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Structure Formation as a Process of Mutual Adaptation of a Product and Material

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Abstract: The article analyzes the influence of the product geometry on the adaptation processes occurring during the structure formation of building composite materials. One of the main aspects determining the structure formation processes are the boundary conditions depending on the product geometry. It is shown that changing the product geometry significantly affects the distribution of stresses and strains, the formation of inner surfaces of partitions and cracks. Active structure elements, such as internal surfaces of partitions and microcracks, are key participants in the adaptation processes, providing stress redistribution. The applied graphoanalytical method demonstrates the possibility of visualizing and analyzing the distribution of deformations. The methods of image analysis and damage coefficient assessment allow us to quantitatively evaluate the adaptive capabilities of the material. Thus, the geometric parameters of the product determine the processes of structure formation in materials and its performance characteristics along with the formulation and technological factors.

Keywords: adaptation; cracks; composite; deformations; product shape; structure formation; surfaces of partition

1 INTRODUCTION

Ensuring the functionality of products made of composite building materials, as well as maintaining their integrity, are determined by continuous dynamic processes of structure formation [1, 2]. The material undergoes adaptive changes due to dynamic changes in external conditions and internal states [3]. Active elements of the structure, which include internal inner surfaces of partition, cracks, as well as local and integral residual (initial, technological, genetic) deformations, selectively participate in the adaptation processes [4]. Active elements, representing a single system with other elements of the material structure, can be transformed against the background of a change in the distribution of residual deformations. The transformed elements adapt to each other, to their environment and to a change in the deformed state - unique adaptation processes are realized. Thus, a change in the parameters of some elements provokes a certain reaction of others, which ensures the non-stationarity of the processes of structure formation - unique adaptation phenomena as the ability of a system to develop according to the principle "from what has been achieved" in such a way as to preserve its basic properties through adaptive transformation.

One of the ways to influence the organization of the material structure is to change the geometric shape of the product [5, 6]. To ensure one or more properties of products made of building composites, an unlimited number of structures can be selected. The properties of a material of the same composition under the same curing conditions change depending on the design features of the product. One of the reasons for such a change in properties is residual local and integral deformations.

Residual deformations are present in products, in fiber-reinforced composites, and are formed because of differences in the values of the coefficients of thermal expansion (or shrinkage) of the components of materials in the composite [7]. During the technological period of obtaining materials, the physicochemical processes of hydration of mineral binders, polymerization and polycondensation reactions of polymeric materials, curing of metals and other materials are accompanied by volumetric deformations [8]. Volumetric changes should be considered as summary processes with many components that arise and develop in materials of different nature and purpose during their processing into a product and during the action of operational loads.

The places of occurrence and the nature of development of residual deformation gradients in magnitude and direction depend on the features of the geometry of the products, which can initiate the formation of process cracks and determine the conditions for the formation of the stress-strain state of the finished product [9, 10]. At the same time, the material implements processes of adaptation of the structure to the changes that have occurred to ensure the integrity and functionality of the product. Directed changes in the geometry of the product will reduce deformation gradients to a minimum, which, in turn, will make it possible to manage the technological damage of products and regulate their physical and technical indicators.

The propose of the work is to research the influence of changes in the shape of products on the structure formation of materials as on an adaptation process, which will allow further improvement of the characteristics of products by selecting their geometric configurations.

2 MATERIALS AND METHODS OF RESEARCH

The analysis was carried out on cement samples with different geometric characteristics. The sizes and shapes of the samples are shown in Fig. 1. Fig. 2 shows rectangular samples with cracks sawn into the finished sample (Fig. 2a) and with cracks introduced during the sample molding process (Fig. 2b).

