The Influence of Concrete Structure on the Destruction of Reinforced Concrete Bended Elements

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Abstract. When ecological effect of the environment on the structural constructions the changing structure of concrete influences definitely on the cracking, bearing capacity and durability. The mechanism of the formation of the composite building materials structure – the concretes with the formation of interfaces on the contact plane, inclusions, and matrix is described. Fine and coarse aggregate are considered as inclusions, and mortar and cement mortar as a matrix. Such a selection of structural levels makes it possible to establish the occurrence of dangerous defects, which size is larger than the size of the constituents of the element's structure. Therefore, the size of the defect, safe at one structural level, becomes dangerous at a lower level. So a crack that is safe for concrete on large aggregates is destructive for cement stone. The questions of structure formation in concrete and reinforced concrete products on micro - and macro levels are considered.

The method of accounting for the initial (technological) damage to the iron reinforced concrete bending elements is presented. The tests of reinforced concrete beams under the action of low-cycle load are made, and their results are presented. The nature of crack formation and the development of cracks under the action of an external load in flexible concrete elements, depending on the technological damage have been established. The crack depth was determined depending on the load, using ultrasonic equipment. It is established that cracks from an external load develop from technological ones, and along their paths.

Keywords: Concrete · Structure · Damage · Beams · Load · Cracking

1 Introduction

Composite building materials are heterogeneous materials, which properties are formed as a result of rather complex processes of interaction of the initial components with the formation of structures that are transformed over time [1–6]. The logical chain "composition - technology - structure - level of properties" allows you to highlight the structure as the main factor that determines the quality indicators of the finished product. It is known that the destruction of any material and structure occurs by its separation into parts by the edges of cracks. This poses the problem of identification of

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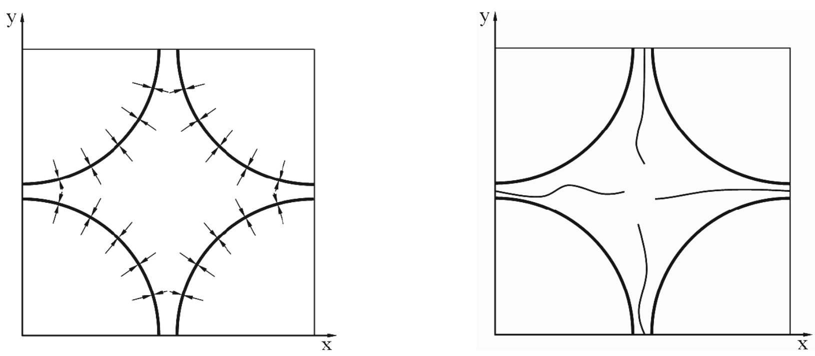
the crack nucleation causes in coarse heterogeneous materials, studying the conditions for their development in a structured medium and their influence on the physical-mechanical characteristics of the materials and the operational characteristics of structures.

In analyzing the causes of the manifestation of the desired properties, the material is considered as heterogeneous, consisting of individual structural elements, interacting through the interface [7–13]. On the interface, the redistribution of strains and stresses between individual components and structures occurs under the action of technological and internal influences on the material, as well as external loads and influences. The composite building structures are considered as specially organized composite materials, the interaction of individual components and structural elements of which provides the functional purpose of the structure [14–17]. Therefore, the structure of the construction includes the whole variety of material's structure: the cracks at the micro and macro levels, pores and capillaries. It is proposed to determine the heterogeneity of the structure through surface damage by technological defects.

2 The Analysis of the Literary Sources

The previous studies have established the theoretical principles of structure formation of building materials and structures [18]. It was determined that during the formation of the material structure in micro - and macro levels on the borders of the matrix material and filler inhomogeneities arise, which leads to the formation of cracks process [19] (Fig. 1).



a b

Fig. 1. The mechanism of distribution of deformations (a) and the nature of crack formation at the macro level (b).

The similar conclusions were also made in the papers [20, 21].

In the general case, in composite materials and structures, several characteristic types of damage can be distinguished, which differ in the formation mechanisms (Fig. 2).

