Experimental investigation on long-term flexural behavior of prestressed Alkali-activated concrete (AaC) girders with cast-in-situ AAC topping

Zhenxu Qian[1], Guang Ye[2], Stijn Matthys[3] and Mladena Luković[4]

[1, 4] Engineering Structures, Delft University of Technology, Delft, The Netherlands. (E-mail: Z.Qian-2@tudelft.nl, M.Lukovic@tudelft.nl)

[2] Materials, Mechanics, Management & Design (3MD), Delft University of Technology, Delft, The Netherlands. (E-mail: g.ye@tudelft.nl)

[3] Department of Structural Engineering and Building Materials, Ghent University, Ghent, Belgium. (E-mail: Stijn.Matthys@UGent.be)

HIGHLIGHTS

- Higher shrinkage and creep effects, which do not reach plateau within 9 months, and relatively lower elastic modulus compared to conventional concrete, result in large prestress losses in AAC.
- Long-term material and structural tests are necessary to assess material properties, cracking moment and ultimate resistance for prestressed applications of AAC.
- Relying on test results at 28 days, like with conventional concrete, will result in an unsafe design of AAC.

Keywords: alkali-activated concrete (AAC), prestressed girder, long-term flexural behavior

INTRODUCTION

Alkali-activated concrete (AAC), in which the binder is formed by the chemical reaction between precursors and alkali activator, has emerged as a promising alternative to conventional concrete (CC). Despite the promising material properties of some AAC mixtures, the structural application is limited. Thus, researchers have shifted their target to AAC structures to establish fundamental knowledge for structural design. The focus of the research so far is on the short-term behavior of reinforced AAC elements. From the literature, it is concluded that reinforced AAC has similar short-term flexural and shear behavior with CC counterparts [1]. Few researchers gave insight into the feasibility of AAC in prestressed elements by studying their short-term flexural capacity and cracking behavior [2-3]. But prestressed AAC as well as its long-term performance has not been widely involved in the state of art. This paper aims to experimentally investigate the long-term flexural behavior of prestressed AAC girders with cast-in-situ AAC topping, which is a commonly used structural system in Dutch construction and therefore could promote the large-scale application of AAC.

In this experimental program, three individual girders with a nominal length of 7000mm, consisting of the precast girder and cast-in-situ topping were fabricated. Self-compacting AAC with the strength class of C45/C55, consisting of blast furnace slag (BFS) as the precursor and activated by a sodium-based alkaline activator, was developed to produce the precast girder [4]. Ready-mixed AAC provided by Cementbouw Betonmortel B.V. was used as cast-in-situ topping. The cross-sectional dimensions and the layout of prestressing strands/ reinforcement of precast girder and topping concrete are illustrated in Figure 1a and 1b, respectively. Prestress was introduced by cutting the strands at 2.75 days after casting of girders. The precast girders were covered with wet burlaps and plastic sheets for

30 days. Afterward, ready-mixed AAC was poured and the composite girders were made. One composite girder, covered with moist burlaps and plastic sheets until the testing age, was tested at the age of 28 days (short-term flexural test, STF). The other two composite girders, which were wrapped with plastic sheets for 3 days and exposed to lab condition for long-term monitoring, were tested at the age of 267 days and 274 days (long-term flexural tests: LTF and LTF_LS, respectively). One of them (LTF_LS) was subjected to sustained load until the testing age. The sustained loading regime consisted of point loads of 70kN applied for 158 days, and subsequently being increased to 130kN for 76 days. Four-point bending configuration was adopted in both monotonic and sustained loading tests (Figure 2). LVDTs were used to measure the midspan deflection. Digital Image Correlation (DIC) was applied to monitor the crack development in the constant moment zone.

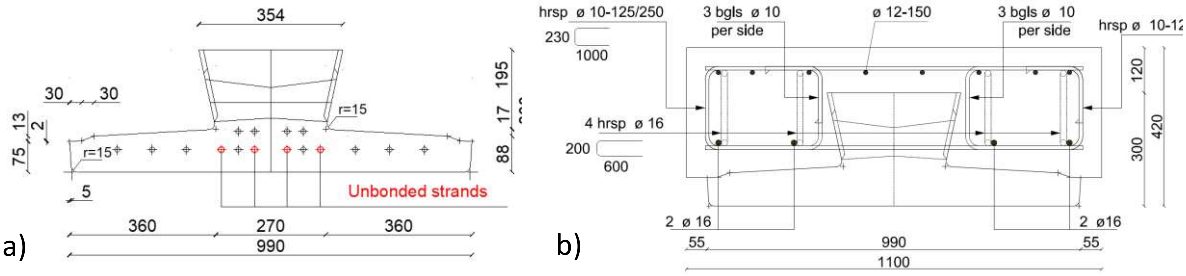

Figure 1. Cross-section of a) prestressed AAC girder with the layout of prestressing strands (16 strands ø12.9, 4 of them being debonded over a length of 1m) and b) composite girder with the layout of reinforcement in topping concrete.

