NDT-CE 2022 - The International Symposium
on Non-destructive Testing in Civil Engineering
Zurich, Switzerland, August 16-18, 2022

Performance of acoustic emission and digital image correlation for fracture analysis in cementitious mortars under fatigue loading

Nuhamin Eshetu DERESSE[1*], Mina SAREM[2], Hussein NASSER[1], Stijn FRANÇOIS[2], Els VERSTRYNGE[1]

[1] Materials and Constructions Section, Department of Civil Engineering, KU Leuven, 3001 Leuven, Belgium
[2] Structural Mechanics Section, Department of Civil Engineering, KU Leuven, 3001 Leuven, Belgium

*Corresponding author: *[nuhamineshetu.deresse@kuleuven.be]*

Abstract
Fatigue loading in brittle materials introduces damage at a micro-scale. These micro-fractures can accumulate and cause a significant reduction in material stiffness or even lead to structural failure. Deformation-based monitoring techniques can be inadequate when detecting damage at a micro-level. Hence, here is where advanced non-destructive testing (NDT) methods such as acoustic emission (AE) and digital image correlation (DIC) can play a great role. The paper aims to combine AE and DIC for advanced fatigue damage analysis on a cylindrical sample subjected to a fatigue Brazilian splitting test. The damage progress quantified from cumulative AE event count, and horizontal displacement measured with DIC showed a very good correlation. The damaged region was identified with an AE localization plot and with a DIC displacement field plot, the damaged area was well represented by both techniques.

Keywords: Fatigue; cementitious mortars; acoustic emission; digital image correlation; fracture process zone.

1 Introduction

Concrete structures are commonly subjected to cyclic loading due to a variety of sources. Examples include earthquakes, traffic loads on bridges and road pavement, wind and wave loading on offshore structures, or thermal loading. When a load is not large enough to cause failure in a single static application yet causes failure with a repetitive application, it is regarded as fatigue failure. Fatigue deterioration is the progressive fracture of materials due to cyclic loads. The repetitive loading causes damage to progress and finally leads to fatigue fracture [1-4]. Under fatigue load, each load cycle introduces damage that accumulates and results in a change in the material stiffness [4]. Hence, fatigue damage monitoring requires measurements with high sensitivity to micro-changes, such as acoustic emission (AE) sensing and digital image correlation (DIC) [5].

In this research, fatigue Brazilian splitting tests are performed on cementitious mortar cylinders. The damage progression is monitored with both AE and DIC. The aim is to compare the performance of the two monitoring techniques in the case of fatigue loading.

2 Experimental methods

Cement mortar samples were made using CEMII/B (S-L) 32.5 N cement type with a composition of 533 kg/m³; 1600 kg/m³ river sand with a maximum aggregate size of 4 mm and 0/2 grain size curve distribution and 266.5 l/m³ water. A mortar cylinder with 27 mm in diameter

https://doi.org/10.58286/27192

and length is prepared in a mold for the fatigue Brazilian splitting test . AE monitoring during the tests was carried out using six piezoelectric broadband sensors (Digital Wave B1025). The sensor layout is shown in Figure 1. In this experiment, stereo-DIC was used to obtain a full-field displacement measurement of the region of interest (ROI)random speckle patterns were manually created by using 0.1 mm thick black pen, as done in [10] (see Figure 1).. They were set to capture the circular surface of the cylindrical sample at 5 second intervals. A step-wise fatigue test was employed by a universal testing machine (Shimadzu AG-X) with a maximum capacity of 100 kN. The test was performed with constant displacement rates of 0.5 mm/min with a fixed upper and lower load limit.

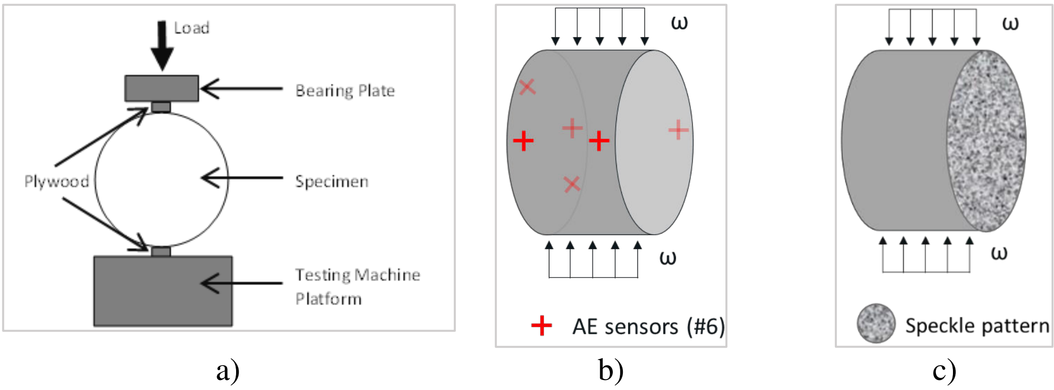
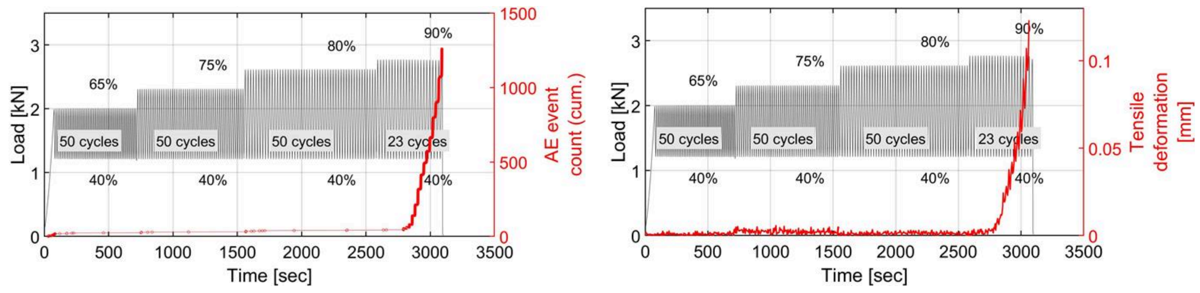


