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GEOCON BRIDGE

Geopolymer Concrete Mixture for Structural Applications

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Abstract

The sustainability of infrastructure projects is becoming increasingly important issue in engineering practice. This means that in the future the construction materials will be selected on the basis of the contribution they can make to reach sustainability requirements. Geopolymers are materials based on by-products from industries. By using geopolymer concrete technology it is possible to reduce our waste and to produce concrete in the environmental-friendly way. An 80% or greater reduction of greenhouse gases compared with Ordinary Portland Cement (OPC) can be achieved through geopolymer technology. However, there are limited practical applications and experience. For a broad and large scale industrial application of geopolymer concrete, challenges still exist in the technological and engineering aspects.

The main goal of GeoCon Bridge project was to develop a geopolymer concrete mixture and to upscale it to structural application. The outputs of projects provide input for development of recommendations for structural design of geopolymer based reinforced concrete elements. Through a combination of laboratory experiments on material and structural elements, structural design and finite element simulations, and based on previous experience with OPC concrete, knowledge generated in this project provides an important step towards a “cement free” construction. The project was performed jointly by three team members: Microlab and Group of Concrete Structures from Technical University of Delft and Technical University of Eindhoven.

Keywords

concrete, geopolymer, reinforced, strength, bridge, compressive

Main results and recommendation

Optimization of geopolymer concrete mixture

The main aim of this task is optimization of the geopolymer mixtures for structural application. This was performed by characterization of workability, mechanical (compressive strength, flexural strength, elastic modulus, etc.) and shrinkage properties of geopolymer paste, mortar and concrete. Several mixtures developed in the Microlab have been initially considered for optimization of the setting time, workability and mechanical properties. The optimized mixture is shown in Table 1. The workability, compressive strength, flexural strength and elastic modulus of the optimized concrete are measured after 7, 28 and 90 days of wet curing and are shown in Fig. 1 - Fig. 4.

table 1

FIGURE 1 Slump test of optimized concrete mixture.

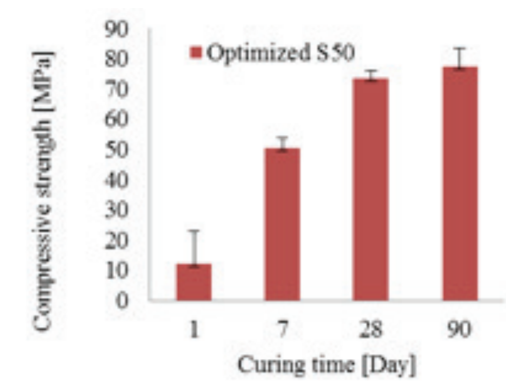


FIGURE 2 Compressive strength test results for reference and optimized mixture.

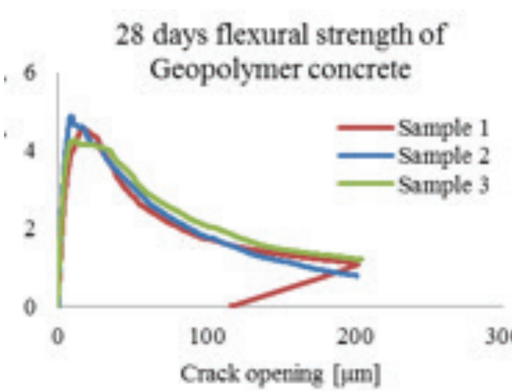


FIGURE 3 Flexural strength at 28 days.

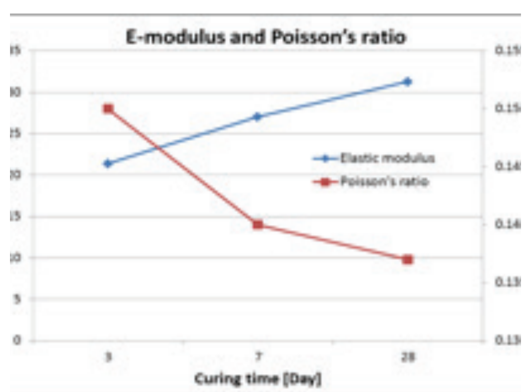
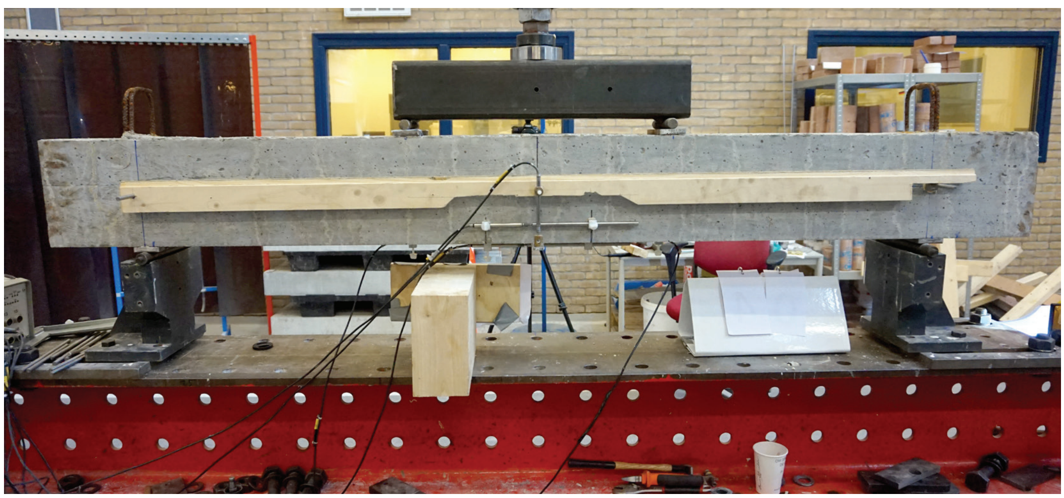


