Fracture process of recycled aggregate concrete using acoustic emission technique under tension

Natalie Williams Portal
M.Sc., Ph.D., researcher
RISE Research Institute of Sweden, Applied Mechanics
Box 857 SE-501 15 Borås, Sweden
E-mail: Natalie.williamsportal@ri.se

Mathias Flansbjer
M.Sc., Ph.D., Adj. Prof., researcher
RISE Research Institute of Sweden, Applied Mechanics
Box 857 SE-501 15 Borås, Sweden
E-mail: Mathias.flansbjer@ri.se

ABSTRACT
Recycled concrete aggregate (RCA) was processed from reinforced concrete edge beams sourced from a demolished bridge in Sweden. The RCA replaced different ratios of coarse aggregate in a benchmark concrete. Acoustic emission (AE) measurements were conducted in conjunction with cyclic uniaxial tensile tests to characterize the tensile behaviour, micro-crack initiation and development, as well as crack localization. The AE measurements indicated similarities between the micro-crack initiation and development for the tested concrete mixes.

Key words: Recycle concrete aggregate, Sustainability, Testing.

1. INTRODUCTION

1.1 Background
Circularity in the construction sector supports the responsible use of concrete as a building material. Residual concrete or demolition concrete waste can be crushed and recycled as aggregates and applied in new concrete or as filler materials; the result of this being denoted as Recycled Concrete Aggregates (RCA). In this work, funded by Infrasweden 2030: a strategic innovation program, RCA was retrieved from processing concrete edge beams from a bridge in Gullspång, Sweden. This bridge was originally constructed in 1935 and demolished in 2016 due to heavy corrosion.

1.3 Recycled aggregate concrete
The edge beams from the demolished bridge were processed with a transportable jaw-crusher that produced a recycled aggregate that included coarse and fine fractions. The processed material offered a continuous grain size distribution and it was divided into conventional sand (0/4 mm) and gravel fractions (8/16 and 16/25 mm). A low percentage of the crushed material was >25 mm which could undergo further crushing to yield smaller fractions. Only the coarse fraction (>4 mm) of this recycled aggregate was employed.

The effect of recycled aggregates in concrete with 0 %, 20%, 50% and 100 % of coarse recycled aggregates was analysed. The concrete composition also included natural granitic sand (0/4 mm) and gravel (4/16) as base materials. The cement used was a CEM I 42.5 R, which is very common in Swedish practice. Further information related to the benchmark concrete can be found in [1].

2 UNIAXIAL TENSILE TESTS

The tensile behaviour, in terms of tensile strength, fracture energy and softening behaviour, of the investigated concrete materials was characterised using uniaxial tensile tests (UTT). Tests were conducted on notched cylinder specimens with fixed end conditions in accordance with RILEM recommendations [2, 3]. Both monotonic (presented elsewhere [4]) and cyclic tensile tests were performed on RCA and benchmark materials.

2.1 Test setup

The UT tests were performed in a GCTS servo-hydraulic machine with a high-stiffness load frame and displacement control. A moment stiff loading device was applied to suppress rotations of the load plates that could lead to bending failure. The loading device was pre-tensioned with a load of 150 kN. The load cell used was rated up to 200 kN and the accuracy of the load measurement was within 1%. Displacement was measured locally over the notch with three inductive displacement transducers with a gauge length of 31 mm. The transducers had a measuring range of ±2.50 mm and a relative error of less than 1%.

2.2 AE measurements

The AE measurements and analysis were performed using an eight-channel Micro-II Digital AE system by Physical Acoustics Corporation. Eight AE sensors (Micro-30S) were used during the tensile testing, whereas four sensors were placed close to each end face according to Fig. 1. A pre-amplification of 40 dB and a threshold level of 50 dB were used. The hit detection parameters were set to PDT = 100 μs, HDT = 200 μs and HLT = 200 μs for all tests. At the time of each registered AE event, the load, actuator displacement and the displacement of the of three displacement transducers were also recorded in the AE system. The waveform of every hit was also recorded and stored for all channels with a sample rate of 1 MSPS.