Figure 1: a) test setup of the Brazilian splitting tests b) AE sensor layout and c) speckle pattern of the DIC monitoring technique.

3 Results

3.1 Fatigue damage analysis from DIC displacements and AE parameters

Figure 2 presents the time-load and time-cumulative AE events count of a step-wise fatigue Brazilian splitting test. It also shows the time evolution of the tensile deformation, measured by a virtual extensometer on the DIC horizontal displacement results. During the first stage of loading (65%), there was very low AE activity and no significant increase in DIC-based tensile deformation was noticed. Hence, in this first stage, there is an absence of irreversible change resulting in the lack of significant AE activity. Throughout the second and third loading stages no significant change occurred in either of these parameters. This means that at those load levels (75 % and 80 %), 50 cycles were not sufficient to induce fatigue damage. In the initial cycles of the fourth loading stage (1^{st} to 8^{th} cycle), the damage introduced by each loading cycle was not large enough to be captured by AE or DIC. However, after passing the critical stage (after the 14^{th} cycle) the gradually growing damage was noticed by the progressively increasing AE activity and DIC-tensile deformation (see Figure 2 a) and Figure 2 b)). It was also observed that fatigue loading causes a relatively more gradual rise in AE activity than the steep rise in AE activity identified for monotonic Brazilian splitting tests on similar samples [3, 7].

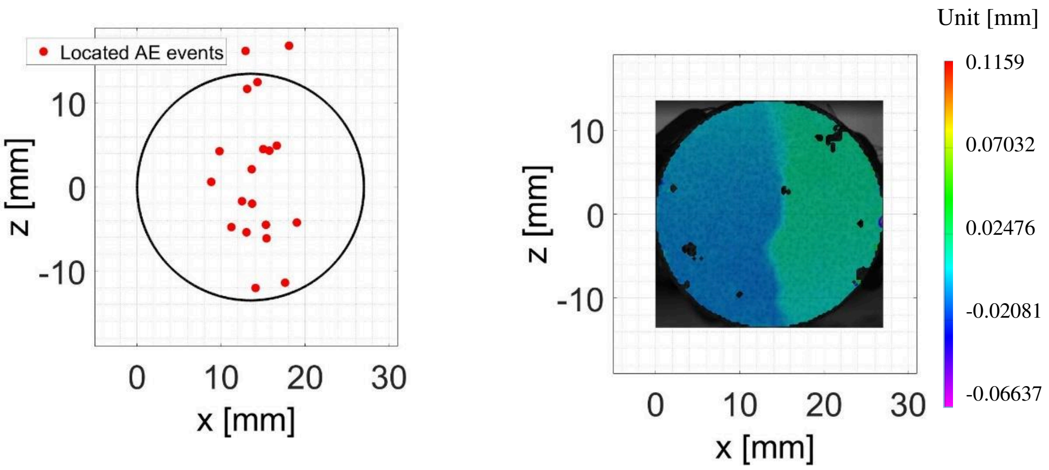


a) b)

Figure 2: a) load-time curve with cumulative AE event count and b) DIC based tensile deformation of a step-wise fatigue Brazilian splitting test.

3.2 Measuring the size of the fracture process zone (FPZ) with AE and DIC

Figure 3 shows the localization plots of the AE events (red dots) and the horizontal displacement (u) field plot of the crack initiation of the load cycle (i.e. the 14^{th} cycle. Here, only the AE events located within the region Y = -10 to 10 mm (i.e., near the surface where DIC is operating) are plotted. The overall damaged region is represented by the area with the high density of located AE events and the region with opposite signs of horizontal displacement. In general, both methods were able to identify the overall damaged region.



a) b)

Figure 3: Identifying damaged zones a) from the AE localization plot and b) from the horizontal displacement field of the DIC analysis at 14^{th} cycle of the of the last loading stage.

4 Conclusions

The research compared the performance of acoustic emission (AE) and digital image correlation (DIC) in fatigue fracture monitoring. The damage growth rate quantified with cumulative AE event count and DIC-based horizontal deformation showed a similar growth pattern. The damaged region was well represented by both the AE localization plot and the displacement field plot.

Acknowledgements

This research was funded by Research Foundation - Flanders (FWO project No. G088920N).

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