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Monitoring and Diagnosis of the Shrinkage and Crack Formation Processes in Concrete Using Holographic Interferometry

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When a concrete structure is deformed or exposed to any other impact, the holographic interferometry method is a unique way to simultaneously observe a single image of deformity over the entire registered surface of the test object, and at the same time, at will, measure all three components of the displacement vector non-contact. With this method, the deformations of concrete and cement at an early stage of hardening was examined; the process of qualitative and quantitative shrinkage and cracking resistance process, appearance of a crack invisible to the eye in the contact zone of a large filler and its development before complete disintegration were evaluated. As a result of deciphering and analyzing the obtained interferometry, it was established that the development and hardening of shrinkage deformities at an early stage is individual. In externally similar sections, variability in the magnitude of the deformation occurs at variable velocity on the surface of the specimens (decrease and increase). The interferograms made it possible to predict the conception of cracks in the concrete and cement stone as well as visual observation of kinetic development, and showed, what role the degree of deformity limitation of large filler grains plays in the deep layers and the cement stone (in the cement matrix and filler contact area). *© 2021 Bull. Georg. Natl. Acad. Sci.*

Holographic interferometry, deformation, shrinkage, crack formation, cracking resistance

Concrete is the main building material for different constructions. Therefore, it is very important to study the long-term processes such as shrinkage, creeping, swelling, temperature impacts and crack resistance that affect its strength. Well-known methods incompletely describe the process of complex composition of materials such as concrete and reinforced concrete [1,2]. The selection of experimental methods is quite important. We may select several basic methods: photo elasticity, moire patterns, X-ray and electronic microscope, tensometry method, method of mercury phorometry; the methods based on the application of elastic waves – acoustic emission, an impulsive ultrasound method and computational methods based on the study of different mathematical models should be also mentioned here.

The purpose of this work was to present the results of our study on the process of shrinkage and crack formation in concrete using holographic interferometry.

Holographic Interferometry

Holography allows us to study diffusely reflective surfaces interferometrically [3-5]. Interferograms are recorded according to the Leith-Upatnieks two-beams scheme [6,7]. Compare the two wave fronts at different times and record the object on the photoplate in the initial state, and after acting on it, the image of the object to be restored will be covered by interference strips, the configuration of which fully determines the change of the object.

Holographic interferogram is obtained by the following method: the first exposure on the holographic plate registers the object to be studied in the initial state, then after the object undergoes deformation it is exposed for the second time without moving the holographic plate; new one is then placed in place of the exposed holographic plate and the holographic process continues. After proper processing of the exposed holographic plate, we obtain a holographic interferogram. The exposure time depends on the laser power and the photofilter.

A holographic interferogram enables noncontact obtaining both a qualitative picture of the deformation as well as a quantitative value of the vector of movement at any point of the object.

The method of holographic interferometry is the best possible way to observe the early stage of the formation of concrete structure and study the processes ongoing in the course of strengthening, which are not visually observed.

It is used in scientific research to measure the deformations, as well as for monitoring and diagnostics of constructions from different materials, including concrete and reinforced concrete structures.

The suggested method is of utmost importance for monitoring of crack formation, shrinkage in the early and different stages of the observation without contact [8-10].

This method is very important for the concrete quality monitoring in the hydraulic construction of concrete dams.

Experimental Study

Investigation of the shrinkage processes in concrete structures and reflection of the dynamics of the stress-state condition allows us to observe concrete at an early stage of its structure formation by the method of holographic interferometry [11-15].

So that the test specimens were close to the linearly deformed (stressed) state since we tried to have a symmetric task.

The following specimens were made: cement matrix (d=150 mm, h=10 mm), and three large granite fillers (d=20 mm) were fixed in the free state. The specimens were stored for 10 hrs. in a humid environment at 20 ± 10^0C. Then thay were fixed in an optical scheme and interferograms were recorded. A continuous cycle of holographic interferograms has been obtained in 462 hours.

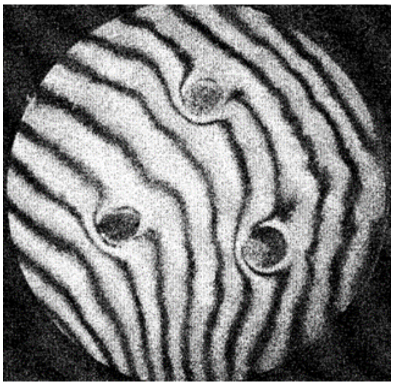


Fig. 1. One of the interferograms from the entire observation cycle (462 hrs.) in a cement matrix with three large granites in the free state for observetion time of 114 hrs.

Fig.1 shows one of the interferograms in a cement matrix with three large granites in the free state for observetion time of 114 hrs. In the cement matrix and the contact area of the large filler, no crack was observed during the entire observation period; during the cement hardening period the fillers moved along the matrix and a non-uniform process of shrinkage took place.

