'accumulation des dommages internes détectés par la technique d'émission acoustique permet d'observer le processus et la nature de la défaillance. L'accumulation des dommages, défini par les amplitudes cumulatives, indique un comportement ressemblant au fluage cyclique de l'adhérence.

ZUSAMMENFASSUNG

Mit Hilfe der Schallemissions-Technik wurde das Ermüdungsverhalten des Verbundes zwischen Stahl und Beton im Hinblick auf die lokale Schädigung untersucht. Diese Analyse liefert dabei wertvolle Hinweise über das Entstehen von inneren Schäden, den Schadensprozess sowie schliesslich über das Versagen des Bauteils. Das Schadenswachstum, ausgedrückt durch die Summenamplitude der Schallemissionen, zeigt dabei ein paralleles Verhalten zum zyklischen Kriechen des Verbundes.

1. INTRODUCTION

Repeated loads produce a progressive deterioration of the materials indicated by increasing deformations and decreasing stiffness. The deterioration is caused by internal damages.

We experimentally studied the failure process of the steel-concrete interaction under repeated loading by simultaneous registration of the acoustic emission (AE) signals and the bond-slip behavior.

Detection and evaluation of AE signals developed considerably [1,2,3] and it seems to be a very promising technique for the analysis of internal damages and their accumulation. The parallel registration of AE signals and the bond-slip behavior provided two sets of independent measurements for comparison.

Interactional (bond) stresses are associated with slip in reinforced concrete members over the steel-concrete interface indicating micro-cracking [4] and micro-crushing [5] in the concrete surrounding the reinforcing bars. Repeated loads induce an increase in slip indicating the progressive local damages without an increase in the load level.

2. EXPERIMENTATION

The specimen was a special pull-out specimen (Fig.1) had a rather short bond length of 20 mm (two rib distances) to minimize the number of sources producing local damages. The high yield (f_y=500 N/mm^2) deformed reinforcing bars of 16 mm diameter were placed centrically into the concrete cubes of 100 mm sides and had a relative rib area of 0.065. The rib pattern consisted of moonshape ribs and two longitudinal ribs.

This type of specimen provided a possibility for the registration of the entire deterioration process from the beginning of loading to the fatigue failure.

Mix proportions of concrete were 1 : 2.82 : 2.22 : 2.37 by weight of Portland cement, fine aggregate (0 to 2 mm), medium size aggregate (2 to 8 mm) and coarse aggregate (8 to 16 mm). The specimens were fog-cured at a temperature of 20°C for 7 days and then were kept in laboratory conditions. The mean compressive strength at testing measured on three cubes of 150 mm sides was 34.9 N/mm^2.

The specimens were tested in a servo-hydraulic machine [6]. The tensile force acted on the reinforcing bar and the specimen was supported by a steel plate (Fig.1). The slip was measured by an LVDT of 1 μm sensitivity at the unloaded end of the specimen.

For the recording of AE signals a transient recorder with eight channels was used with a sampling rate of 1 MHz and an internal storing facility of 256 kWord for each channel (1 Word = 2 Byte). Using only the internal memory, 243 events could be recorded with a length of 1 kWord each. The amplitude resolution of each A/D-converter was 12 bits. The signals were recorded by eight piezo-transducers, coupled to the five sides of the specimens. Six had a so-called broadband characteristic type UPE by GEOTRON and 8694 by KISTLER; two transducers operated in resonance type 8612 by KISTLER with a main frequency of about 20 kHz. They were amplified by an eight-channel preamplifier with a gain between 0 and 100 dB. We carefully paid attention to the electric decoupling of the AE monitoring system to prevent the recordings being effected by the noise of the servo-hydraulic machine.

