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Influence of processing factors over concrete strength.

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Abstract. Construction of facilities of cast in-situ reinforced concrete poses additional requirements to quality of material, peculiarities of the construction process may sometimes lead to appearance of lamination planes and inhomogeneity of concrete, which reduce strength of the material and structure as a whole. Technology compliance while working with cast in-situ concrete has a significant impact onto the concrete strength. Such process factors as concrete curing, vibration and compaction of the concrete mixture, temperature treatment, etc., when they are countered or inadequately followed lead to a significant reduction in concrete strength. Here, the authors experimentally quantitatively determine the loss of strength in in-situ cast concrete structures due to inadequate following of process requirements, in comparison with full compliance.

1. Introduction

Monolithic construction plays an important role in modern construction industry: it is more economically viable and allows building structural elements of any form. All this factors stipulate leading positions for cast in-situ reinforced concrete buildings and structures in construction market. Cast in-situ reinforced concrete finds a wide range of applications in a number of industrial and residential facilities, in mining development, extraction of minerals and other areas of activity. However, despite many advantages of monolithic construction, there is a number of disadvantages, reducing strength and reliability of cast in-situ structures. Segregation of concrete and cement paste happens due to gravity, difference in grain size and inadequate compliance with process requirements. Coarse and heavy particles relocate from the top to bottom layers, compacting them. Simultaneously, some quantity of water is released on the surface of the paste. Segregation may also happen inside the concrete, under grains of coarse aggregate and reinforcement bars. As water-cement ratio of a concrete mixture is usually significantly higher than that stipulated for normal slurry concentration, water gain becomes especially noticeable; it largely defines uniformity of concrete and adhesive strength between aggregate and cement stone. Such structural imperfections may form directly during building process or appear only later, during operation of the building, e.g., under influence of dynamic loads or due to concreting process flow disruption [1].

2. Methodology

Curing of concrete is necessary to attain required quality of concrete, influencing its strength later. Impact pile sinking activities, blasting operation, as well as movement of heavy machinery (cranes, earthmovers) are prohibited in the vicinity of recently concreted structures to exclude dynamic loading. Methods of concrete curing depend on a type of structure, type of cement, local climatic conditions; such activities continue until concrete reaches 70% of its design strength. For regular portland cement-based concrete curing duration is 7 days, for fast-curing aluminous cement it is 2...3 days. Curing time extends if the weather is hot and dry. During the initial curing period, concrete shall be protected from elements and loss of water. Hardening of concrete is accompanied with change in its volume. Concrete shrinkage, which increases in fast curing, leads to appearance of small cracks on the concrete surface. Non-uniform heating due to exothermic processes in cement hydration may also cause appearance of cracks in massive structures.

Compaction of mixture causes its particles to get closer, while some water, being the lightest component, goes up forming capillary passages and cavities under coarse aggregate grains. Coarse aggregate with density different from that of slurry (a mixture of cement, sand and water) also moves through the concrete mixture. If the aggregate is dense and heavy, e.g., granite road metal, its particles subside (Fig. 1) while lighter cement-and-sand particles float. All these processes impair the structure of concrete, making it non-uniform, increasing water permeability and lowering freeze-thaw resistance. To increase concrete mixture cohesion and prevent its segregation, it is necessary to prescribe a certain amount of components of concrete, as well as to reduce a tempering water ratio with the help of water reducing admixtures [2].