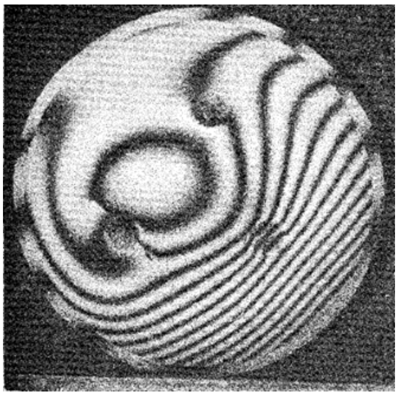
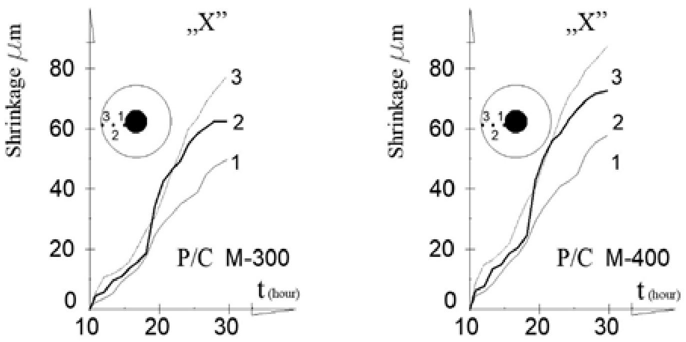


Fig. 2. Interferogram of cement matrix and strongly fixed granite filling for the observation time of 62 hrs.

Concrete shrinkage is a long-term and uneven process. The existing nondestructive methods of observing the development of deformation at an early stage of hardening, are associated with great difficulties and little study. Fundamental research and visualization of the process of concrete hardening and structure formation by the method of holographic interferometry is very important, as the stability and durability of structures are depended on these.

The following experiment was carried out to investigate this. The specimens of the same size were made (d=150 mm, h=10 mm) and a one large filler of granite was placed in the middle (d=20 mm, h=10 mm). The integral curves were obtained for two types of cement: Portland Cement B-22.5 M-300 and B-30, M-400 (Figs. 3 and 4).

After analysis of interferograms and processing the experimental data the following results were obtained: the displacement of point 1 in the B-22.5



Figs. 3 and 4. Integral curves along the X axis for Individual 1, 2, 3 point's movement for two types of cement stone.

The duration of the long-term cycle of observations was 489 hours. After 62 hrs., a crack appeared in the contact zone of one of the fills, which developed periodically, and 489 hours later, when the crack crossed the sample, it was only then visually fixed. During the experiment, the stress-deformed state of the sample has been changed. During the period of intensive crack formation, it decreased and increased at certain periods, there was an uneven process of shrinkage.

M-300 Portland cement at 30 hrs. is 8 μm less than in the B-30 M-400 sample; the displacement of point 2 is 10 μm less, while the displacement of point 3 is of 11 μm less.

Conclusion

Holographic interferometry enables us to evaluate qualitatively and quantitatively the stressed-deformed state of concrete and the processes of shrinkage, crack formation and development of concretes of different composition. The advantages of this method can be considered as the following:

1) High accuracy (tenth of wavelength of 633 nm equals 63 nm, which is a nano-technological research method).

2) Large amount of information received.

3) Ability to study real materials and constructions without models.

4) No contact with the study object (non-contact method).

This method enables further facilitate the reliability and durability of concrete and reinforced concrete structures, one of the major building materials in construction, in particular in hydro-technical construction.

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გამოყენებითი მექანიკა

ჰოლოგრაფიული ინტერფერომეტრიის გამოყენებით ბეტონში შეკლებისა და ბზარების წარმოქმნის პროცესზე მონიტორინგი და დიაგნოსტიკა

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(წარმოდგენილია აკადემიის წევრის დ. თავხელიძის მიერ)

ბეტონის კონსტრუქციული ელემენტი, როდესაც დეფორმირებულია ან განიცდის სხვა რაიმე ზემოქმედებას, ჰოლოგრაფიული ინტერფერომეტრიის მეთოდი უნიკალური საშუალებაა, ერთდროულად დავაკვირდეთ დეფორმირების ერთიან სურათს გამოსაკვლევი ობიექტის მთელ რეგისტრირებულ ზედაპირზე და იმავდროულად, გავზომოთ არჩეულ წერტილში გადაადგილების ვექტორის სამივე კომპონენტი უკონტაქტოდ. ჰოლოგრაფიული ინტერ-ფერომეტრიის მეთოდის საშუალებით გამოკვლეულ იქნა გამყარების ადრეულ სტადიაზე ბეტონისა და ცემენტის დეფორმაციები, შეფასდა ხარისხობრივად და რაოდენობრივად შეკ-ლების და ბზარმედეგობის პროცესი, თვალით უხილავი ბზარის ჩასახვა მსხვილი შემვსების საკონტაქტო ზონაში და მისი განვითარება სრულ რღვევამდე. აღნიშნულის საშუალებას არ იძლევა არსებული ურღვევი მეთოდები. მიღებული ინტერფეროგრამების გაშიფვრისა და ანალიზის შედეგად დადგინდა, რომ შეკლების დეფორმაციების განვითარება და გამყარება ადრეულ სტადიაზე ინდივიდუალურია, გარეგნულად ერთნაირ მონაკვეთებში ნიმუშების ზედაპირზე ცვლადი სიჩქარით ხდება დეფორმაციის ცვალებადობა (შემცირება და მატება).

ინტერფეროგრამების საშუალებით შესაძლებელი გახდა პროგნოზირება ბეტონსა და ცემენტის ქვაში ბზარების ჩასახვისა და ასევე კინეტიკური განვითარების ვიზუალური დაკვირვება, აგრეთვე ნაჩვენებია, თუ რა როლს თამაშობს სიღრმულ ფენებსა და ცემენტის ქვაში მსხვილი შემვსების მარცვლების დეფორმაციის შეზღვუდვის ხარისხი (ცემენტის მატრიცასა და შემვსების საკონტაქტო ზონაში).

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