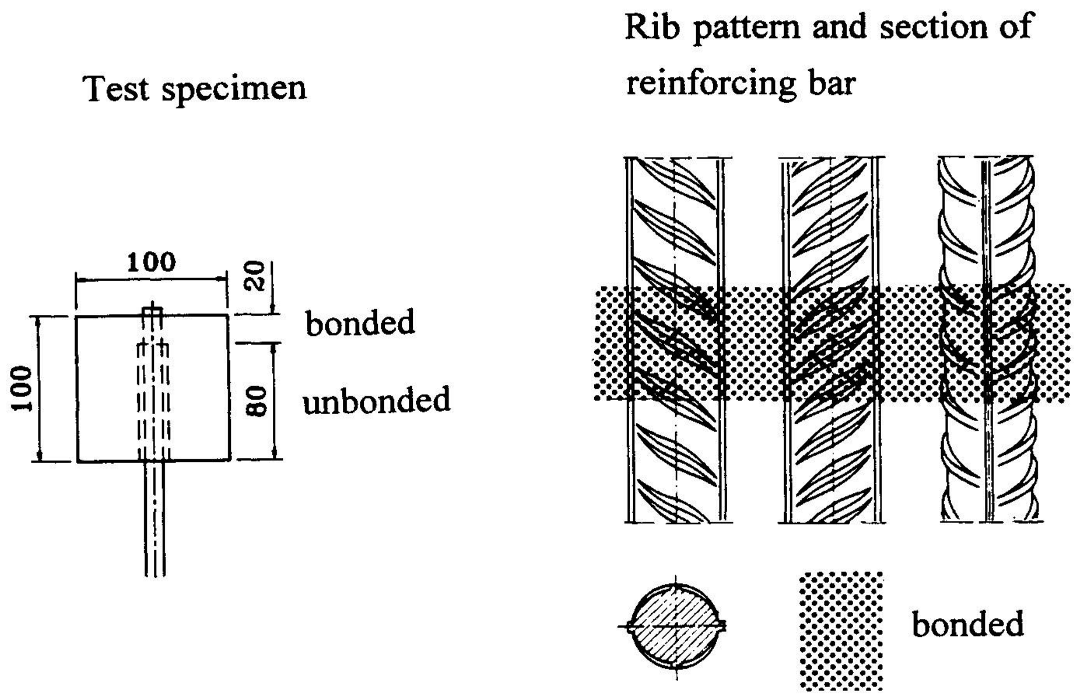

Fig.1 Test specimen and rib pattern of tested reinforcing bar

3. DETERIORATION IN FATIGUE

The results of six deformation controlled monotonic pull-out tests together with the comparison of AE signal patterns using the coherence spectrum analysis based on the fast Fourier transforms of the signals are discussed in Ref. [6].

Three typical results of the six fatigue tests are presented in Figs.2 to 4 applying one, two or four blocks of constant amplitude cyclic load. The frequency of repeated loading 4 s^{-1}. The load levels are given in percentage values, i.e. the maximum value of repeated load ($\tau_{b,max}$) related to the monotonic bond strength (τ_{bu}) measured on an average 15.4 N/mm^2. The minimum value of repeated load ($\tau_{b,min}$) was 10 percent of the maximum value.

The upper parts of Figs.2 to 4 indicate the load histories as well as the registered AE amplitudes as bar graphs. The amplitudes are given in relative values of the maximum peak-to-peak-values of the signals (denoted as PA sum per time unit) and are summed in 10 or 15 s intervals. The bottom parts of the same figures indicate the *accumulated damage* as the accumulated sum of the AE amplitudes with bar graphs as a function of the time (called Cumulative PA) together with the simultaneously measured slip versus time (number of load cycles) relationships.

Most of the AE signals were registered by applying the initial monotonic load up to the mean value of cyclic load, then at the beginning of the cyclic load or at an increase in the cyclic load level and preceeding the pull-out failure. However, signals were also detected during a block of constant amplitude cyclic load.

From the comparison of bottom figures in Fig.2 to 4 it is seen that the internal damage accumulation, defined as the cumulative AE peak amplitudes indicate a similar tendency to the cyclic creep of bond given as a slip versus time relationship.

Nevertheless, the internal damage accumulates rather linear in a block of constant amplitude cyclic loading following a transitional period after reaching the cyclic load level and accelerates preceeding the failure.

4. CONCLUSIONS

The internal damage accumulation under repeated loading was experimentally studied on the steel-concrete interaction using the AE technique with simultaneous registration of the bond slip.

