Concrete Loaded in the Axial Direction with Strengthening Reinforcement in the Transverse Direction

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Abstract: The attention of the article is focused on the use of additional concrete reinforcement to increase material parameters. Concrete structures are demanding in terms of material consumption, energy used in cement production and CO_2 production. The first part of the article describes the method of preparation and production of test specimens. Subsequently, the methodology for measuring material properties is discussed. The result of the measurement is a comparison of contact and non-contact methods of measuring deformations, ascertaining the material properties of the tested concrete.

Keywords: Concrete, Strain and stress, Digital Image Correlation, Strain measurement, Transverse direction reinforcement

1 Introduction

The social effort to reduce the energy demand of the construction industry leads to the search for economical solutions. One of the many possibilities for savings is the more economical use of building materials. Concrete, as the most widespread building material, can offer an opportunity to find savings. The production of concrete, and especially cement, is a very energy-intensive process, with a high production of CO_2. There are more options for optimizing concrete production. For example, more efficient use of production raw materials in the production of cement, more appropriate use of selected types of cement in concrete for a specific type of construction, or appropriate use of the mechanical properties of concrete in building construction.

This paper is focused on the last of the mentioned optimizations, i.e. influencing the mechanical properties of concrete in the structure. Specifically, attention is paid to increasing the load-bearing capacity of concrete by means of transversely oriented external reinforcement, which increases the compression strength of concrete in the axial direction.

The compressive strength of concrete is mainly influenced by the composition of the concrete. Reinforced concrete structures have increased compressive strength due to concrete reinforcement. Nevertheless, the basic component of the concrete strength of reinforced concrete remains the strength of the concrete and the strength of the steel reinforcement [1]. Often in construction applications there is no need for a rapid increase in concrete strength and the ability of concrete to increase compressive strength over time can be used.

Many concrete building structures are loaded with long-term loads after a few months of their construction. The increase in strength of concrete over time strongly depends on the type of cement used [2]. The Portland cements type I have the fastest increase in strength. In contrast, the use of blended Portland cement results in a lower evolution of heat of hydration during concrete maturation, as well as a significantly slower increase in compressive and tensile strength. Nevertheless, over a longer period of time, concrete made from mixed cement can achieve the same parameters as concrete in which Portland cement was used.

2 Tested material

The work aims to capture the change in strength over time, which is influenced by the composition of the concrete, as well as by the method of reinforcement. The question is whether reinforcement has an effect on increasing the bearing capacity of concrete?

Concrete from mixed Portland cement CEM II was chosen for testing. This cement has a slower increase in strength than CEM I cement. Reducing the amount of cement would result in low strength. A replacement for cement was chosen using ground limestone. The detailed composition of the concrete mixture is described in Table 1.

Table 1. Mixture of the tested concrete.

Part	Description	Content [kg/m³]
1	CEM II/A-LL 42,5	272
2	Limestone	148
3	Sand 0-4	980
4	Aggregate 4-8	216
5	Aggregate 8-16	380
6	Plasticizer	2.5
7	Stabilizer	1.5
8	Water	175

The plasticizer and stabilizer were added to the mixture for processing without vibrating the mixture and for preventing the separation of individual components from the mixture.

The production of concrete specimens consisted of concreting cylindrical test specimens with a base diameter of 100 mm and a cylinder height of 200 mm. The basic cylinders were concreted into steel forms without reinforcing rings. These specimens were used to determine the basic strength of the produced concrete. Other cylinders were made by inserting aluminum rings with an outer diameter of 100 mm into steel molds. Plastic spacer rings of the same diameter and thickness were inserted between the individual rings. Two ring thicknesses of 2 and 3 mm were chosen for reinforcement. The plastic intermediate rings were removed after removing the specimens from the steel molds.

Three specimens without reinforcing rings, three cylinders with 2 mm thick reinforcing rings and three bodies with 3 mm thick rings were prepared for testing. The production was prepared for the verification of properties at the age of 28 and 90 days. After concreting, the specimens were left in a laboratory environment, i.e. at 20°C and a relative humidity of 50%. Storing the specimens in an environment with 100% relative humidity was not feasible due to the need to exclude a chemical reaction between concrete and aluminum.

As can be seen from Fig. 1, cylindrical specimens with 12 reinforcing aluminum rings of two thicknesses of 2 mm and 3 mm were used for testing.

