Structure-formation of contact layers of composite materials

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Abstract. Often in practice, there are problems with the creation of contact layers of a wide variety of composite materials. During the construction of any building or facility there is a creation of joints of structural elements that can be represented by masonry of different materials. The authors propose a law of structures affinity in materials science designed to reflect the existing internal binds and generated as a result of creation of structures during target development of new composites that should provide the necessary conditions for reliable function of materials, items and structure. On the basis of proposed by the authors the law of affinity structures in materials science backgrounds of formation of strong contact layers of composite materials are showed. Examples are given to confirm the practical significance of the proposed law of structures affinity in materials science.
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Introduction

The fundamental basis of the construction materials for various purposes is a physical-chemical approach to understanding the complex structure and associative properties of microscopic formations: compounds, molecules, atoms, and even knowledge of the microstructure is not enough to predict the final microscopic properties of the created system. To assess the characteristics of the material all the complex of interactions is taken into account, both its components and structural organizations.

Often in practice, problems arise with the generation of contact layers of the various composite materials. During the construction of any building or facility there is a creation of joints of structural elements that can be represented by masonry of different materials (natural stones or plates, ceramic and silicate bricks, various LECA blocks, dense concrete or porous concrete, etc.), as well as application of special mortars prepared on the basis of variety of raw materials; carrying out installation of large-panel, large-block and monolithic buildings and constructions, for making exterior finish of buildings, creation of protective materials and coatings, etc. When making the above operations it is necessary to create strongest, reliable middle layer of mortar, bonding different materials, providing a protective coating and durability in general. Special problems arise when creating mortars for connecting several different materials, especially if the construction works under extreme conditions.

The main part

Nowadays, there are a number of provisions on the formation of lasting reliable durable material, individual views and ways to implement the development of advanced composites in accordance with the required mechanical and performance properties. In this paper we attempt to formulate a common approach for solving this problem. Due to what is noted above the hypothesis about the required target formation of composite with desired properties, establishing the bonds between different raw materials that compose this composite material or a contact layer between different materials is suggested.

And here it is necessary to use the "experience" of geological processes [1], meaning the genesis of a wide range of anisotropic rocks (banded, schistose structures, etc.), which anisotropy coefficient can be reduced to 2...3, in contrast to 5...7 and higher for layered structures produced by human.

To create a durable and reliable contact between the elements it is necessary to create a stable internal bound designed to provide specific physical and mechanical and operational requirements for the construction in general. This contact area should have similarity, proximity, or rather affinity by the basic properties and common genetic origin with the material matrix.

Such affinity requires the creation of a structure that would ensure the proper relative positions and connection of components and eventually guaranteed to work together of this zone with elements of two or, perhaps several adjacent materials.

Considering the affinity of construction composites it is probably necessary to keep in mind the concepts and properties of the chemical affinity of elements since speaking of building materials, we first take into account the chemical composition of composing elements of these materials.

The notion of chemical affinity in chemistry does not apply now, though creating any material, including construction material, is primarily based on chemical affinity of its components. Still the creation of affinity of structures in building materials is deeper and multifaceted as ultimately established structure should satisfy many requirements.

In our opinion, the affinity of structures in construction materials science is useful for the characteristics of two or more separate materials to interact with each other and stability characteristics of the resulting contact layer. Affinity of structures can be assessed by various parameters of strength, density, porosity, etc. The equation can be derived to express the quantitative and qualitative dependence of these values on the characteristics of the contacting interacting materials and ratio of quality indicators of contacting materials in accordance with the Gibbs law.

But the main criterion for evaluating the characteristics of affinity, in our opinion, should be the strength and durability of the contact layer. When creating a material to suit structures affinity it is necessary to consider the structural features of the material and take it into account when laying it into a construction and during its further operation.

Currently, architecture of structure of building materials was studied at three levels: macrostructure of material – architecture of material, visible to the naked eye; microstructure of the material – architecture visible in an optical microscope; nanostructure of material – internal structure of the substances that make up the material on the molecular-ion level, studied with modern research methods.

Study of the internal structure of matter that composes the material is known for several centuries and there is a considerable amount of knowledge that described above, and current methods of physical-chemical studies allow comprehending more and more knowledge.

However, the laws of structures affinity at the micro and macro-level, determining the properties of materials has not been established yet, but it is obvious that the combination of various structures in a single unit requires the fulfillment of certain requirements and conditions necessary to ensure their joint work and durability.