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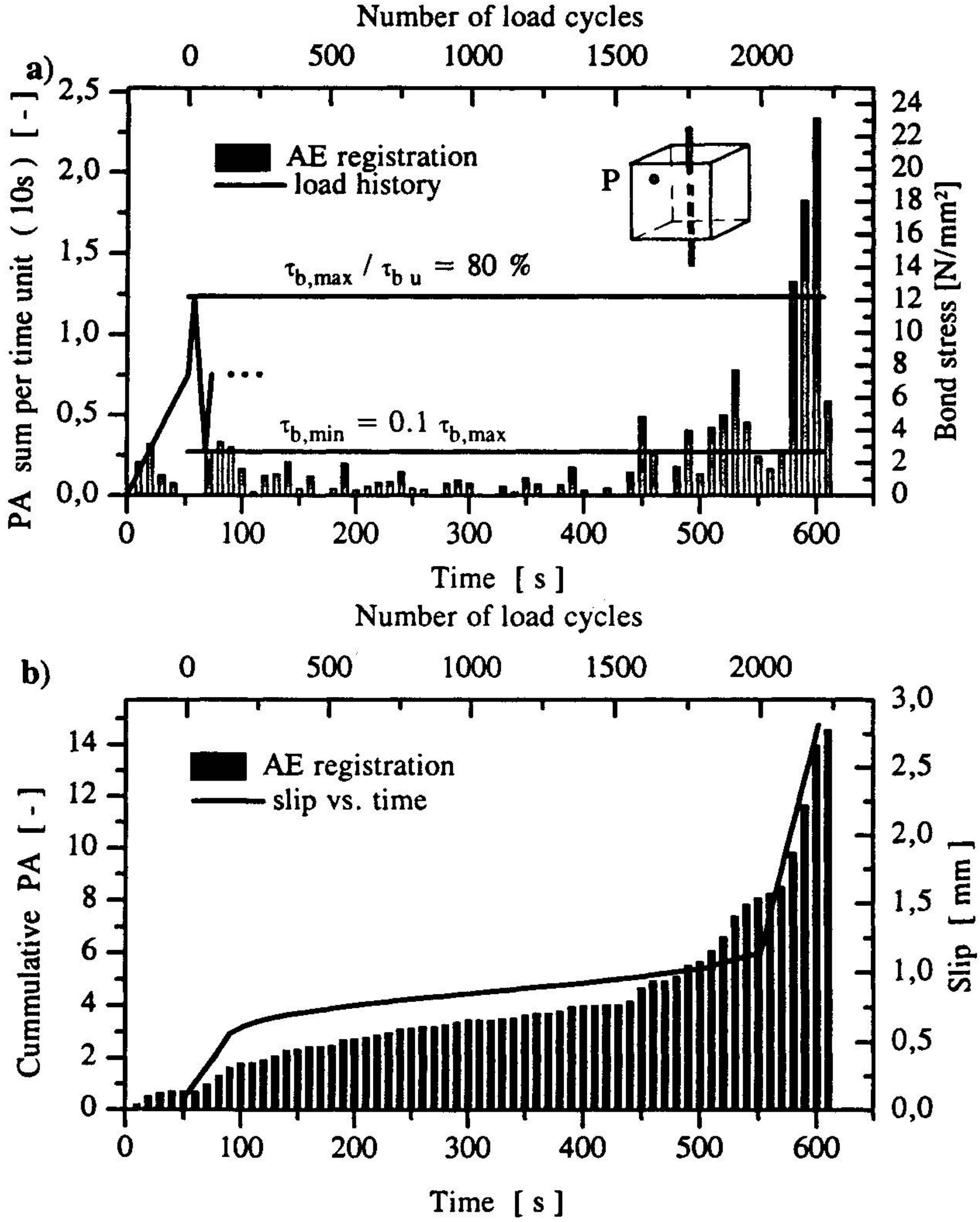

Fig.2 Cyclic pull-out test with *one load level* to pull-out failure (P: piesotransducer)
a) PA sums in 10 sec intervals and τ_b vs. time b) Cum. PA vs. time