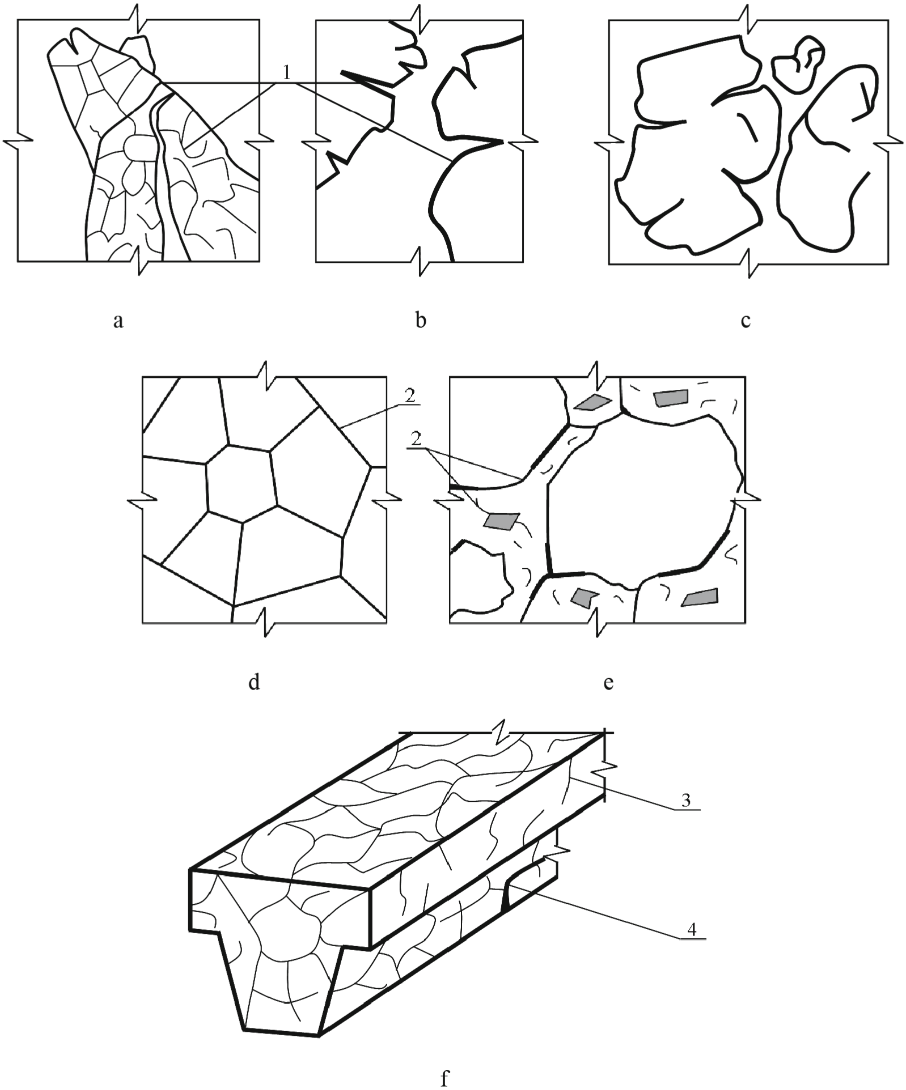


Fig. 2. The nature of the damage to crystals (a), grains of cement (b), fine aggregates (c), cement stone (d), concrete (e) and structure (f): 1 – cracks in the initial components; 2 – cracks formed during the structure formation of the materials; 3 – cracks formed due to geometric design features; 4 – operational cracks.

The defects of the individual components of the material can be considered as occasional, the quantitative and qualitative composition of which can be predicted only by special methods; therefore, they are excluded from further analysis. The object of our analysis is the defects that occur during the technological processing of building materials and structures. Such defects relate to technological, initial or hereditary defects, and they are present in the material before the application of operational loads and influences. It is assumed that the cracks that occur in the material are automatically structural cracks, and determine its deformability, crack resistance and bearing capacity. Therefore, we set the task of studying the appearance and development of cracks in bending structural elements, and their destruction under the action of low-cycle loads.

3 The Research Methodology

A quantitative assessment of concrete damage by technological defects was carried out by determining the extent of surface cracks.

Cracks appeared when using water solution of tannins that allows to detect and fix the cracks. The concrete, damaged by the defect was determined by measuring the length of surface cracks odometer along the geodesic line (Fig. 3) and by the calculation of the damage coefficient by Eq. (1), that for the studied beams constituted 1,05 and 1.03.

$$K_d = l_{cr}/l \tag{1}$$

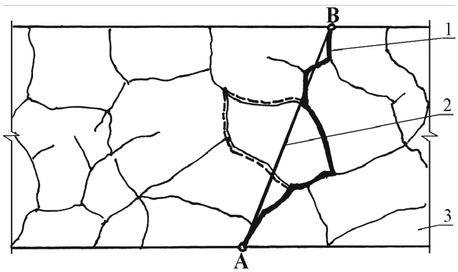


Fig. 3. The method for the coefficient of damage determination: 1 – technological crack along the boundaries of the blocks $l_{cr;}$ 2 – geodesic line $l;$ 3 – selected area on the surface of concrete.

