Concrete as a self-organizing system

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Abstract. All levels of the product heterogeneities, including the product itself, are open complex systems, which are organizing themselves in autopoiesis mode. Such order of structure formation assumes a certain selectivity of the organization of the system while maintaining its openness to the influence of the environment. Factors of control may only initiate structural changes, but do not determine in what ways they will occur. The mechanisms of the structure organization at the selected levels of heterogeneities are qualitatively differing. Individual complex of processes and the phenomena is realized at each level; however, all heterogeneities are in the multi-scale co-ordination and influence each other, causing the interconnected structural variations. This supports the self-organization of the material structure. The mutual influence of the structural self-organization of individual levels of heterogeneities at the formation of the integral concrete structure is analyzed. Deformations determine the structure formation and functioning of concrete. Controlling the manifestation of deformation allows providing a directed structure of the material. For receiving the given sets of active elements, the factors controlling the processes of organization of micro- and macrostructures of concrete are accepted.

1. Introduction

Building constructions can be represented as complex self-organizing systems. It implies the existence of constructions in the form of a set of interconnected subsystems. At the same time, building constructions can be represented as a material of a certain geometric shape. The outline of the external boundary of such a material as a holistic object is specified at the same time as its structure formation begins. Design features of building products largely determine parameters of their structure and change of properties. This suggests that the external boundary of the construction is an active participant in its structural system organization as one of the elements.

Decomposing the building construction as a system it is possible to distinguish certain subsystems ensuring its integrity and performance of functions [1]. Concrete can be represented as a subsystem that has a decisive influence on the organization of the integral structure of constructions [1, 2, 3]. The complexity of structural design of concrete makes it possible to consider it as a system including a certain set of its own subsystems. Taking into account polystucture of concrete, its structural heterogeneities can be distinguished as subsystems. These heterogeneities are separate volumes of a system that differ in the mechanisms of structure formation and interact across surfaces of partition.
Concrete structure formation as a subsystem occurs within the external boundary of the building construction, determined by its configuration. At the same time all structural components of concrete are dynamically connected into a network of continuous interactions, which creates them and is produced by them, including the boundaries of the heterogeneities levels in the process of its realization. This suggests a special order of structural organization of concrete, carried out on the principle of autopoiesis [4]. Based on this, the task was determined - to analyze the genesis of the structure of concrete as a self-developing system.

2. Modelling of structural heterogeneities of concrete

For to solve the problem, structural heterogeneities of concrete were allocated at the level of “aggregates - matrix material” (macrostructure) and the level of binder particles (microstructure) and the level of products of new growths (nanostructure) under certain assumptions.

The macrostructure of concrete has been presented as a coarse-heterogeneous system consisting of a matrix in which the aggregates are distributed in a certain way. Aggregate sizes allow them to create their own deformations and stress fields at interfacial interactions. Matrix material is accepted as a heterogeneous medium with a complex internal organization, which manifests itself as an integrity. The macrolevel structure is formed by the interaction between matrix and aggregates.

The microstructure of concrete can be represented by heterogeneity of the type “dispersed phase particles - dispersion medium” in the form of a multiphase heterogeneous highly concentrated lyophobic system with a lyophilic phase boundary [1, 5]. The micro-level structure is organized by spontaneous distribution of dispersed particles over ordered structural aggregates with simultaneous modification of interfacial surfaces of partition. As a result, is formed a set of cluster structures as unique communities with a unique set of elements that are in mutual relations and interactions. The microstructure is a subsystem of the macrostructure. It implies the formation of its external boundaries by the surfaces of partition between the aggregates and the matrix material.

The nanostructure of concrete can be represented by levels of structural heterogeneities of the type “products of new growths - dispersion medium” and “products of new growths – particles of the dispersed phase”. The nanolevel structure formation occurs as a result of thermodiffusion effects of ion movement with the emergence of stable new phase germs involved in the formation of both crystalline formations and the gel part [6, 7, 8]. The nanostructure as a subsystem is included in the microstructure; therefore, its external boundaries as structural heterogeneity will be inter-particle and inter-cluster surfaces of partition.

Aggregates in the concrete mix are arranged relative to each other in arbitrary orientation and at different distances. Groups of aggregates and matrix material enclosed between them form structural cells that differ from each other: - shape determined by the methods of packing aggregates; - sizes that depend on distances between aggregates; - ratios of adhesion-cohesive bonding forces at the interface between matrix and aggregates [1]. It can be assumed that the material formed as the construction is a complex of unique macrostructures with various physical, geometric and spatial characteristics. Depending on the configuration, the external boundary of the construction as its integrity determines the spectrum of possible forms of macro-structural parts of concrete.

The microstructure is an integral part of the macrolevel and, like matrix, is part of the structural cells. It implies the influence of cell parameters on the formation of its external boundaries. In turn, the conditions for structural organizing of the micro- and nanolevel are determined by the condition and morphology of the external boundary of the microstructural heterogeneity.