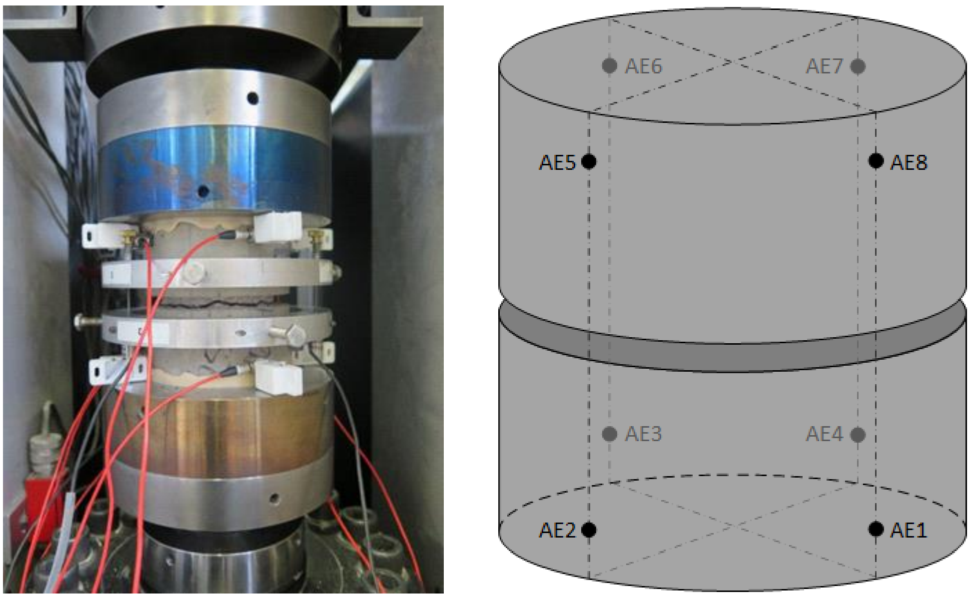

Figure 1 – Uniaxial tensile test setup. Left: AE sensors during cyclic testing. Right: Schematic of AE sensor locations and numbering.

3 RESULTS

3.1 Cyclic tensile tests

Cyclic tensile tests were performed on one specimen of the benchmark (0%) and of each RCA material. The stress-displacement relationships from the four tests, namely RT-5 (benchmark), R20T-4 (20%), R50T-4 (50%) and R100T-4 (100%) are shown in Fig. 2.

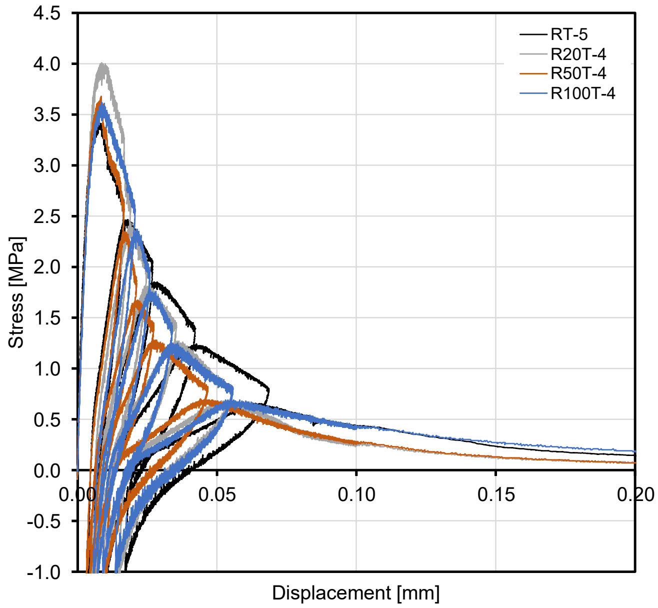

Figure 2 – Stress-displacement relations for RT-5 (benchmark), R20T-4 (20%), R50T-4 (50%) and R100T-4 (100%).

From the stress-displacement curves, it can be observed that some irreversible deformation occurs during the crack closing cycles in conjunction with an increasing hysteresis effect with each cycle. The change in slope is notable during both the crack opening and closing phases, as a result of the tensile to compressive loading of the fracture zone. Resultantly, the increased damage in the fracture zone leads to a successively decreased stiffness in the crack opening phase for each cycle.