5. ACKNOWLEDGEMENTS

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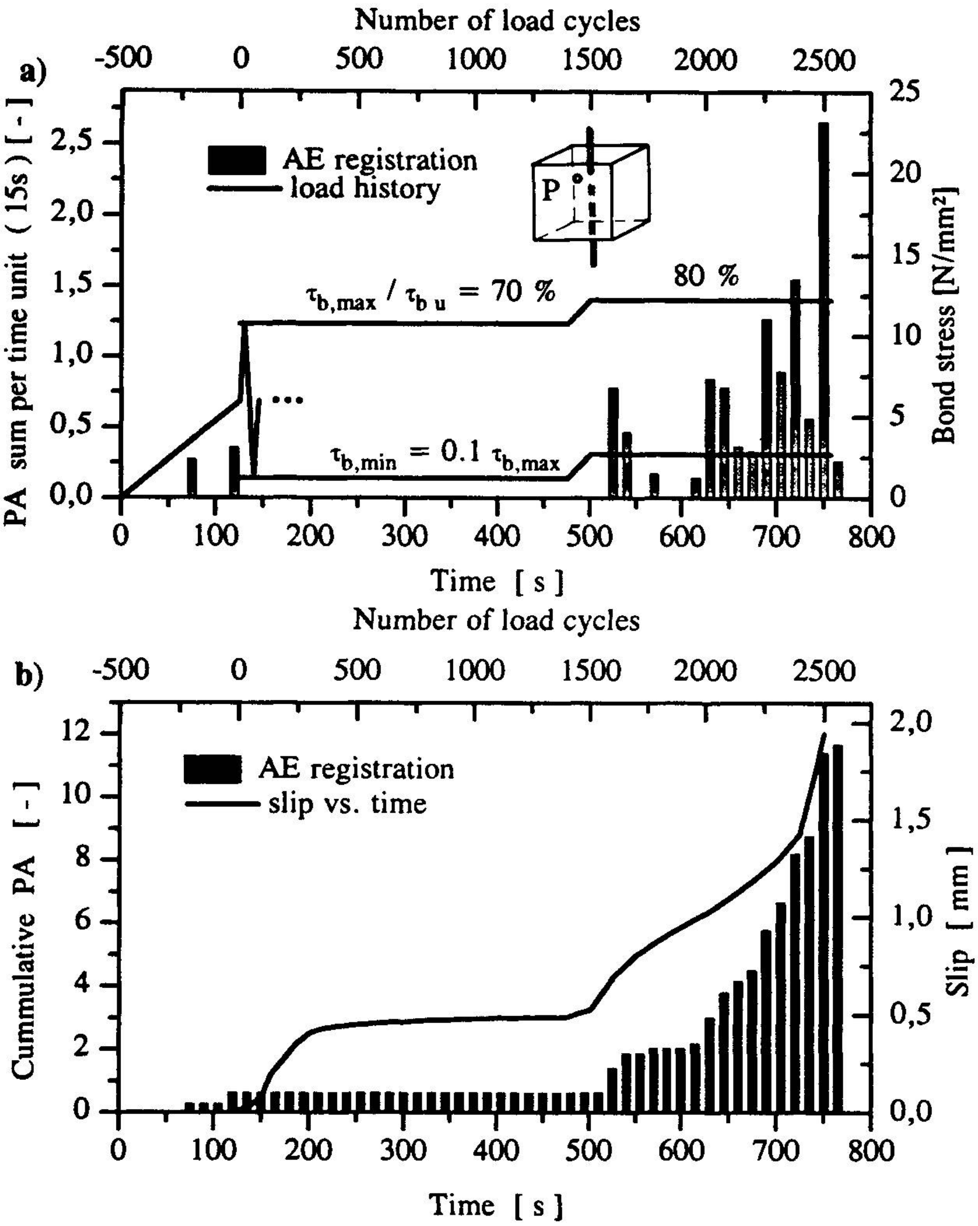