Under the structure, or the internal structure of the building materials, as well as other physical bodies, we mean the spatial arrangement of particles of different fineness that are in stable mutual links (primary or secondary) to a specific order of coupling them together. The concept of the structure comprises, in addition, the size and arrangement of pores, capillaries, interfaces, microcracks, and other elements. In connection with new goals for material scientists in modern conditions and with the establishment of new efficient materials the structure of the material requires new attitudes, approaches, especially when creating thin layers of materials that are widely popular at the moment. Studying such materials raises the question about the structure of the surface and inner layers of the material, since they work in completely different conditions. The structure of the surface layer of the artificial construction materials, as a rule, differs from the internal layers by the following reasons: the atoms and molecules that are located on the outer surface of the material have excess energy in comparison with the particles located inside of material, moreover, the surface layer of material has actual contact with the environment and constantly experiences environmental influences, both during manufacture and during usage. The excess energy of the surface layer is due to the fact that each particle on the surface of solid and liquid materials has uncompensated chemical bonds that form on the surface an asymmetric force field. This force field draws the surface particles inside the material, creating a compressive stress on the surface.

Thus, the surface layer is constantly in elastically stressed state and the particles have a significantly larger supply of potential energy than the particles in the inner layer. Consequently, the surface layer of the particles reacts more actively with an environment and more actively enter into chemical reactions. The amount of energy of the surface layer is directly proportional to the chemical binding energy of the material and depends on environmental parameters. So, for example, the surface energy of the solid body at the interface with the liquid that it wets, reduced by an amount equal to the force of interaction of the particles with the liquid surface. Significant impact on the structure and surface and inner layers of material have tramp elements, moisturizing of surface with active liquids, diffusion processes. Impurities have different effects on the properties of the external and internal layers. If the impurities have a lower surface energy than the material that they are evenly distributed over the surface, reducing its energy. And if surface energy is greater, impurities concentrate on certain areas of the surface or move into the inner layers of the material, where they can have both positive and negative effects on its properties. Moisturizing has important

sense in the formation of artificial composite materials and is necessary to reduce the surface energy of the solid constituents that allows obtaining more dense packing of the particles created in the materials. Diffusion is the spontaneous movement of particles of matter, which results in an equilibrium distribution of the concentration of these particles in volume of gas, liquid and solid body. The macrostructure of the inner layer of building material is easily visible on the cleavage with the naked eye or through normal lens. The structure includes individual solids (grain) of different size, pores and matrix that combines grains in a single conglomerate. As matrix may be used cement paste, aluminosilicate glass, clay, calcite, quartz of varying crystallinity, etc.

It should be noted that the structure of the building materials division at the macro- and microstructure is very conditional. That type of division is purely methodological significance: it simplifies the reological models of deformation systems characterized by different sizes of components and, therefore, allows to use more simple mathematical models for description of processes.

If we consider the establishment of a contact zone of two different materials with theoretical positions of accumulated and available knowledge on the subject, it is necessary to know the basic properties of each material, their genetic characteristics, their macro-, micro- and nanostructures, the required physical, mechanical and operational characteristics, purpose and conditions of application of this construction. And all of these properties and requirements have to be merged into a single entity.

Law of structures affinity in building materials is based on the basic properties and regularities inherent in the main base and the fastening material and the necessary set of properties that provide guaranteed properties of contact layer for the reliability and durability of construction. A graphical interpretation of proposed law can be represented by the following scheme (Fig. 1).

First of all, to create a reliable and durable contact layer between the main and auxiliary materials, for example, between some wall materials and plastering mortar we must take into account the chemical affinity of the used materials, their compatibility, their preconditions for the creation of a reliable contact, the absence of antagonistic causes between them. Performing all of these conditions will provide guaranteed long service of the contact layer and the reliability and safety of the construction as a whole. Note that often there are complex structures, which may consist of a plurality of chemical elements, but nonetheless, it is necessary to consider the compatibility, incompatibility, and, possibly, even synergistic effect.

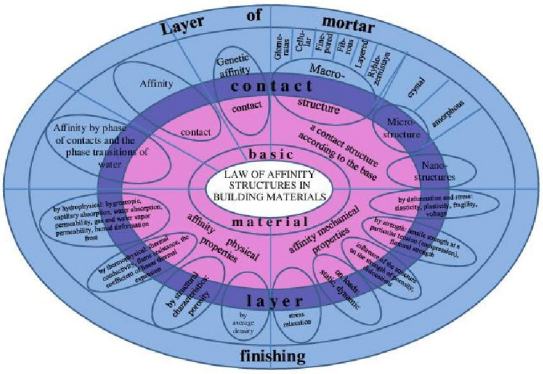

Fig. 1. Law of structures affinity in building materials

A significant influence on the establishment of the contact layer have genetic characteristics of basic and auxiliary materials as well as raw materials of the contact layer, in this connection it should be taken into account and raw materials should be selected in view of their origin, and whereby the reactivity of the constituent elements in the system may be adjusted with tasks being taken into account.