Thus, the structure of concrete as a subsystem of a building structure is a certain hierarchy of levels of structural heterogeneities that act as subsystems for concrete itself, but systems for its structural parts (Figure 1). The interaction and organization of levels takes place by means of their external and internal surfaces of partition due to development of volumetric deformation processes on them. At the same time, the levels themselves form their borders in the process of their own organization, thus determining the dynamics of its implementation. The external boundaries of some levels are the internal boundaries of the heterogeneities in which they are included.
3. Interdependence of structural transformations of concrete as a self-organizing system

According to the provisions of the works by U. Maturana and F. Varela, the analysis of systems, whose structural formation is carried out as a result of self-development with the participation of the boundaries that determine their integrity, can be carried out using the concepts of the theory of autopoiesis. The term “autopoiesis” [4] means the process of self-creation, self-construction. This view suggests that the organization of autopoiesis systems occurs through the development of nonlinear networks of relationships on a certain set of elements. At such method of structural formation of systems, network components constantly generate and transform each other, realizing a network of processes that produce them. A distinctive feature of an autopoietic network is the creation of the boundary of this network as an active component involved in its implementation, which designates the scope of the network’s operations and defines it as a unit.

The presentation of concrete as an autopoiesis system eliminates the rigid subordination of some of its constituent parts to others. All concrete subsystems coexist in overall interaction consistency.

In [9] it is shown that the formation of the general structure of concrete is largely determined by the mutual influence of the levels of structural heterogeneities. This is manifested in the fact that a change in the parameters of one level is affects on organization of the structure of other levels with a change in the parameters of their structural components. The realized changes cause the change in the initial structures that provokes further mutual initiation of structure formation at various levels. The participation of each level of heterogeneities and its individual parts in the structural organization of each other is a characteristic feature of autopoietic systems.

Coexistence of external boundaries implies organizationally closed (autonomous) [10] structural heterogeneities of concrete as systems that causes indirect (perturbing) effects at their interaction. Each level can only initiate structural changes of other levels, but not control them. At the same time, heterogeneities react to external influences by certain transformations of their structural design only on the basis of internal capabilities. The conditionality of the structure formation of levels by their own structural potential allows them to independently organize themselves, using non-specific activation of their environment, with which they are in relations of mutual causation. At the formation of the integral structure of concrete as a complex organized system, the dominant position is occupied by processes and phenomena that occur at the level of binder particles. This is due to the fact that the organization of the microstructure initiates all subsequent structural transformations of concrete at all levels of heterogeneities. The micro-level structure formation takes place in accordance with the characteristic features of the organization of autopoiesis systems that is due to its autonomous as
certain integrity, as well as its inactivation and iteration properties. The concept of inactivation implies that the inducement to the beginning of the organization of the system is caused not by external influences, but is provoked by internal conditions. For a microstructure, such a reason is its desire to reduce excess surface energy due to a no equilibrium condition. The iteration property manifests itself in the openness of the microstructure organization cycle, in its constant self-renewal and self-completion, which allows the system to build new levels of the structural complexity. On this basis, it is possible to distinguish cluster formation processes at the microlevel as fundamental ones, which determine both the organization of the microstructure itself and the formation of the integral structure of concrete.

Physical and mechanical features of micro-level self-organization appear in unbalanced inter-particle interactions depending on the ratio of the particle size of the dispersed phase, the distance between them and their nature. In this case, a certain set of separate but interconnected subsystems is formed. Potentially probable forms of organization of cluster structures are determined by the internal characteristics of the microstructure, including the condition and shape of its external boundaries, determined by the parameters of the structural cells of the macrolevel only in the initial period.

Inter-particle and inter-cluster interactions manifest themselves as indirect effects exerted by particles or clusters on each other, selectively reacting to a source of excitement. The freedom of manifestation reactions to perturbing influences is embedded in the autopoietic network itself and is determined by the parameters of its components. This suggests that the microstructure as an autonomous system independently regulates fluctuations of the material composition, predetermining individual conditions for realization the physic and chemical processes of its organization.

Processes and phenomena of binder hydration provoke the appearance of a sufficient number of ions of a new phase, spontaneous redistribution of which over the surface of dispersed particles and in the volume of liquid phase initiates the organization of a new structural heterogeneity of concrete at the level of products of new growths. The nanometric size of hydrated substances allows imagining a new heterogeneity as nanostructure with its characteristic mechanisms of structure formation and as set of substructures (stable structural formations – nanoclusters). Considering that the nanostructure is an integral part of the micro level, it can be assumed that its external boundaries as integrity will be inter-particle and inter-cluster surfaces of partition. The existence of external surfaces of partition and their direct participation in the processes of self-reproduction of their own components causes the autopoietic organization of the nanolevel of structural heterogeneities of concrete.