FIGURE 4 E-modulus and Poisson's ratio.

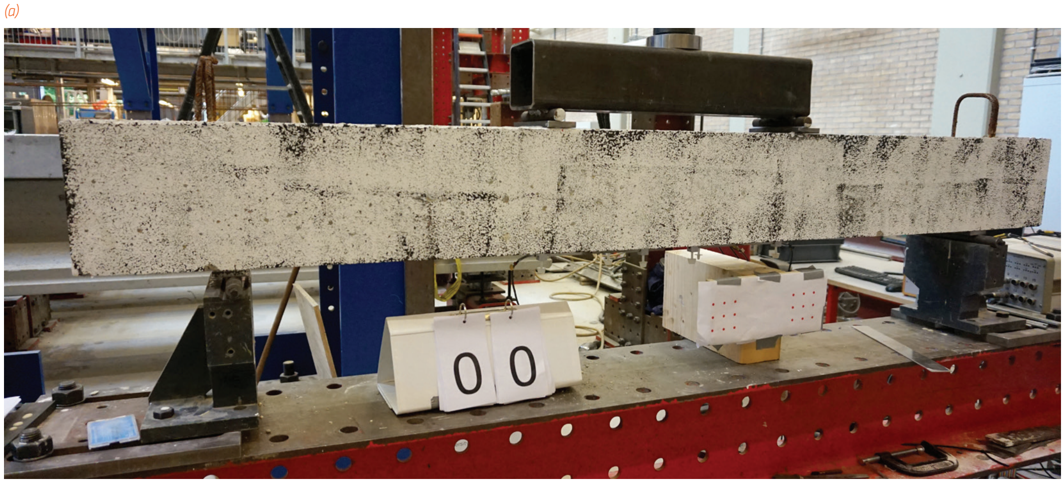
The properties of the optimized mixture are used for upscaling to geopolymer reinforced concrete element and as input for the structural design of the geopolymer bridge.

Upscaling and structural application

The current design codes for concrete structures are based on compressive strength (concrete class) and most of the other mechanical properties that are used in calculations (e.g. E-modulus, tensile strength, flexural strength, etc.) are based on known relations between these properties and the compressive strength. Therefore, the first step was to investigate if the relations, valid for conventional concrete, are also valid for the geopolymer concrete. Furthermore, the long term development of mechanical properties over time, as well as structural behaviour of the reinforced elements over time had to be known. The flexural behaviour (flexural capacity, crack width and crack spacing) of reinforced geopolymer beams for optimized mixtures were examined (Figure 5). Generally, for similar compressive strength, flexural and splitting strength of geopolymer concrete are similar to the flexural and splitting strength of conventional concrete. However, the E-modulus of geopolymer concrete is around 20% lower than of the conventional concrete and this should be considered in the structural design of geopolymer concrete. Based on long term mechanical tests it was found that probably curing conditions that are commonly used for concrete (wet curing until the age of 28 days) might not be appropriate for geopolymer concrete.



(a)



(b)

FIGURE 5 Test set-up: painted side of beam for image analysis (a) and LVDTs to measure deformation (b).

Results on reinforced geopolymer beams showed that the structural performance of geopolymer concrete (flexural capacity, crack spacing and crack width) is quite similar to OPC concrete control beam (that had similar E-modulus, but lower compressive strength) (Figure 6). The results of the four-point bending tests shows that the stiffness of reinforced geopolymer concrete is lower than the stiffness of OPC concrete, and confirm that the overall stiffness of reinforced AAC is decreasing over time, as the beam tested at an age of 69 days show a lower stiffness than the beam tested at an age of 33 days. Possibly due to this reduced stiffness, reinforced AAC beams show larger deflections and exhibits more ductile behavior (higher rotational capacity) compared to reinforced OPC concrete, which is consistent with results reported by (Shah & Shah, 2017). However, care should be taken with the large deflections that might be governing with the design of reinforced concrete (and geopolymer) bridge. Therefore, focusing on a prestressed geopolymer bridge, where benefits of fast hardening can also be utilised, might be more promising than design and execution of a reinforced geopolymer bridge. Then, beside the investigated mechanical properties, creep and shrinkage of the geopolymer mix become very important and have to be investigated in future.