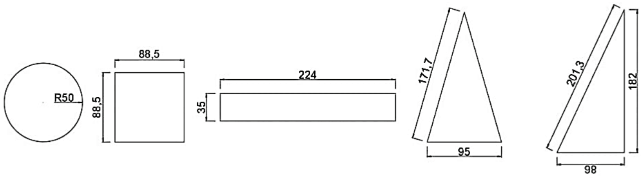
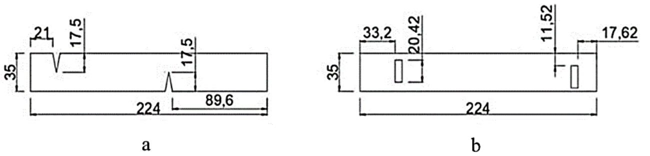


Figure 1 Types and geometric parameters of models

The distribution pattern of deformations was analyzed using a graphoanalytical method, which is used to study the distribution of shrinkage deformations and shrinkage kinetics when changing the shape of a sample [11]. The use of the graphoanalytical method facilitates the analysis of the deformations that arise due to the visualization of their distribution pattern. In addition, the method is applicable to complex shapes and materials, which allows the design features to be taken into account.



a b

Figure 2 Types and geometric parameters of models: a - sample with a sawn crack; b - sample with a built-in crack

Triangular and round cement samples were also used (Fig. 3), in which the inner surfaces of partition and cracks that arose during the formation of the structure and adaptation of the material to the shape of the product, were revealed using tannin. Then, using image-processing methods [12, 13] in the *Scion Image* software [14], the structural characteristics of the samples, including the damage coefficient, were determined.

3 RESULTS OF THE RESEARCH

The distribution patterns of shrinkage deformations (Figs. 3 and 4) were obtained for samples of different shapes and sizesusing the graphoanalytical method as a result of the analysis of the sample models (Figs. 1 and 2). Cracks formed in the already hardened sample in the sample in Fig. 4c, and cracks formed at the initial stage of product formation in the sample in Fig. 4d.

To construct the deformation diagrams a section was selected passing through the axis of the model and perpendicular to its lateral face (Figs. 3 and 4) in each model.

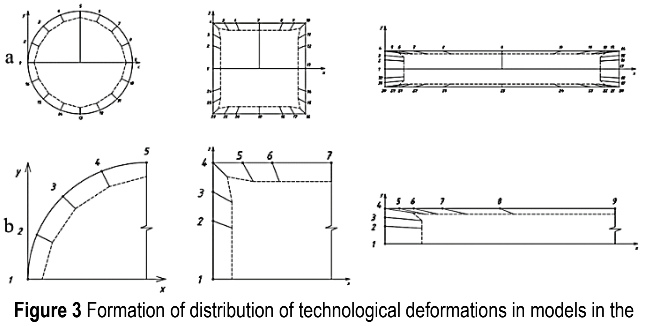


Figure 3 Formation of distribution of technological deformations in models in the process of structure formation: a – first stage; b – fragment of the model

It should be noted that when analyzing using the graphoanalytical method, the material is considered as an isotropic and continuous medium. In this case, each point lying on the interface interacts with all points belonging to its own interface and with all "visible" points on the sample surface and at the interface with voids.

By comparing the shrinkage deformation distribution diagrams in Figs. 3 and 4, it can be noted that the nature of the formation of residual (technological, initial, hereditary) deformations significantly depends on the geometric characteristics of samples and products. The introduction of a coordinate system made it possible to construct an absolute direction of movement of all points of the models, taking into account their geometric features. The movements of all points were brought to the same scale for a quantitative assessment of the obtained results. In each model, the value of the movement of the point related to the x-axis was taken as one. The adopted technique allows one to qualitatively assess the change in the nature of the distribution of residual deformations with the allocation of such parameters as the relative magnitude of deformations and the direction of their action through the angle φ.