Interfacial interactions occurring in the nanostructure are accompanied by the manifestation of gradients of volume deformations, causing a change of its external boundaries as a system. This provokes a change of the conditions of realization of subsequent exchange reactions and the processes of nanoclusters organization. This is reflected in the structural forms of nanoclusters and their distribution in the nanolevel volume that determine the change in the parameters of the internal nanostructure surfaces of partition. This initiates a new wave of deformations with the shape change of the external surfaces of the system and, as a result, another round of structural transformations.

Due to the hierarchical subordination of the levels of structural heterogeneities of concrete, the external boundaries of the nanostructure are structural components of the microlevel that implies their active participation in the processes of its organization. Upon transition the microstructure level, the gradients of volumetric deformations affect the conditions of inter-particle and inter-cluster interactions that continue to spontaneously realize themselves. This determines the kinetics of further structure formation of the nanolevel and the development of volumetric deformation processes on it. Thus, there is mutual initiation of return waves of volume deformations transition from level to level. It allows structural heterogeneities of concrete to create them in the form of certain integrity.

Gradients of volume deformations, which appear on the internal surfaces of partition of the microstructure, determine the organization of its structure as a subsystem (matrix) of the macrolevel. Non-additive transfer of deformations to the external boundaries of the hardening matrix material leads to spontaneous shaping of the surfaces of partition between the matrix and the aggregates, unique to each structural cell depending on its parameters. The individual distribution of deformation
gradients on the external boundaries to the matrix material initiates the formation of a unique return wave of deformation effects on the levels of micro- and nanostructures. It causes mutually interdependent responses of their structural transformations. This leads to a redistribution of deformations and their gradients in the macrostructure. Results of the mutual influence of the processes of structure formation of all heterogeneities of concrete as a subsystem of a construction determine the organization of its structure as a system.

It should be borne in mind that the realized structural features of the levels are predetermined by a given form of construction. The gradients of local and integral volume deformations of concrete, appearing on external boundaries of the structure, lead to a change in the density of the material and, thereby, form fields of residual stresses. This implies that the organization of the structure of the individual levels of heterogeneities of the concrete and the construction itself will occur under the constant action of the forming fields of their own deformations. In addition, volume changes provoke the emergence and development the various surfaces of partition at all levels of heterogeneities. These new elements are automatically included in the organization of structures, participating in the manifestation and redistribution of volume deformation gradients. This creates the prerequisites for spontaneous generation and growth of such structural components of concrete as technological cracks and inner surfaces of partition. These constituent structures, together with residual stresses, determine the heterogeneity of the material of the construction, and, therefore, the safety of its operation.

4. Conclusions
The building construction structure can be presented in the form of a certain integrity, which includes as equal components both the structure itself and the material from which it is made. It assumes that all features of the structural design of material become an integral part of structure of a construction. Concrete as a subsystem of the building construction is a complex organized polystructural system with characteristic levels of structural heterogeneities. Each level has an individual structural organization and can be represented as a unique set of substructures with a unique combination of structural elements. The structure organization of levels of heterogeneities occurs as a result of the mutual initiation of the formation of their substructures. This makes it possible to imagine concrete as a self-developing system. Structural organization of such system is determined by the participation of all its structural components, including the boundaries of levels as a whole, in the implementation of the network of processes that ensure their genesis.

References
[1] Vyrovoy V, Dorofeev V and Sukhanov V 2010 Composite building materials and constructions. Structure, self-organization, properties (Odessa: TES)
[2] Sheynich L and Pushkareva K 2009 The processes of self-organization of structure of build composites (Kyiv: Gamma-Print)
[3] Cherniavsky V 2008 Adaptation abiotic systems: concrete and reinforced concrete (Dnipropetrovsk: DNURT)
[4] Maturana H R and Varela F J 1987 The Tree of Knowledge: The Biological Roots of Human Understanding ( Boston: New Science Library/Shambhala Publications)
[5] Solomatov V, Takhirov N and Shakhekh Shah 1989 Intensive technology of concrete (Moscow: Stroyizdat)
[6] Delmon B 1972 Kinetics of heterogeneous reactions (Moscow: Mir LLC)
[7] Budnikov P and Gistling A 1971 Reactions in mixes of solid substances (Moscow: Stroyizdat)
[8] Shpynaeva L and Chih M and Sanitskiy M and et al 1981 Physical and chemical bases of formation of structure of a cement stone (Lviv: Vyshcha shkola)
[9] Korobko O and Vyrovoy V 2012 Role of microstructure in organization of the integral structure of concrete Bulletin of OSACEA 47 174-181
[10] Varela F 1981 Autonomy and autoopoiesis Self-Organising Systems: An Interdisciplinary Approach 14-24