3 Measurement of the parameters

The specimens were tested in compression at the age of 28 and 96 days. Table 2 shows how the strength of the cylinders without reinforcement and with reinforcement increased in the given period. Simultaneously with the determination of the compressive strength, other mechanical parameters such as the modulus of elasticity and Poisson's ratio are possible determinate.

A compression test for concrete specimens was chosen for testing. The loading speed was chosen in accordance with standard regulations [3]. For the measurement, as can be seen from Fig. 1, two attached extensometers with a measuring length of 150 mm were used. The measured length of the extensometers guaranteed the measurement of deformations that could occur on the cylinder. The sensors were mounted in the direction of loading of the test specimens. The force signals and total deformation of the cylinder in the axial direction were also recorded from the test device.

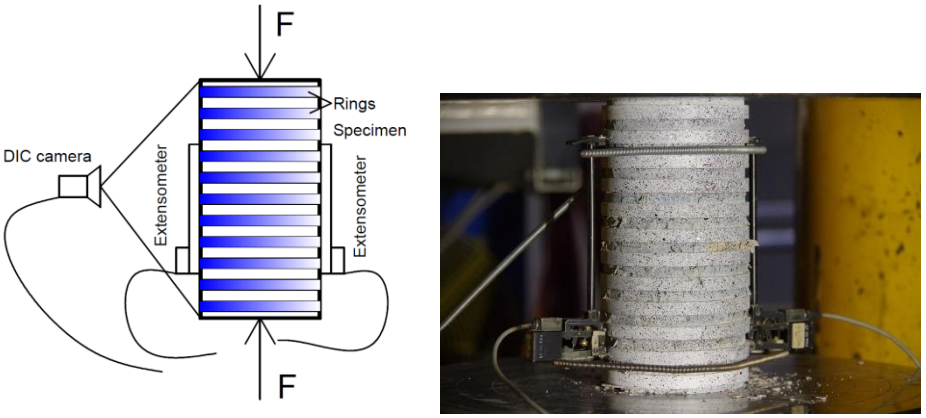

Fig. 1 Concrete specimen strengthened by external reinforcement in the shape of rings. The cylinder after completion of the compressive test (right) and principle of the measurement of deformation (left).

The measurement was carried out until the destruction of the surface reinforcement, which was made of an aluminum alloy. Axial deformations were measured using attachment extensometers. From the previous measurements, a DIC (Digital Image Correlation) with a stereo deformation recording device manufactured by Dantec Istra was chosen for a more detailed analysis.

To measure deformations using DIC, all specimens were provided with a pattern. The image recording from both cameras was stored in a storage device. The time step between frames was chosen to be 5 seconds. The test of the unreinforced specimen is quite fast and approximately 150 images could be recorded during the test. Testing cylinders with reinforcement to complete failure is more time-consuming. In this case, a record of 300 to 400 images was taken, which were used for processing by digital image correlation.

The processing of the measured signals enables the creation of working diagrams. Using extensometers, it is possible to determine the changing strain in the axial direction. From the total deformation and strength record, a working diagram can be established, including the strength behavior of the concrete. The overall working diagram cannot be determined from extensometer measurements and force recording. The result is strongly dependent on the fact whether the crack formation takes place in the area measured by the extensometer or not.

This aspect can be avoided by using non-contact measurement. With the help of DIC, suitable places on the body can be selected for the placement of virtual extensometers, both in the axial and transverse directions with respect to the loading axis.