For creation of a contact layer structures of the general (basic) and finishing materials are very important, which in turn have their own characteristics of macro-, micro- and nanostructures. The task of creating a contact layer is forming such structure that germinated into these structures and created a single monolithic layer and formed structure ensured sustainable mutual bonds with a certain order of coupling them together. The concept of the structure include the size and arrangement of pores, capillaries, phase contacting area, microcracks. These elements of the structure play a crucial role in generating strong and stable structure of the contact layer.

Particularly noteworthy is affinity by phase composition of basic, auxiliary material and the contact zone and the phase transitions of water in pores, which has the most significant effect on all the properties and behavior of the material during the application.

The affinity of the main (basic) and finishing layers and their contact zone must satisfy a number of physical properties, including the figures of average density, porosity, hydro-physical and thermal properties. A rational surface area with considering these properties will provide high and reliable performance of the composite.

Establishment of a reliable contact zone between the basic and finishing materials provides a

high affinity by the mechanical properties. With these conditions the desired goals can be achieved, however, it should be remembered that when creating a contact zones recommendations on the management of construction works should be considered.

For example, to create a reliable contact layers between the bases of two fundamentally different materials submitted by ceramic and silicate bricks and put on them finishing mortar layers based on the cement binder is necessary to know the genesis and composition of these materials bases. So, for ceramic brick the main structure formation substance is clay that creates during the firing micro- and macrostructure and is characterized by content of basic oxides: SiO_2 – 40 ... 70 %, Al_2O_3 – 15 ... 35 %, K_2O and Na_2O – 1 ... 15 %, Fe_2O_3 – 0 ... 7 %. As a result of the firing and the solidification of the melt micro conglomerate is formed in which crystal grains of mullite, silica of various modifications and other substances crystallize during cooling and cemented by amorphous mass of solidified melt, the last fringes individual grains of aggregate and locates in interstitial voids.

Unlike ceramic bricks, silicate brick – is cementless artificial material obtained by compressing of mixture of hydrated lime and quartz sand with subsequent hydrothermal synthesis (in the medium of saturated steam pressure of 0.8...1.3 MPa and temperature of 175...200 °C) resulting in a its different calcium hydrosilicates depending on the composition of the mixture: tobermorite $5CaO{\cdot}6SiO_2{\cdot}5H_2O$, lightly crystallized calcium hydrosilicates: (0,8–1,5) $CaO{\cdot}SiO_2{\cdot}H_2O$ and (1,5–2,0) $CaO{\cdot}SiO_2{\cdot}H_2O$. In high limy mixtures hillebrandite $2CaO{\cdot}SiO_2{\cdot}H_2O$ is synthesized.

Thus, in these systems the basic materials for the application of mortar topcoat are presented by cementless conglomerates resulting from firing and hydrothermal treatment and, of course, with different mineral and chemical compositions, as well as specific, inherent to them genesis which predetermines creating of different conditions for the formation of structure of contact layer. Due to the different origin the formation of macro-, micro -and nanostructures in ceramic and silicate bricks occurs at different stages of treatment, depending on their technological features and has its own specific features. An important factor in the formation of the contact layers is the state of the bedding, we should take into account the structure of the surface layer of the basic material to create the first structures of the future contact because, depending on the state of the surface the structure the surface layer is formed and it is created by the atoms and molecules located on the outer surface of the basic material and with excess energy as compared to the inner layers of the basic material surface layer responds more actively to the environment and actively enter into chemical reactions .

To ensure reliable contact zone of considered joints on physical and mechanical properties we must carefully analyze for each factor and make the best decision with regard to the conditions and peculiarities of their functioning. Particular attention should be given to features of affinity by phase composition of contacts and phase transitions of water in these areas, since it is this factor that largely determines the operating conditions of all constructive solutions.

Combining all these elements, we can talk about the creation of the law of structures affinity to achieve a specific task. Noting that in modern conditions it is necessary to develop and create wide range of new efficient low-power construction materials with the required properties – it is time to talk about the need to create Law of structures affinity in building materials.

