New methods for manufacturing composite materials

L Kh Zagorodnuk, V S Lesovik, M Y Elistratkin, D A Sumskoy, D S Makhortov and S V Zolotykh
Belgorod State Technological University named after V G Shukhov, 46, Kostyukov Street, Belgorod, 308012, Russia
E-mail: zagorodnyk.lh@bstu.ru

Abstract. The law of affinity of structures developed by the authors is based on basic properties and regularities inherent in the basic and bonding material and the combination of properties that ensure properties of the contact layer for reliable and durable construction operation. In recent decades, new composites with a number of required physical, mechanical and operational properties have been developed. To produce modern efficient materials which would be uniform, strong and durable, it was proposed to apply the law of affinity of structures.

1. Introduction
The fundamental basis for designing materials is a physical chemical approach to the combination of structural and associative properties of microscopic formations: compounds, molecules, atoms. However, knowledge of the microstructure is not sufficient to predict final microscopic properties of the system. To assess characteristics of the material, the whole system of interactions of individual components and structural organizations is taken into account.

We have proposed a unified approach to the problem. A hypothesis about the production a composite with target properties, links between various raw materials composing this composite material or contact layers between different materials was put forward [1-6]. To create a strong and reliable contact between elements, it is necessary to create an internal stable connection designed to meet certain physical, mechanical and operational requirements of the structure. This contact zone should have similarity, closeness, or affinity for main properties and a common genetic origin with the material matrix. This affinity requires such a structure that would ensure interposition and proper communication of the components and ensure the joint work of this contact zone with elements of two or several related materials.

2. Materials and methods
Modern equipment operating in various extreme conditions (high and low temperature, aggressive environment, high dynamic loads) requires high-strength efficient composites with required performance characteristics.

The authors conducted numerous laboratory and field studies producing composites at the junction of several bordering materials and established principles for the creation of related structures on their border.

The basis for the development of new approaches to the production of durable reliable composite materials was numerous experimental data.

3. Main body
The essence of affinity of composites is properties of chemical affinity of elements, since we take into account the chemical composition of constituent elements from which these materials are made.

The main criterion for assessing affinity is strength and durability of a contact layer. When producing a material taking into account the affinity of structures, it is necessary to account for structural features of the material and its further operation.

The law of affinity of structures reflects internal connections and directional structures in the targeted development of new composites to ensure required conditions for reliable functional operation of building products and structures. The law of affinity of structures is a complex system consisting of subsystems or elements performing their own functions. The elements are grouped so as to ensure the expediency of the entire system; any changes cause changes in properties of the whole system. The elements are interconnected with each other; the more versatile their communication, the more effective the created system is.

It is advisable to use the affinity of structures to characterize two or several separate interacting materials and the stability of the resulting contact layer. The affinity of structures can be assessed by strength, density, porosity, etc. You can derive the equation expressing the dependence of these values on the characteristics of contacting interacting materials and the dependence of quality indicators of contacting materials in accordance with the Gibbs law.

At present, the structure of building materials is studied at the macro, micro, and nano-levels. The internal structure of building material is a spatial arrangement of particles of different dispersion which are in stable mutual relations (primary or secondary) with a certain order of their adhesion to each other. It includes the size and location of pores, capillaries, interfaces, micro-cracks and other elements. Due to new tasks for materials scientists and the need for new efficient materials, the analysis of the structure requires new approaches, especially when creating thin layers of materials that are currently in great demand. When creating such materials, the question about the surface structure and internal layers of the material arises, since they work in very specific conditions.

The structure of the surface layer of artificial composites differs from internal layers: atoms and molecules located on the outer surface of the material have excess energy compared to particles located inside the material; being in real contact with the environment, the surface layer of the material is constantly experiencing environmental effects during the manufacturing process and operation. Excessive energy of the surface layer develops due to the fact that each particle on the surface of a solid and liquid body has uncompensated chemical bonds that form an asymmetric force field on the surface. This force field draws surface particles into the material creating a compression stress on the surface.