When testing reinforced concrete beams, we used the ultrasonic method of non-destructive testing that also allows to control the crack development under the loads action [22, 23].

To determine the depth of the technological cracks we used an ultrasonic device UK-14P. The range of time measuring of ultrasound spreading was UT –20…8800 mcs. The range of the front duration of the first arrival of the received signal is 3…30 mcs, and the absolute sensitivity of the device is not less than 110 dB (decibels). The scheme for measuring the depth of the crack is shown in Fig. 4.

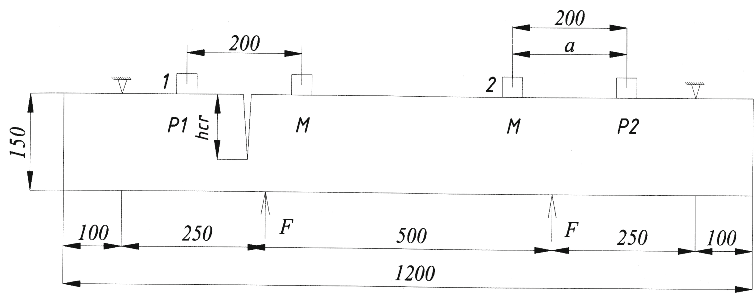


Fig. 4. The scheme for measuring the depth of the crack: 1 – measurement base on concrete through a crack (position of M-P1 sensors); a – measurement base on intact concrete (position of M-P2 sensors).

The device automatically calculates the crack depth using the Eq. (2):

$$h_{cr} = \frac{a}{2} \cdot \sqrt{\left(\frac{t_1}{t_a}\right)^2 - 1} \tag{2}$$

The appearance and development of cracks was fixed using markers.

Beams were loaded in steps of 500 kgf cyclically, with exposure at each stage and subsequent unloading. Two twin-beams were tested, their durability characteristics are given in Table 1.

Table 1. The characteristics of the experienced beams.

A beam's model	b, см	h, см	d, см	f_c, МПа	f_{cd}, МПа	$E_{cm} \times 10^{-5}$, МПа	The return in the days
A1	10,0	15,0	12,9	25,0	19,5	2,70	205
A2	10,0	15,1	13,0	25,1	19,3	2,60	225

On one beam A1 while testing, the devices, according to Fig. 4, were installed; on a twin-beam A2 the visual supervision on the cracks development was conducted.

4 The Research Results

The cracks parameters, obtained in the result of beam's A1 testing, is given in Table 2.

The two beams were destructed under the load of 2750 kgf on the sloped section (Fig. 5). According to the tests' results, given in Table 2, the graph of the dependence of crack depth on load was built (Fig. 6).

The studies have shown that on the first stage of loading the cracks developed at a depth of up to 70 mm, and after the load shedding they closed. Under the load of 1000 kgf the crack grew to 71 mm and after load shedding had a depth of 19 mm.

Table 2. The results of beam testing.

The load F, kgf	The device's UK–14P indicators, mks		The crack's height, mm
0	The measuring on pure concrete (the layout of the sensor MP1)	t_1 = 54	8.6
0	The measuring on pure concrete (the layout of the sensor MP2)	t_a = 53,8	–
500	The load supply	t_1 = 66,1	70.59443
500	The exposure under the load during 5 min	t_1 = 65,8	69.62667
0	The load's discharge	t_1 = 54	8.6
0	In 5 min. after the load's discharge	t_1 = 54	8.6
500	The load's return on the previous stage	t_1 = 66,1	70.59443
1000	The load's increase up to 1000 kgs	t_1 = 66,3	71.2347
1000	In 5 min. after the load's increase (the exposure under the load)	t_1 = 66,3	71.2347
0	The load's discharge	t_1 = 55	19.3339
0	In 5 min. after the load's discharge	t_1 = 55	19.3339
1000	The load's return on the previous stage	t_1 = 66,3	71.2347
1500	The load's increase up to 1500 kgs	t_1 = 67,4	74.69095
1500	In 5 min. after the load's increase	t_1 = 67,4	74.69095
0	The load's discharge	t_1 = 56	27.4674
0	In 5 min. after the load's discharge	t_1 = 55,6	24.52288
1500	The load's return on the previous stage	t_1 = 68,6	78.348
2000	The load's increase up to 2000 kgs	t_1 = 68,8	78.94712
2000	In 5 min. after the load's increase	t_1 = 69,3	80.43286
0	The load's discharge	t_1 = 57	33.79313
0	In 5 min. after the load's discharge	t_1 = 56,7	32.01562
2000	The load's return on the previous stage	t_1 = 70	82.4854
2500	The load's increase up to 2500 kgs	t_1 = 70,8	84.7946
2500	In 5 min. after the load's increase	t_1 = 70,9	85.08065
0	The load's discharge	t_1 = 57,1	34.3672
0	In 5 min. after the load's discharge	t_1 = 57,1	34.3672
2500	The load's return on the previous stage	t_1 = 71,8	87.63076
2750	The beam's destruction	t_1 = 72,8	90.4159

At a load of 2000 kgf, the crack grew to 80 mm, and at load shedding it amounted to 33 mm.