Discussing the structures affinity, one of the most striking and obvious examples is the affinity of the mortar with basic block material of the most ancient structures of the planet – the Egyptian pyramids.

At this point there are a lot of opinions, hypotheses, but the obvious is the fact that it is the affinity of the contact zone on the boundary of plates which build the Pyramids has provided durability of construction for dozens of centuries. It is this contact zone formed from the dispersed phase of sandstone contributed to the creation of a dense skin to prevent centuries of harsh climate impacts on elements of the structure.

It is known that every law reflects objectively existing necessary link between some phenomena, sustainable relationship between the phenomena existing internal dependences between the cause and the consequence of some event or a material object.

Law of structures affinity in building materials is intended to reflect the existing internal bonds and created as a result of generation of target structures aimed at the development of new composites which should provide the necessary conditions for reliable functional operation of building products and constructions and we can formulate this fundamental law as follows: "The law of structures affinity establishes their causal dependences, interacting with each other, defining the properties of the total system as a whole ".

Law of structures affinity – is a complex system consisting of subsystems or components, each of which performs its functions. Elements of the system are not isolated from each other, and are

grouped so as to ensure appropriateness of entire system, any change in a given element or the replacement of one element to another generally results in a change of properties of the entire system. Law of structures affinity in building materials science is based on the basic properties and regularities inherent to the main basic and the binding material and the necessary set of properties that provide guaranteed properties to contact layer for the reliability and durability of construction. Elements of the system are interconnected and the more versatile this communication, the more effective is the created system.

Considering the practical implementation of the proposed law of structures affinity in building materials, we can show a number of examples for creating target structures for building composites for various purposes [2-4].

Studies conducted by the authors [5-7] with the principles of the law of structures affinity proved the possibility of directional change in capillary porous structure and management of water transfer in lime and cement stone with the combined use of super- plasticizing agents and mineral fillers of a certain particle size that allows designing composites based on binders for the restoration of monuments. This methodology was tested during the restoration of ensembles in Tsaritsino and Rostov Veliky, architectural, historical and cultural buildings in Siberia and Bulgaria.

Using the law of structures affinity allows to create new effective heat-isolating and construction silicate material based on active granular aggregates with stable high thermal insulation properties and with increased adhesion to mortar, which is especially important in seismic regions and a mechanism of formation of the contact zone of granular aggregate with a silicate matrix during autoclave treatment was established. Established patterns of changes in structure and physico-mechanical properties of silicate products allowed to form a three-dimensional contact area between the developed filler and the matrix. Creating, or adding into their structure the most efficient in terms of thermal insulation, closed pores can significantly reduce the thermal conductivity, increase the thermal resistance of walls of buildings, reduce the mass of wall constructions, improve adhesion to mortars [8.9].

Considering the law of structures affinity we have established effective heat-isolating mortars on the basis of dry construction mixtures, effectively working on various surfaces: heavy and light concrete, ceramic and silicate bricks [10]. It was found that heat-isolating mortars applied to different bases have different adhesion to surfaces, so heavy and light concrete and ceramic bricks have approximately the same index of adhesion and silicate brick has adhesion rate higher by 50 %, due to affinity of minerals of silicate brick and effective heat-isolating mortar.

Conclusions

Nowadays preparation of high-performance building materials of new generation is accompanied by using complex composition in chemical and mineral point of view in order to obtain high-quality construction materials for various functional purposes with improved and sometimes with fundamentally new properties and with certain predetermined structure. The basis of foundation of such binders is the principle of purposeful management of technology in all its phases: the application of active components, the development of optimal compositions, the use of chemical modifiers, the use of mechanical-chemical activation of components and some other techniques.

Implementing of Geonics regulations [1] in construction materials science creates new high-performance, "smart" composites with predetermined properties. Implementation of laws of structures affinity involves the creation of system of hardening composite, which laid the foundations for a response to changing conditions of synthesis and exploitation; purposefully synthesizing neoplasms and creating nano-, micro - and macrostructure with ability to self-healing of defects arising in a certain range of operating loads. Theoretical and practical approaches should be the prerequisite for the generation of a new class of "smart" construction materials with advantageous properties. Thus, for the creation and application of any building there are certain requirements, breach of which leads to a decrease in strength, non-compliance of operational requirements and sometimes to structural failure, and violation of the laws of structures affinity leads to the above consequences.

The proposed theoretical approaches to the creation of the law of structures affinity could provide a strong scientific base for the further development of modern construction materials science to create a low-power, ecological and competitive in the domestic and foreign markets, high-performance materials with improved properties and a predetermined structure.

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