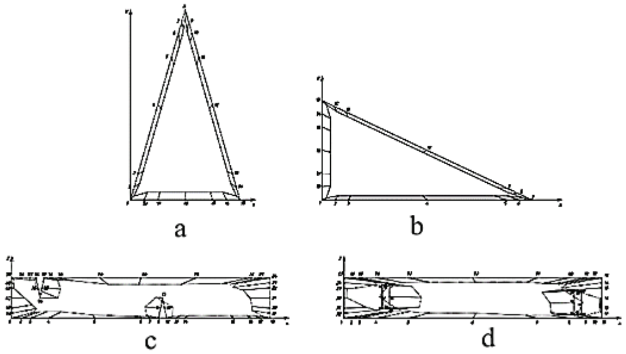


Figure 4 Formation of distribution of technological deformations in models in the process of structure formation

Each model, depending on its shape, develops an individual distribution pattern of technological deformations as can be seen from Figs. 3 and 4, The configurations of the shape of the outer boundary of the models cause the emergence of deformation gradients (Figs. 3a and 4). The curvature of the interface creates conditions for the concentration of multidirectional deformations in places of maximum shape change.

The analysis carried out using the graph-analytical method allows us to conclude that the formation of the distribution pattern of process deformations is a kinetic process that entails constant changes in the configuration of the inner surfaces of partition. Prerequisites for the formation of process cracks and internal inner surfaces of partition arise in areas of the greatest shape change, due to the concentration of multidirectional deformations.

Cement samples (Fig. 5) with a manifested structure were used for visual observation of the process of structure organization. The geometric characteristics of the products were determined according to the models in of a given shape (Figs. 1 and 2).

It is evident from Fig. 5 that the distribution pattern of the internal inner surfaces of partition and cracks significantly depends on the shape of the sample, which confirms the results of the analysis of the distribution of residual deformations in model samples using the graph-analytical method.

It should be noted that one of the aspects of the structure formation of composite materials is the formation of cracks, internal inner surfaces of partition and pores in samples and products. Since the products are characterized, on the one hand, by the presence of an individual shape and, on the other hand, by the composition and structure of the composite, all these factors in interaction will determine the crack resistance and porosity of the products and, in the case under study, the distribution of internal inner surfaces of partition. The factor that largely predetermines their formation is, as shown above, shrinkage deformations. Thus, for samples of different shapes made of the same material and even for different sections of the same asymmetric sample, completely different geometric characteristics of the active elements of the structure are characteristic.

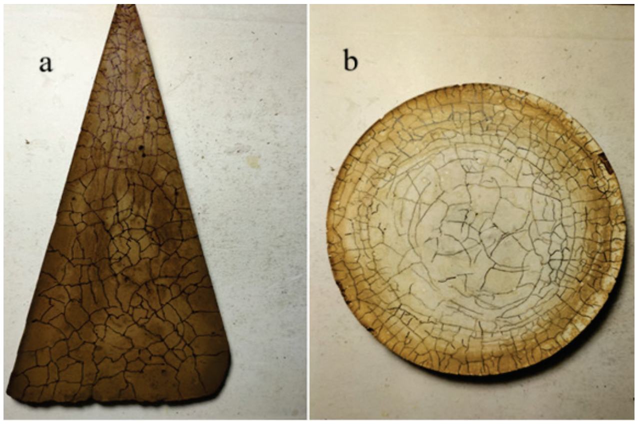


Figure 5 Distribution of internal interfaces and cracks in samples of different shapes: a – triangular; b – round sample

The considered facts can be confirmed by the method of computer processing of images of the studied samples, the first step of which is the "manifestation" of the pattern of internal inner surfaces of partition surrounding each discrete module. The image was transformed to a gray scale, the brightness level was equalized by the rolling sphere method, the boundaries were highlighted, and a median filter was used. As a result, images similar to those shown in Fig. 6 were obtained.