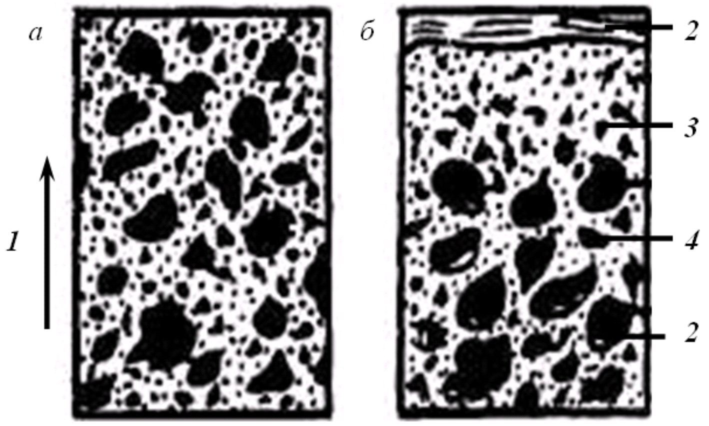


Figure 1. Scheme of possible concrete mixture segregation: *a* – during transportation and compaction; *b* – after compaction; *1* – direction of water movement; *2* – water; *3* – cement-and-sand particles; *4* – granite road metal

Casting of concrete and its compaction is performed in horizontal layers of uniform thickness, with the same direction of casting in all layers. The layer thickness is determined by a type and capacity of a vibrator used to ensure compaction of the layer. The vibrator transmits oscillation of a certain frequency to the concrete mixture, resulting in a release of free water and the mixture becoming fluidized (flows). Such mixture completely fills the internal volume of timbering (including nodes, narrow sections, etc.), air and excess water (added for increased mobility) are removed from the mixture as well, thus making future cured concrete denser and stronger [3].

Non-compliance with the work rules for concrete casting leads to appearance of a number of defect in a reinforced concrete structure. Certain non-compliance with the process leads to quite significant defects:

- insufficient strength of concrete;

- layered structure;
- large open cavities;
- lack or incorrect installation of concrete inserts;
- beyond-design openings;
- exposure of reinforcement over a significant area, etc.

3. Main part

To determine difference in strength characteristics in full and partial compliance to the work rules of in-situ casting, an experiment was conducted during which 5 cubic samples 100×100×100mm were produced by concrete casting. Several months after completion of the casting works, 5 core samples were collected from the cast in-situ reinforced concrete structures of the studied building (Fig. 2), with height ranging from 145mm to 153mm, design grade of the concrete is B20 [4]. Dimensions of cubic and cylindrical samples were measured and then their concrete strength was determined with a destructive method as per [6] in Test lab no. 1 of BGTU-sertis testing center by destruction of concrete samples of cylindrical (Fig. 3) and cubic (Fig. 4) form with a hydraulic press PSU-125 [5]. The results of the tests are shown in Tables 1 and 2.

Figure 2. External appearance of the subject of research

Figure 3. Unsatisfactory fracture pattern in cylindrical samples collected from cast in-situ structures

Figure 4. Satisfactory fracture pattern in cubic samples produced under production control conditions

It is noted that fracture pattern in cylindrical samples taken from cast in-situ structures is unsatisfactory, as per diagrams no. 4, 5, 9, 10 of [6], that of cubic samples produced under production control conditions is satisfactory as per [6].