Fig.3 Cyclic pull-out test with *two load levels* to pull-out failure

a) PA sums in 15 sec intervals and τ_b vs. time b) Cum. PA vs. time

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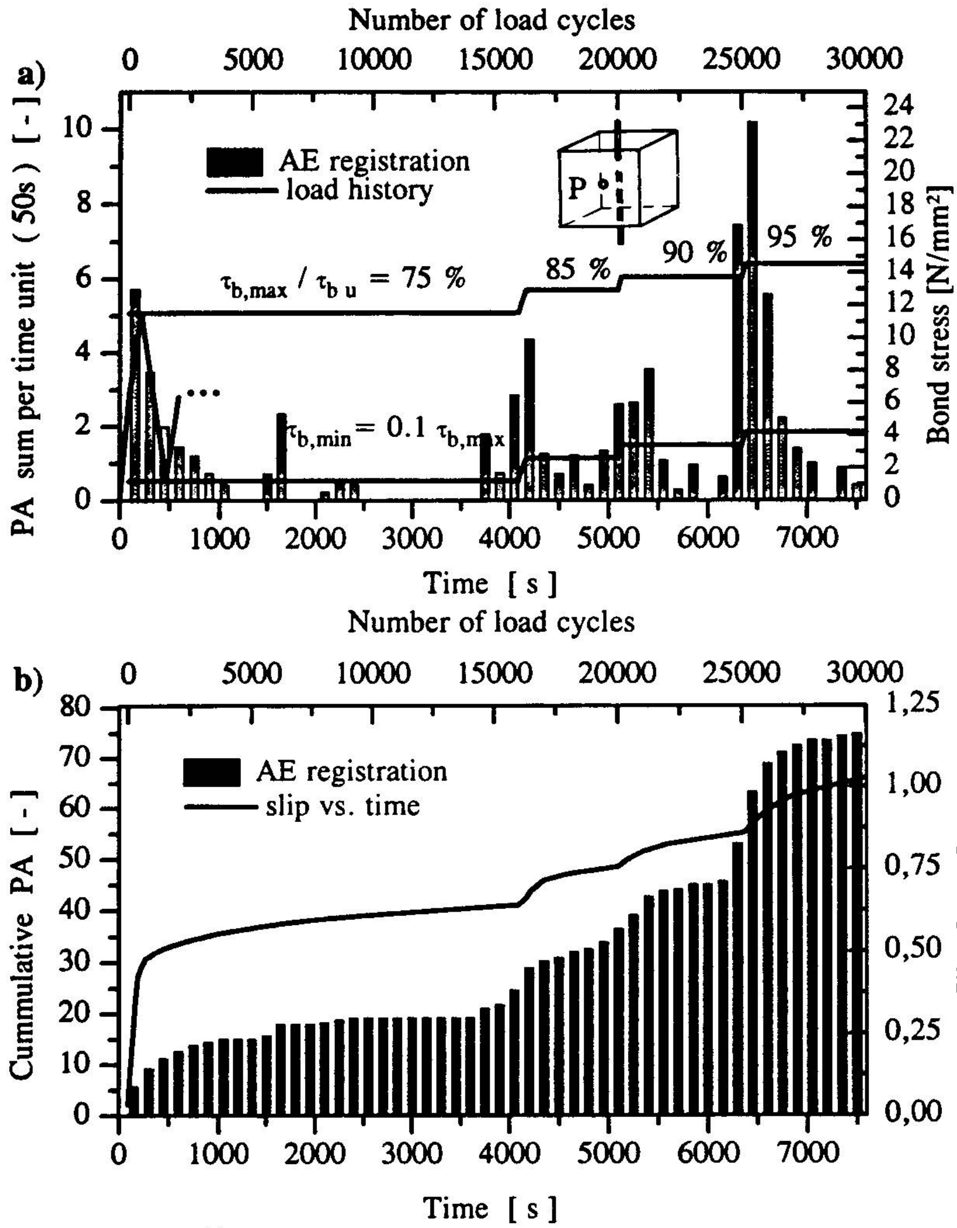

Fig.4 Cyclic pull-out test with *four load levels*
a) PA sums in 50 sec intervals and τ_b vs. time b) Cum. PA vs. time