Thus, the surface layer is constantly in an elastically stressed state, and its particles have a much larger margin of potential energy than particles of the inner layer. As a result, the particles of the surface layer interact with the environment entering into chemical reactions. The energy of the surface layer is directly proportional to the energy of the chemical bond. It depends on environmental parameters. For example, the surface energy of a solid body at the boundary with the liquid that wets it decreases by an amount equal to the strength of interaction of surface particles with the liquid. Impurities wetting the surface with active liquids, and diffusion processes have a significant effect on the structure of both the surface and inner layers of the material. Impurities have different effects on properties of the outer and inner layers. If impurities have less surface energy than the material, they are evenly distributed over the surface, reducing its energy; if they have larger surface energy, they are located on certain parts of the surface or move into the inner layers of the material, where they can have both positive and negative effects on its properties. Wetting is of great importance when producing artificial composites. It is used to reduce the energy of the surfaces of solid components which allows for production of more dense particles.

The macrostructure of the inner layer is visible. The structure consists of individual grains of various sizes, pores and a matrix that combines grains into a single conglomerate. There can be various materials in the structure: cement, aluminosilicate glass, clay, calcite, quartz, metal, ceramics, etc.
It is necessary to take into account basic properties of each material, genetic features, their macro, micro and nanostructures, physical, mechanical and performance characteristics, purposes and conditions of operation. All these properties and requirements should be combined into a single whole.

The law of affinity of structures is based on basic properties and regularities inherent in the basic and bonding material and the combination of properties that ensure properties of the contact layer for reliable and durable construction operation.

To create a reliable and durable contact layer between primary and auxiliary materials, for example, between any wall material and a plaster solution, it is necessary to take into account the chemical affinity of the materials used, their compatibility, prerequisites for creating a reliable contact, the lack of antagonistic causes. These conditions are relevant for the creation of contact layers during repair works. Fulfillment of all these conditions will ensure the long-term service life of this contact layer, reliability and safety of the structure. We often have complex structures that consist of many chemical elements, but their compatibility, incompatibility, and synergistic effects must be taken into account.

The genetic characteristics of main and auxiliary materials, raw components of the contact layer have a significant impact on the creation of the contact layer; it is necessary to take into account and select raw materials taking into account their genesis; reactivity of constituent elements in the system can be adjusted.

To create a reliable contact layer, the structure of main (base) and finishing materials which have their own characteristics of macro-, micro- and nanostructures is of great importance. The task of creating a strong contact layer is the formation of a structure which will grows into contact structures and create a single monolithic layer; the structure will ensure stable mutual relations with a certain order of their adhesion. The structure includes sizes and locations of pores, capillaries, phase interfaces, micro-cracks. These elements play the most important role in creating a solid, stable structure of the contact layer.

Affinity of the phase composition of main and auxiliary materials has the most significant effect on the properties and behavior of the material under operational loads.

Affinity of the main (base) and finishing layers and their contact zone should satisfy a number of physical properties, including density, porosity, hydrophysical and thermophysical properties. A rational contact zone will ensure high reliable performance properties of the composite.

Creating a reliable contact zone between main and finishing materials ensures affinity for mechanical properties. When these conditions are met, high strength and reliability of created joints of materials can be achieved; however, it when creating contact zones, it is necessary to follow recommendations for construction works.

An important factor in the formation of contact layers is the state of the base; it is necessary to take into account the peculiarity of a surface layer of the base material to create initial structures of the future contact, because the structure of the surface layer created by atoms and molecules located on the outer surface of the base material has excess energy compared with the inner layers of the base material; the surface layer interacts with the environment and enters into chemical reactions.

To ensure a reliable contact area of the joints of materials in terms of physical and mechanical properties, it is necessary to analyze and make optimal decisions for each factor taking into account conditions and peculiarities of their operation. Particular attention should be paid to the peculiarities of affinity of the phase composition of contacts and phase transitions of water in these areas, since they determine operating conditions of the entire design solution.

Combining all these elements, we developed the law of affinity of structures to create strong reliable contact zones at the borders of various materials.

It is known that any law reflects an objective relationship, a stable relationship between phenomena, and an internal relationship between causes and consequences of a phenomenon or a material object.

The law of affinity of structures is based on basic properties and regularities inherent in the basic and bonding material and the combination of properties that ensure properties of the contact layer for reliable and durable construction operation. The elements are interconnected; the more versatile communication, the more effective the created system is.
One can cite a number of examples of creating target structures for building composites [7–13].

Studies conducted in compliance with the principles of the law of affinity of structures proved the possibility of directional changes in the capillary-porous structure and moisture transfer management in limestone and cement stones which allows for producing composites based on binders used for the restoration of monuments [1].