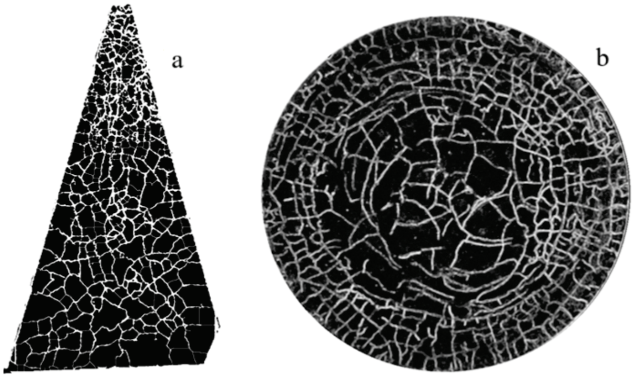


Figure 6 The manifested picture of the distribution of inner surfaces of partition and cracks in samples of different shapes: a – triangular; b – round sample

After threshold division for the samples, the damage coefficients were determined in local geometrically inhomogeneous areas with significantly different shrinkage deformation patterns arising due to the geometric inhomogeneity of the studied areas. Thus, for the triangular sample (Fig. 6a), the parts containing the acute angle (Fig. 7a) and the base (Fig. 7b) separately was studied, in the round sample (Fig. 6b) - the central (Fig. 7c) and peripheral parts (Fig. 7d).

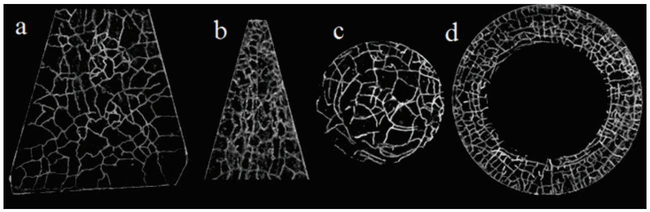


Figure 7 The studied images of local areas of the original samples with different distribution of cracks and inner surfaces of partition

The damage coefficient was estimated using the cumulative polygons method. For the analyzed fragments on a black background (Fig. 7), histograms were constructed, and then, based on them, cumulative polygons were constructed, visually corresponding to some curves. An example of construction for the leftmost fragment (Fig. 7a) is shown in Fig. 8.

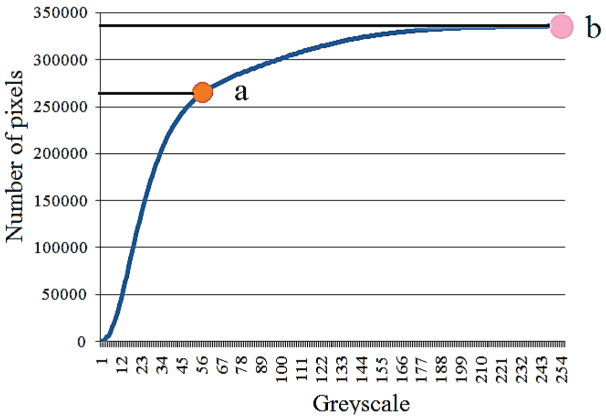


Figure 8 Illustration of the image processing stage using the cumulative polygons method

In the curve corresponding to the polygon, the point of greatest curvature was determined, as well as the maximum number of pixels corresponding to the projection area of the sample under study. In the work under consideration, the definition of inflection points was carried out visually, but if necessary, it can be carried out by constructing a curvature graph. It should be noted that the light lines correspond to the boundaries of the section. Then the damage coefficient can be estimated $\tilde{K}$ using Eq. (1):

$$\tilde{K} = \frac{N_{\max} - N_{\text{borders}}}{N_{\max}}, \qquad (1)$$

where $N_{\max}$ is the maximum number of pixels of the object under study; N_{borders} is the number of pixels at the point of maximum curvature.

Because of applying the method under consideration, the following data were obtained (Tab. 1).

Table 1 Assessment of the damage coefficient for different sections of triangular and round-shaped samples

Researchable sample	$N_{\max}$	N_{borders}	$\widetilde{K}$
Base of triangle (Fig. 6a)	336117	260867	0,22388
Apex of triangle (Fig. 6b)	102091	60000	0,412289
Center of round sample (Fig. 6c)	198901	136565	0,313402
Periphery of round sample (Fig. 6d)	324858	165940	0,489192

The data (Tab. 1) clearly shows that the damage coefficient differs in sections of products with different shapes. It is particularly high in sections where structure formation occurs under restricted conditions like wall effects and high curvature values. This highlights the importance of considering factors such as material structure, composition, and product geometry systematically. Shrinkage deformations, especially in the area of their unevenness, create a "canvas" for the formation of internal inner surfaces of partition and cracks.