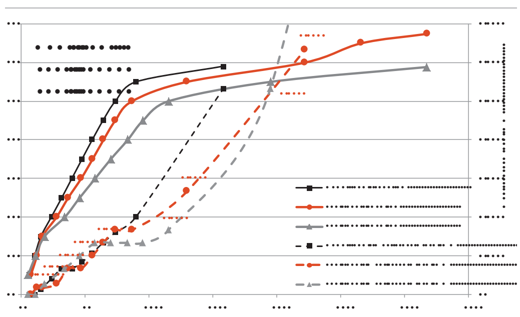


FIGURE 6 Development of cracks during four-point bending tests on S50 beams at 33 and 69 days and comparison with OPC concrete control beam, results by Zhekang Huang. S50 specimens have been cured (20°C and 95% RH) for 28 days. After this, the samples were exposed to laboratory conditions (20°C and 55% RH) until testing. OPC concrete was kept in the mould for 33 days (covered with plastic) in lab conditions and then unmoulded.

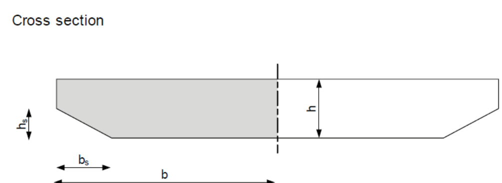
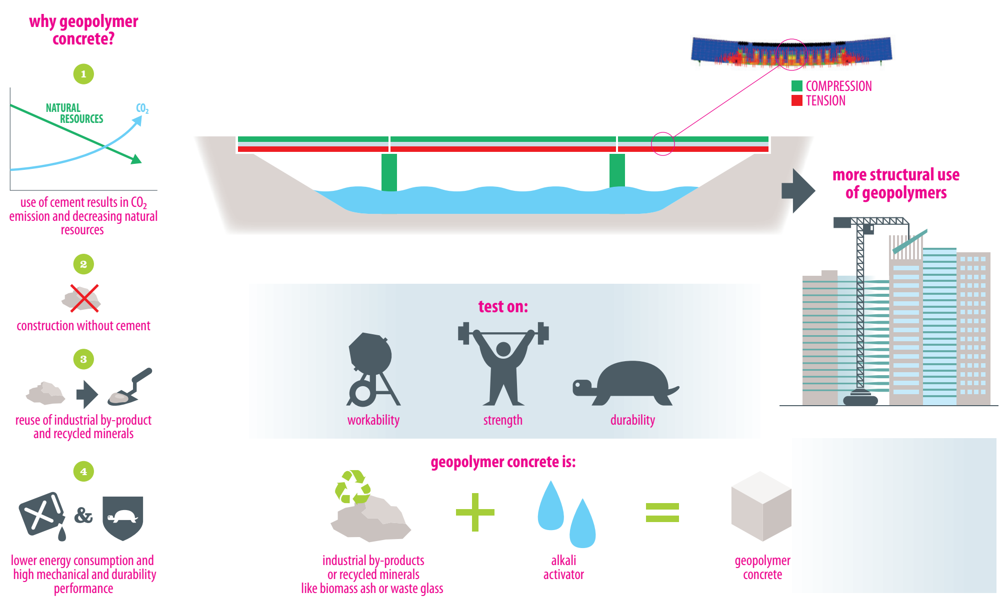


FIGURE 7 Geopolymer concrete bridge

Design of geopolymer concrete bridge

A reinforced geopolymer concrete bridge was designed. The calculation has been made for a bridge with a span of 12 m and a width of 3 m The total height is chosen equal to 350 mm (see figure 7). The mechanical properties of geopolymer concrete were taken from the optimized mixture. The required amount of reinforcement were calculated and it seems practical. The deformations value of 58 mm due to the permanent load without creep effects being considered seems rather large. Recalculation should be done when the shrinkage and creep tests are completed.

FIGURE 8 Reinforced geopolymer concrete bench made of the optimized geopolymer concrete mixture. The bench has been located in the street G.J. de Jonghweg, Rotterdam.



Main output of the project

- The work performed in Microlab was done within the additional master thesis project of Zainab Aldin. The optimized mixture was also applied in the design and production of reinforced geopolymer concrete bench. The bench has been placed in the street G.J. de Jonghweg, Rotterdam (Fig.8) and news in https://www.rotterdam.nl/nieuws/groene-betonbank/
- The work performed in the group of Concrete Structures was done within the MSc thesis project of Silke Prinsse.