3.2 AE measurements

The development of AE activity (hits), crack opening and stress with respect to time are presented in Fig. 3 for the cyclic tensile tests. The macro-crack initiation that is assumed to take place at peak stress is marked with a dashed line, while the crack closing phases are highlighted as grey zones in the figures. The hits are zero during the first elastic stage in the pre-peak regime yet increase during the second stage associated with micro-crack initiation taking place shortly before peak stress. Thereafter, they increase rapidly at the macro-crack initiation around peak stress. The AE activity reduces when the crack closing cycle starts, and the tensile stress is unloaded. The hits are much lower during the closing phases compared to the opening phases, although they increase marginally when the fracture zone is subjected to compressive stress. In subsequent crack opening phases, activity initially decreases, but significantly increases at a crack opening which is smaller than the maximum crack opening achieved in the previous cycle.

The overall characteristics captured by the AE activity are rather similar for all specimens, but the amount of activity slightly differs. When comparing R20T-4, R50T-4 and R100T-4, there is a tendency towards the amount of hits decreasing with an increasing amount of RCA replacement, which in turn could signify differences in the fracture process.

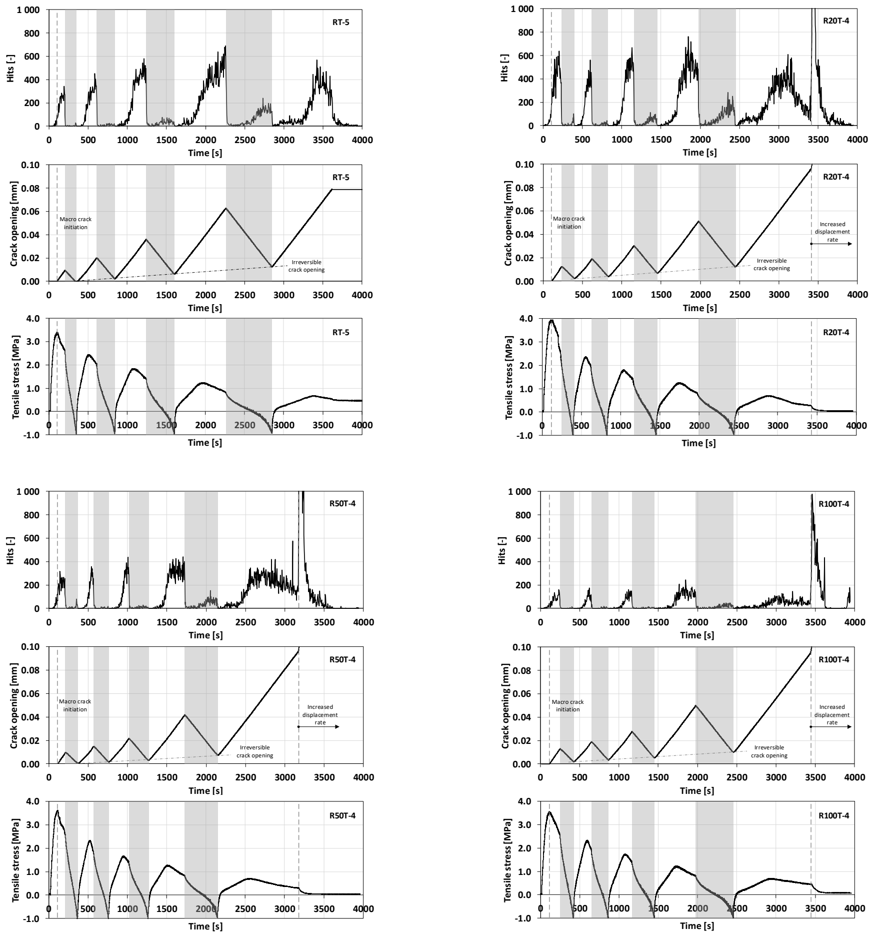

Figure 3 – Cyclic tensile test results summarized as Hit-time relation (upper), crack opening-time relation (middle) and stress-time relation (lower). Left-top: RT-5. Left-bottom: R50T-4. Right-top: R20T-4. Right-bottom: R100T-4.

4 CONCLUDING REMARKS

The AE activity measured during cyclic tensile tests could be related to the different stages of the fracture process, associated with micro-crack initiation in the pre-peak regime, macro-crack initiation around peak stress, as well as the crack opening and crack closing cycles taking place during the post-peak regime. The results also indicated similarities between the fracture process for the benchmark and RCA mixes.

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