The law of affinity of structures allowed for creation of new effective thermal insulation and structural silicate materials based on active granulated aggregates with consistently high thermal insulation properties, increased adhesion to masonry mortars which is especially important in seismic regions. It also allowed for establishing a mechanism for forming a contact zone of the granular aggregate with a silicate matrix. The patterns of changes in the structure and physical and mechanical properties of silicate products made it possible to form volumetric contact zones between the aggregate and the matrix which reduced thermal conductivity, increased thermal resistance of building walls, decreased the mass of wall structures, and improved adhesion of masonry mortars [11-12].

Taking into account the law of affinity, effective heat-insulating solutions based on dry construction (heavy and lightweight concrete, ceramic and silicate bricks) [7-10] were produced.

Production of high-performance building materials is accompanied by the use of complex compositions of components in order to obtain high-quality building materials of various functional purposes with improved new properties and a predetermined structure. The basis for creating such binders is the principle of purposeful control of technology at all production stages: the use of active components, the development of optimal compositions, the use of chemical modifiers, mechanical and chemical activation of components, etc.

Considering the peculiarities of modern composites, the law of affinity can be used for designing complex composites for various operating conditions (ultrahigh temperatures, pressures and dynamic loads).

4. Conclusions
To implement the law of affinity, it is necessary to create a system of hardening composites which lays the foundation for responding to changing conditions of synthesis and operation. The nano-, micro-, and macrostructures that can heal defects occurring under operating loads are created. Theoretical and practical approaches should be a prerequisite for a new class of “intelligent” composites with effective properties. The law of affinity could serve as a serious scientific basis for the production of modern building materials which will be competitive in domestic and foreign markets.

5. Acknowledgments
The work was performed as part of the RFBR funded research project No. 18-29-24113, using equipment of High Technology Center at BSTU named after V G Shukhov.

References
[1] Lesovik V S, Zagorodnyuk L H, Chulkova I L 2014 The law of affinity of structures in materials science Fundamenta Research, 3(2) 267–271
[2] Zagorodnuk L H, Lesovik V S, Shkarin A V, Belikov D A, Kuprina A A 2013 Creating Effective Insulation Solutions, Taking into Account the Law of Affinity Structures in Construction Materials World Applied Sci. J. 24(11) 1496–1502
[3] Lesovik V S 2012 Geonics. Subject and Objectives. (Belgorod: BSTU) 100 p.
[4] Zagorodnyuk L Kh, Lesovik V S, Sumskoy D A 2018 Thermal insylation solutions of the reduced density. Construction Materials and Products. 1(1) 40–50
[5] Zagorodnyuk L H, Lesovik V S, Shamshurov A V, Belikov D A 2014 Composite binders based on organo-mineral modifiers for dry repair mixtures Bulletin of BSTU named after V G Shukhov. 5 25–31
[6] Zagorodnyuk L H, Lesovik V S, Belikov D A 2014 To the problem of designing dry repair mixtures, taking into account the affinity of structures *Bulletin of the Central Regional Branch of the RAABS* 18 112–119

[7] Zagorodnyuk L H, Lesovik V S, Gainutdinov R 2014 Specificity of hardening of mortars based on dry mixtures *Bulletin of the Central Regional Branch of RAABS*. 93–98

[8] Lesovik V S, Zagorodnuk L H, Tolmacheva M M, Smolikov A A, Shekina A Y, Shakarna M H 2014 Structure-formation of contact layers of composite materials *Life Science J*. 11(12s) 948–953

[9] Kuprina A A, Lesovik V S, Zagorodnyk L H, Elistratkin M Y 2014 Anisotropy of Materials Properties of Natural and Man-Triggered Origin *Res. J. of Applied Sci*. 9 816–819

[10] Lesovik V S, Chulkova I L, Zagordnyuk L Kh, Volodchenko A A and Popov D Y 2014 The Role of the Law of Affinity Structures in the Construction Material Science by Performance of the Restoration Works *Res. J. of Applied Sci*. 9 1100–1105

[11] Elistratkin M Y, Lesovik V S, Zagorodnjuk L H, Pospelova E A, Shatalova S V 2017 *IOP Conf. Ser.: Mater. Sci. and Eng.* 032020

[12] Elistratkin M Yu, Pospelova M A 2017 On the question of the formation of an artificial human environment *Fundamental foundations of building materials*. *Collection of reports of the International Online Congress*. pp. 66–73

[13] Elistratkin M Yu, Minakova A V, Jamil A N, Kukovitsky V V, Issa Jamal Issa Eleyan 2018 Composite binders for finishing compositions *Construction Materials and Products*. 1(2) 37–44