It should also be noted that the nature of the distribution of internal inner surfaces of partition and cracks in the samples in Fig. 5 shows that structural blocks are formed in the continuous medium of the material. Inner surfaces of partition initiate the appearance of discrete structures, and the material adapts to the changes occurring in the system through these surfaces. The shape and configuration of these structural blocks, determined by the network of inner surfaces of partition and cracks formed because of the structure formation processes, varies depending on the location of the material section in the sample.

4 CONCLUSION

The geometric shape of the product determines the distribution of deformation in the material, as well as the configuration of the network of internal inner surfaces of partition and the nature of crack propagation. Changing the geometry of the samples affects the nature of such a network, especially near lines and surfaces of significant curvature. Controlling the structure of this network through changing the geometric shapes of the product is one of the ways to redistribute internal stresses and deformations, and, consequently, reduce the probability of destruction. Since the geometric characteristics of the network under consideration are adapted to the boundary conditions expressed macroscopically in the form of the sample boundaries, the analyzed integral structure-forming process is an adaptive property of the product as a system.

5 REFERENCES

[1] Vyrovoy, V. N., Dorofeev, V. S. & Sukhanov, V. G. (2010). *Composite construction materials and structures: Structure, self-organization, properties*. Odessa: ODABA. (in Russian)

[2] Gusev, B. V. at al. (2006). *Formation of the structure of composite materials and their properties*. Moscow: Nauchny Mir. (in Russian)

[3] Chernyavskiy, V. L. (2002). *Adaptation of concrete:* Monograph. Dnipro: Nova Ideologiya. (in Russian)

[4] Vyrovoy, V. M., Korobko, O. O., Sukhanov, V. G., Kazmirchuk, N. V. & Makarova, S. S. (2020). *Formation and destruction of building composites*: Textbook. Odessa: ODABA. (in Ukrainian)

[5] Vyrovoy, V. M., Sukhanov, V. G. & Korobko, O. O. (2022). *Material structure in the structure of the construction* (2nd ed., revised and expanded). Odessa: ODABA. (in Ukrainian)

[6] Dvorkin, L. Y. (2022). *Theoretical foundations of building materials science*. Rivne: NUVGP. (in Ukrainian)

[7] Solodkyi, S. Y. (2008). *Crack resistance of concretes based on modified cements*: Monograph. Lviv: Lvivska Politechnika. (in Ukrainian)

[8] Vyrovoy, V. N., Dovgan, I. V. & Semenova, S. V. (2004). *Features of structure formation and property development of polymer composite materials*. Odessa: TES. (in Russian)

[9] Lermit, R. (2017). *Problems of concrete technology* (Translated from French, stereotype edition). (in Russian)

[10] Korobko, O., Vyrovoy, V., Zakorchemny, Yu. & Kushnir, O. (2019). Formation of technological damage of building constructions by regulation of deformations. *Actual Problems of Engineering Mechanics*: Materials of the 6th International Conference, Vol. 968, 324-329.

[11] Solomatov, V. I., Vyrovoy, V. N., Dorofeev, V. S. & Sirenko, A. V. (1991). *Composite construction materials and structures with reduced material consumption*. Kyiv: Budivelnyk. (in Russian)

[12] Russ, J. C. (1990). *Computer-assisted microscopy: The measurement and analysis of images* (1st ed.). Springer.

[13] Kolesnykov, A. V., Semenova, S. V., Vyrovoy, V. M. & Kersh, V. Y. (2024). *Image processing methods in building materials science problems*: Monograph. Odessa: ODABA. (in Ukrainian)

[14] https://mesonpiold.cbpf.br/e2002/cursos/NotasAula/ScnImage.pdf

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