With a load of 2500 kgf per crack, it grew to 85 mm, and with a load shedding – 34.5 mm. Before the destruction, the crack grew to 90 mm, and the beam collapsed due to crushing of the compressed zone of concrete. Also, before the destruction, an inclined crack formed in the beam, which propagated along the trajectory of the main tensile stresses from the support to the force, which can be explained by the influence of the transverse force.

Fig. 5. The characteristic beams' destruction.

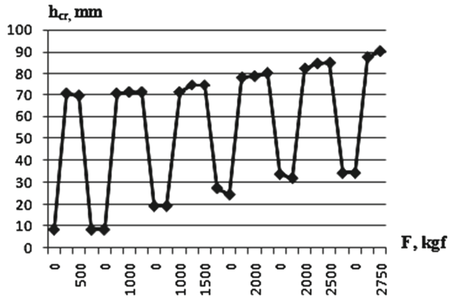


Fig. 6. The dependence of crack depth on load.

The nature of the crack formation and the development of cracks from the action of an external load occurs according to the technological ones in the zone of action of the maximum bending moment. A force crack passes along an energetically advantageous path. The disclosure width of the technological cracks amounted to 0.005…0.3 mm, which was paid attention to in [24], and the crack depth in the zone of the extended working reinforcement was 5.0…8.0 mm. The large depth of the technological cracks in the protective layer of reinforcement can be explained by the influence of shrinkage deformations, especially since the prototypes were tested at the age of 240 days.

Before the destruction of the beams, the development of vertical cracks was stopped, the critical crack began to cross the blocks, and the crushing of the compressed zone of concrete started. At the same time, an inclined crack appeared in both studied samples, passing from the support to the force. This can be explained by the influence of the transverse forces on the nature of fracture.

5 The Conclusions

1. The technological cracks in reinforced concrete beams had a width disclosure of 0.005…0.3 mm with a depth of 5.0…8.0 mm, the maximum depth and width of disclosure were observed in the zone of location of the working reinforcement. The fact of technological fractures presence can be explained by shrinkage deformation.
2. The nature of the spreading of power cracks repeats the “pattern” of technological cracks that pass along an energetically advantageous path and stop the development in a compressed zone due to the influence of transverse forces.
3. Ultrasonic observations showed the presence of invisible (technological) hairline cracks that also occur in the absence of bending moment.
4. The depth of the technological and power cracks, emerging on the surface ranged from 8…87 mm with a concrete protective layer thickness of 20 mm.

References

1. Blikharskyy, Z., Brózda, K., Selejdak, J.: Effectivenes of strengthening loaded RC beams with FRCM system. Arch. Civ. Eng. **64**(3), 3–13 (2018)
2. Bobalo, T., Blikharskyy, Y., Kopiika, N., Volynets, M.: Serviceability of RC beams reinforced with high strength rebar’s and steel plate. In: Lecture Notes in Civil Engineering, vol. 47, pp. 25–33 (2020). https://doi.org/10.1007/978-3-030-27011-7_4
3. Krainskyi, P., Blikharskyy, Y., Khmil, R., Vegera, P.: Crack resistance of RC columns strengthened by jacketing. In: Lecture Notes in Civil Engineering, vol. 47, pp. 195–201 (2020). https://doi.org/10.1007/978-3-030-27011-7_25
4. Lobodanov, M., Vegera, P., Blikharskyy, Z.: Planning experiment for researching reinforced concrete beams with damages. In: Lecture Notes in Civil Engineering, vol. 47, pp. 243–250 (2020). https://doi.org/10.1007/978-3-030-27011-7_31
5. Selejdak, J., Blikharskyy Y., Khmil R., Blikharskyy Z.: Calculation of reinforced concrete columns strengthened by CFRP. In: Lecture Notes in Civil Engineering, vol. 47, pp. 400–410 (2020). https://doi.org/10.1007/978-3-030-27011-7_51
6. Vegera, P., Vashkevych, R., Blikharskyy, Z.: Fracture toughness of RC beams with different shear span. In: MATEC Web of Conferences, vol. 174, p. 02021 (2018). https://doi.org/10.1051/matecconf/201817402021
7. Blikharskyy, Z., Vashkevych, R., Vegera, P., Blikharskyy, Y.: Crack resistance of RC beams on the shear. In: Lecture Notes in Civil Engineering, vol. 47, pp. 17–24 (2020). https://doi.org/10.1007/978-3-030-27011-7_3
8. Bobalo, T., Blikharskyy, Y., Kopiika, N., Volynets, M.: Theoretical analysis of RC beams reinforced with high strength rebar’s and steel plate. IOP Conf. Ser. Mater. Sci. Eng. **708**(1), 012045 (2019)
9. Khmil, R., Tytarenko, R., Blikharskyy, Y., Vashkevych, R.: Influence of load level during strengthening of reinforced concrete beams on their reliability. IOP Conf. Ser. Mater. Sci. Eng. **708**(1), 012054 (2019)
10. Krainskyi, P., Vegera, P., Khmil, R., Blikharskyy, Z.: Theoretical calculation method for crack resistance of jacketed RC columns. IOP Conf. Ser. Mater. Sci. Eng. **708**(1), 012059 (2019)