Table 1. Concrete strength of cubic samples produced with production control

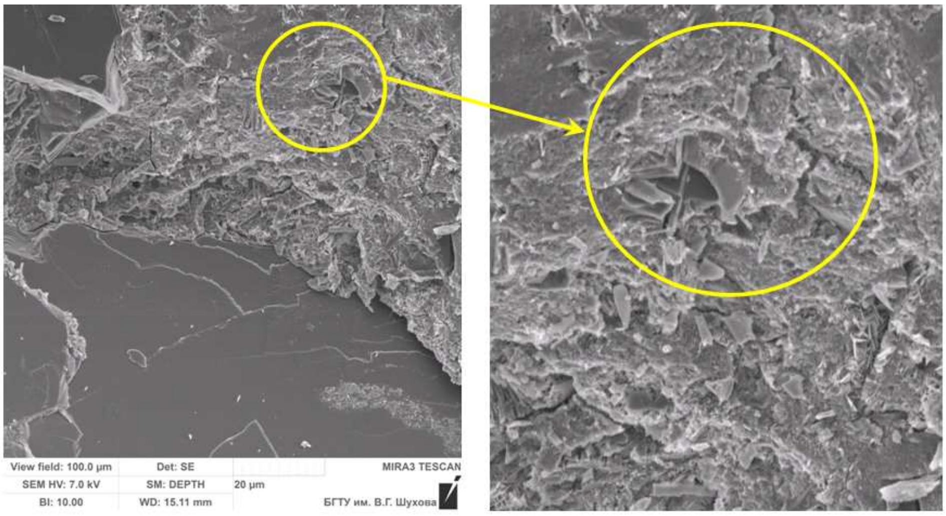
Cube no.	Dimensions, mm	Breaking strength, kN	Scale factor, α (item 8.2 of GOST 10180-2012)	Cross-section area, S, m^2	Compressive strength of concrete, R, MPa (item 8.1 of GOST 10180-2012)	Compressive strength of concrete R_{av}
1	100×100×100	180 (defect)	-	-	-	
2	100×100×100	242.5 (defect)	-	-	-	
3	100×100×100	237.5	0.95	0.0100	22.56	21.61
4	100×100×100	237.5	0.95	0.0100	22.56	
5	100×100×100	207.5	0.95	0.0100	19.71	

Table 2. Concrete strength for cylindrical samples collected from cast in-situ structures

Core no.	Core height, mm	Core cross-section diameter, mm	Breaking strength, kN	Scale factor, α (item 8.2 of GOST 10180-2012)	Cross-section area, S, m^2	Compressive strength of concrete, R, MPa (item 8.1 of GOST 10180-2012)	Compressive strength of concrete R_{av}
1	149	110	70 (defect)	-	-	-	12.88
2	153		102.5	1.15	0.0095	12.41	
3	145		90	1.14	0.0095	10.80	
4	149		127.5	1.15	0.0095	15.44	
5	152		130 (defect)	-	-	-	

Analysis of results in Tables 1 and 2 shows a big difference in compressive strength of concrete R between the samples produced under production supervision and samples taken from the structure [7]. An average value of strength for supervised production samples is 21.61 MPa, while for structure samples it is 12.88 MPa. Strength of cubic samples produced under production supervision is higher by a factor of 1.67 or by 67% than that of the cylindrical samples taken from the structure.

Morphology of fresh fractures was also studied in the samples under different magnification (Fig. 5) [8…10].