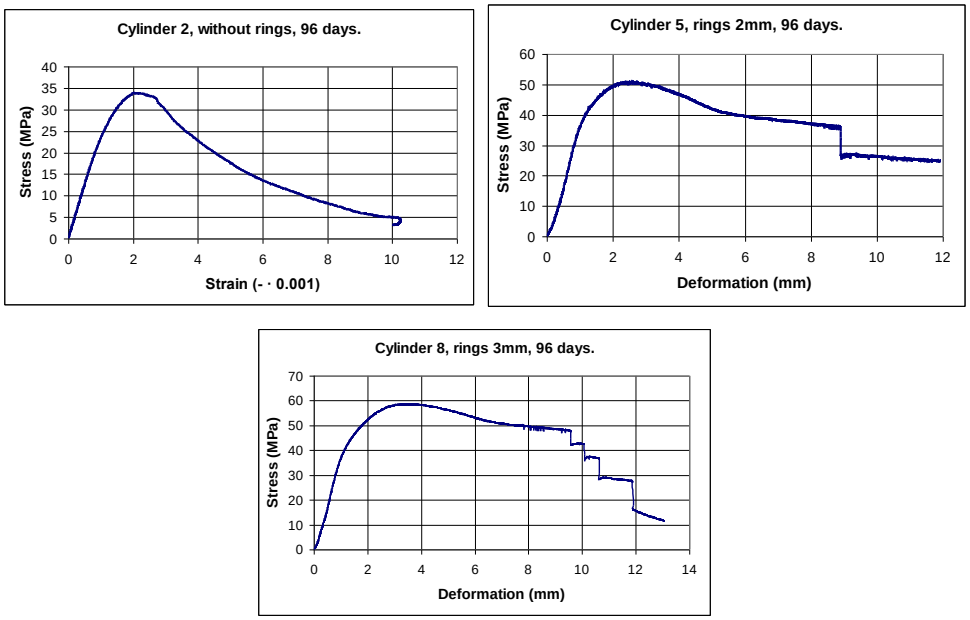

Fig. 2 Working diagrams created from contact measurement for specimen without rings (up left), for specimen with 2 mm rings (up right) and specimen with 3 mm rings (below).

4 Results

Fig. 2 shows working diagrams for specimens aged 96 days. The first is determined from extensometers and the horizontal axis is expressed as strain from extensometers. The second and third graphs, which are measurements on cylinders with reinforcing rings, are drawn using the total deformation of specimens 200 mm high.

Fig. 3 shows the steps in the processing of recorded DIC images. As an example, specimenss aged 96 days, cylinder No. 2 without reinforcing rings and cylinder No. 8 with reinforcing rings of 3 mm thickness are used. The colored field captures the total deformation (in horizontal and vertical direction) of the selected area. In the defined field, it is possible to enter any points for the definition of the distance measurement and also the proportional deformation. In the figure, they are indicated by red lines in the defined field.

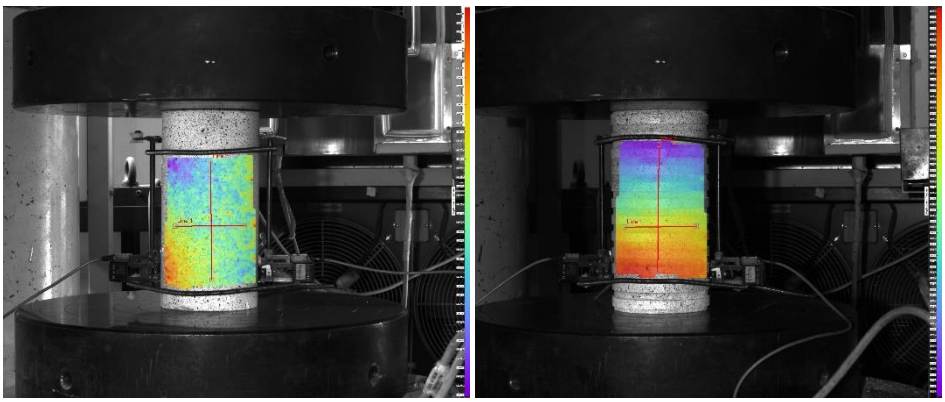

Fig. 3 Processing measurements using DIC. On the left, the total deformation of the body No. 2, on the right, the total deformation of the cylinder 8. Fitting extensometers.

Conclusions

The results of contact and non-contact measurements yielded very consistent results both in terms of the quality of the measurements and information on the use of a specific type of additional reinforcement. A very positive aspect can be found to be a significant increase in the compression strength of concrete already when using 2 mm thick rings. Furthermore, an almost 30% increase in strength is evident in 2 months from the first testing.

Table 2. Compression strength of tested concrete cylinders.

Age	Reference [MPa]	Cylinders with rings 2mm [MPa]	Cylinders with rings 3 mm [MPa]
28	25.1	50.8	57.9
96	34.0	58.3	67.6

As can be seen in Table 2, the compressive strength of concrete when using 3 mm circumferential reinforcement reaches even higher values than with 2 mm reinforcement. This strength is almost 2 x higher than the unreinforced material at the age of 3 months. Trends in material behavior can bring significant savings in the use of the amount of concrete, or cement binder in concrete which is evident from the values of the increase in strength over time when using less energy-intensive CEM II cement.

Acknowledgements

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