11. Vegera, P., Khmil, R., Vegera, P.: Shear strength of reinforced concrete beams strengthened by PBO fiber mesh under loading. In: MATEC Web of Conferences, vol. 116, p. 02006 (2017). https://doi.org/10.1051/matecconf/201711602006
12. Krainskyi, P., Blikharskyy, Y., Khmil, R., Blikharskyy, Z.: Experimental study of the strengthening effect of reinforced concrete columns jacketed under service load level. In: MATEC Web of Conferences, vol. 183, p. 02008 (2018). https://doi.org/10.1051/matecconf/201818302008
13. Blikharskyy, Y., Kopiika, N., Selejdak, J.: Non-uniform corrosion of steel rebar and its influence on reinforced concrete elements, reliability. Prod. Eng. Arch. **26**(2), 67–72 (2020). https://doi.org/10.30657/pea.2020.26.14
14. Blikhars'kyi, Y.Z.: Anisotropy of the mechanical properties of thermally hardened A500s reinforcement. Mater. Sci. **55**, 175–180 (2019). https://doi.org/10.1007/s11003-019-00285-0
15. Kharchenko, Y.V., Blikharskyy, Z.Y., Vira, V.V., Vasyliv B.D.: Study of structural changes in a nickel oxide containing anode material during reduction and oxidation at 600 °C. In: Fesenko, O., Yatsenko, L. (eds.) Nanocomposites, Nanostructures, and Their Applications. NANO 2018. Springer Proceedings in Physics, vol. 221. Springer, Cham (2019). https://doi.org/10.1007/978-3-030-17759-1_42
16. Kharchenko, Y., Blikharskyy, Z., Vira, V., Vasyliv, B., Vasyliv, B.: Study of nanostructural changes in a Ni-containing cermet material during reduction and oxidation at 600 & °C. Appl. Nanosci. (2020). https://doi.org/10.1007/s13204-020-01391-1
17. Zhang, Q., Mol'kov, Y.V., Sobko, Y.M., et al.: Determination of the mechanical characteristics and specific fracture energy of thermally hardened reinforcement. Mater. Sci. **50**, 824–829 (2015)
18. Dorofeyev, V.S., Vyrovoy, V.N.: Technological damage to building materials and structures. The place of masters, Odessa (1998)
19. Szeląg, M.: The Influence of Cement Composite Composition on the Geometry of their Thermal Cracks. Lublin University of Technology, Lublin (2017)
20. Malakhov, V., Vykydanets, S., Pushkar, N.: Influence of quantity and quality of filler on technological damage of reinforced concrete beams. In: Proceedings of the fib Symposium "Concrete - Innovations in Materials, Design and Structures", vol. 47, pp. 328–334 (2019)
21. Szeląg, M., Fic, S.: Analysis of the development of cluster cracks in the cement paste modified by microsilica. Constr. Archit. **14**(4), 117–127 (2015)
22. Jones, R., Fakeoaru, I.: Non-Destructive Testing Methods for Concrete. Stroyizdat, Moscow (1974)
23. Popova, A.I.: The definition of the quality of a concrete layer of a concreted tube. Transp. Storage Petrol. Prod. Hydrocarbons **1**, 28–33 (2013)
24. Znaychenko, P.A.: The determination of crack depth by ultrasonic method in the lining of transport tunnels of large cross section. Min. Inform. Anal. Bull. Sci. Tech. J. **1**, 34–37 (2006)