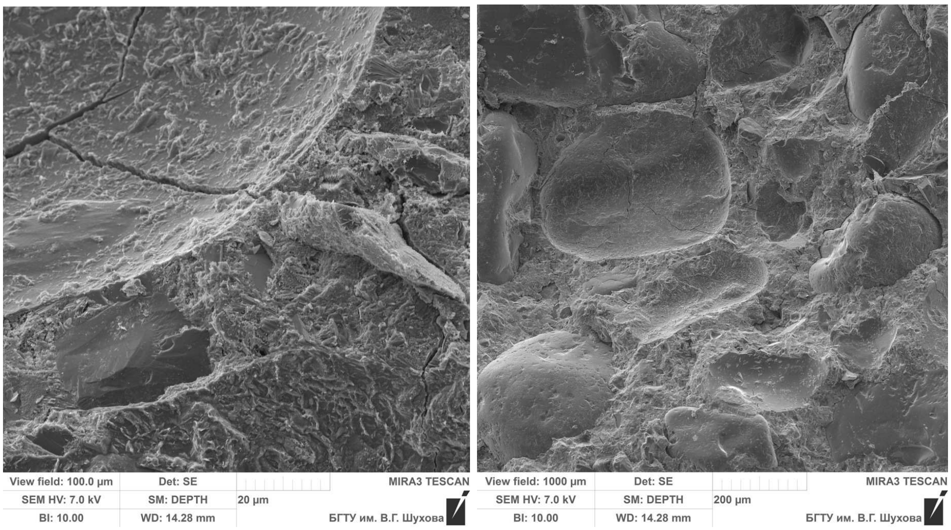


Figure 5. Microstructure of samples

Newly-formed composite matrix consists of portland cement hydration products of diverse fineness, morphology and composition. Hydrated calcium silicates create a certain spacial structure that includes unreacted grains of cement with a newly-formed cover of globulas and aggregate grains, as well as inter-grain space more or less filled with new growth. Presence of micro fractures indicates incorrectly selected composition of heavyweight concrete, having led to mixture segregation, as well as curing regime and water solid ratio that directly contribute to significant reduction in strength of concrete and the structure as a whole. Appearance of micro fractures may also be explained by shrinkage due to fast drying of concrete under non-uniform heating resulting from exothermic hydration of cement.

The cement rock microstructure consists of layered scaly polycrystal. The samples show a porous open-grain structure (Fig. 6).

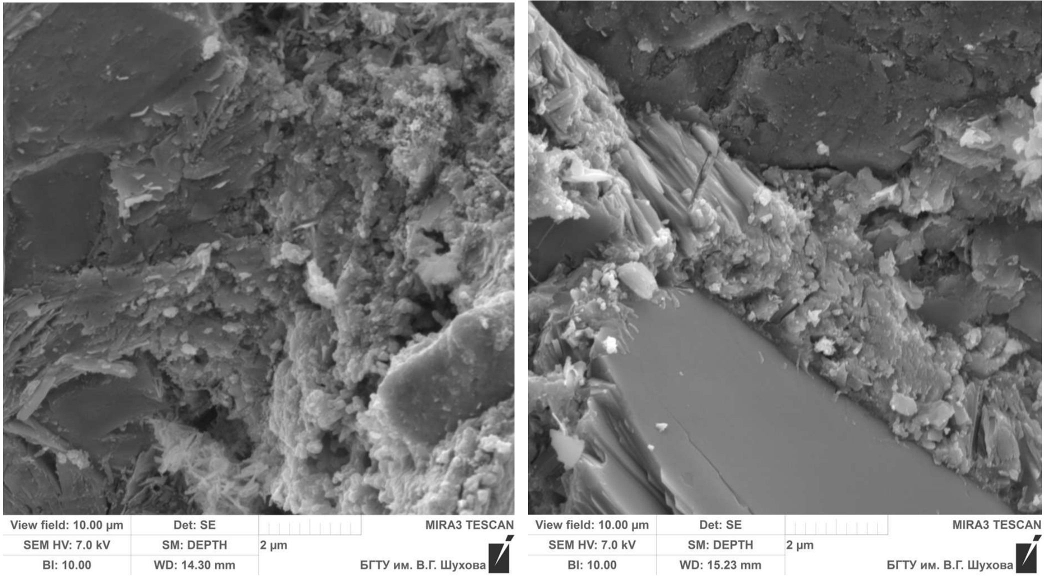


Figure 6. Microstructure of a sample with pores and pinholes

The above mentioned defects demonstrate that while studying a construction material, it is very important to consider microstructural features of its elements. Study of defects in initial materials allows predicting mitigating measures to remedy the defects by synthesizing controlled-quality concrete [12].

4. Conclusion

It was found out that cubic sample were manufactured fully compliant with the concreting process with considerations for correct vibration treatment and curing, while the cast in-situ structures wherefrom cylindrical samples were collected were manufactured with partial compliance with the technology: vibration treatment was subpar, curing was insufficient, water-proofing was absent [13]. On the basis of testing performed on both cubic and cylindrical core samples, one may conclude that non-compliance with process requirements of vibration treatment, non-uniform compaction and incorrect concrete curing reduce strength of concrete by 40% [14]. A significant reduction of concrete strength in comparison with its design values due to non-compliance with the in-situ casting process requirements resulting in concrete non-uniformity, increased permeability, reduced freeze-thaw resistance, leading to reduced bearing capacity of the structure, its shortened life cycle and accelerated accumulation of physical wear.

5. Financing

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