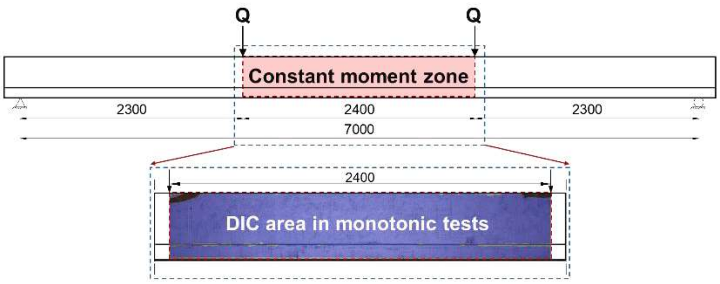

Figure 2. Position of (sustained) load in test setup.

RESULT & DISCUSSION

The long-term midspan deflection of specimen LTF and LTF_LS is plotted in Figure 3. Note that a negative value represents hogging trend of the girder while a positive value represents sagging trend. Almost the exactly same deflection development of two specimens was observed in the initial stage. The downward deflection of LTF_LS reached a plateau shortly after applying the load of 70kN. Once loaded with 130kN, the deflection increased and kept increasing gradually for the next three months. Minor flexural cracks were found at the soffit of LTF_LS within the constant moment region. The unloaded specimen (LTF) kept deforming upwards, which might be mainly attributed to the large creep effects. A horizontal crack between precast girder and topping concrete was observed for both specimens and resulted in the stiffness reduction.

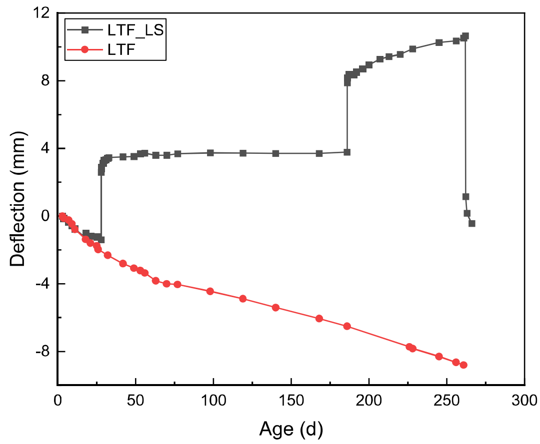

Figure 3. Long-term midspan deflection of LTF and LTF_LS.

In Figure 4, the load-deflection curves of all girders under four-point bending are shown. In the short-term test, although approaching the yielding of the prestressing strands, the maximum stroke of the jack was reached, and the specimen did not fail. The measured strain level in the concrete at the height of prestressing strands was 4.1mm/m, which was slightly lower compared to the yielding strain of 5mm/m.

On the other hand, in the long-term test girder (LTF), anchorage failure occurred at the loading level that was lower than the one in the short-term test. Finally, concrete crushing, as an indicator of flexural failure, was observed in LTF_LS. The change of failure mode might be related to the different bond capacities between strands and AAC, and different creep effects. The reduction of Hoyer effect due to creep and shrinkage causes the decrease of bond strength [5]. Since the application of sustained load results in a lower stress level in LTF_LS compared to LTF, the degradation of bond capacity in LTF_LS might be less significant.

Note that different loading schemes were applied in beams and significant nonlinearity after applying load cycles with high load levels was observed. Therefore, the focus of comparison of flexural test results of three girders was on the load-deflection relationship and cracking behavior until 195kN. At the same load level, LTF had the largest midspan deflection compared with the other specimens, indicating its lowest stiffness. Considering the cracking behavior, multiple cracks on the side surface of LTF were already observed at 130kN, unlike cracking in the other samples that first occurred at 160kN and 190kN for LTF_LS and STF, respectively. LTF showed both earlier cracking and larger cracks compared with LTF_LS (see Figure 5).

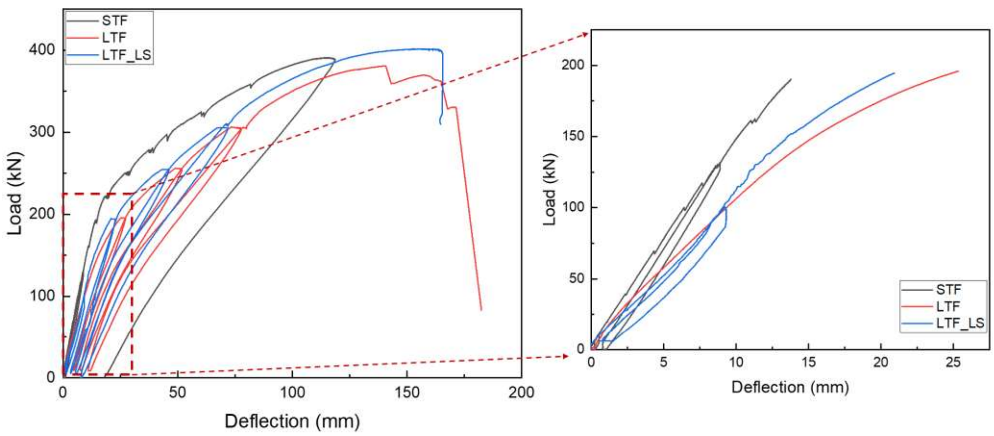

Figure 4. Load-deflection relationship of STF, LTF and LTF_LS.

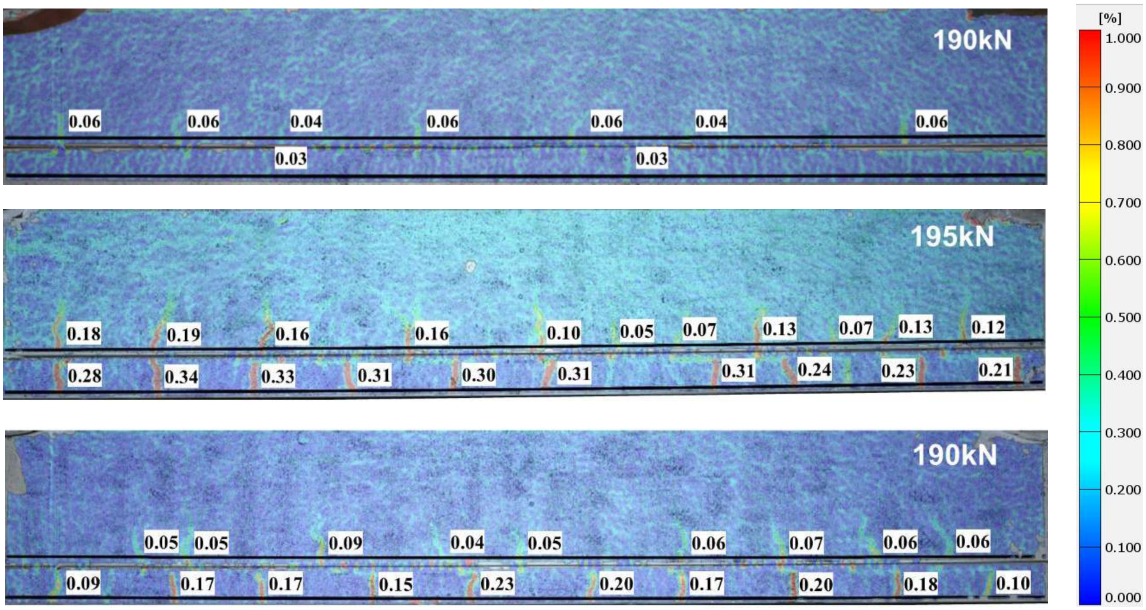

Figure 5. Crack pattern of STF, LTF and LTF_LS at around 190kN (measurement points in the tests).

The difference in the short-term and long-term flexural behavior of the three girders might result from the decrease of elastic modulus of AAC [4] and the significant prestress loss induced by pronounced shrinkage and creep effects [4]. The bond degradation also seems to play a role. Therefore, evaluating the structural resistance of AAC based on short-term test results, similar to CC, will lead to an unsafe prediction of ultimate capacity and cracking performance. Conducting long-term tests is necessary for AAC structural design.

CONCLUSION

This paper presents the experimental investigation of the long-term structural behavior of prestressed AAC girder with cast-in-situ AAC topping. Short-term and long-term flexural tests, including sustained loading tests and residual strength tests, were conducted. Based on the experimental results, the following conclusion could be drawn:

(1) Deflection of the specimen subjected to sustained load reached plateau while the unloaded specimen kept deforming upward, indicating the ongoing and pronounced creep effects.

(2) Compared with the specimen tested at 28 days, specimens tested at around 9 months showed lower stiffness and cracking resistance. Different creep effects induced by different stress levels play a role in structural behavior. This is in line with observations on the two girders exposed to different stress levels where sustained load has beneficial effects, thereby reducing stress level at the level of prestressing strands and reducing creep effects. Bond degradation also seems to play a role.

(3) It is of vital importance to investigate the long-term behavior of AAC structural members. Simply relying on the test results at 28 days will cause an unsafe structural design.

ACKNOWLEDGMENT

The authors would like to express their appreciation for the support of the sponsors with Project No CM2B17.

REFERENCES

[1] Mo, K. H., Alengaram, U. J. and Jumaat, M. Z. Structural performance of reinforced geopolymer concrete members: A review. *Construction and Building Materials* 120 (2016), 251-264.

[2] Liu, H., Lu, Z. and Peng, Z. Test research on prestressed beam of inorganic polymer concrete. *Materials and Structures* 48 (2015), 1919-1930.

[3] Sonal, T., Urmil, D. and Darshan, B. Behaviour of ambient cured prestressed and non-prestressed geopolymer concrete beams. *Case Studies in Construction Materials* 16 (2022), e00798.

[4] Zhang, S., Luković, M., Herder, H., Scharringa, A. and Ye, G., Geopolymeerbeton voor infrastructurele toepassingen (1): Ontwikkeling van zelfverdichtende mengsels. *Cement: vakblad voor de betonwereld* 2022(7), 42-50. https://www.cementonline.nl/geopolymeerbeton-voor-infrastructurele-toepassingen-1

[5] Barnes, R. W., Grove, J. W., and Burns, N. H. Experimental assessment of factors affecting transfer length. *Structural Journal* 100 (2003), 740-748.