A model taking account of the contribution of the filler, binder, and ensemble of microcracks in the characteristics of reactor graphite is proposed. An analytical solution of this model is obtained. The solution is used as a basis for calculating the elastic moduli and sound speed in graphite. It is shown that the anisotropy of the computed sound speed and its dependence on the hydrostatic pressure are in agreement with experiment.

The unique properties of graphite are determined by its morphology, which is characterized by two main components – the filler and the binder, as well as by the presence of an ensemble of microcracks and process pores [1–4]. The binder possesses a fine-crystalline, uniform structure and the filler has a hierarchical structure, formed by graphite microcrystallites whose crystal structure perfection, in turn, can be destroyed, depending on the burn temperature, by the presence of a definite fraction of turbostratic structure. The microcrystallites form various formations – crystallites with different degree of texturing [3] and property anisotropy [5].

To describe radiation-induced effects, graphite is regarded as a polycrystal consisting of crystallites which are ordered in a definite manner. A crystallite is determined in a natural manner as the largest formation of microcrystallites. The deformation and shape change of a crystallite can be regarded as being affine. Long-range textural order in graphite is either greatly weakened or absent depending on the degree of disordering in the orientation of the crystallites. The difference in the orientation of neighboring crystallites in the presence of anisotropy of their properties results in the appearance of microcracks at the boundaries of the crystallites; these cracks make a determining contribution to the elasticity of the structurally disordered solids.

The reason that microcracks form during the preparation of artificial graphite at the cooling stage is a strong anisotropy of the coefficients of thermal expansion of the graphite crystallites forming a crystallite. The subsequent evolution of the system of microcracks at the stage of irradiation of graphite is initiated by the form of the crystallites because of the radiation-induced microstructure development in them. Such a microstructure is formed mainly by basal dislocation loops, whose orientation is determined by the orientation of the basal planes of the crystal lattice of a graphite crystallite. Thus, radiation-induced shape change of crystallites is the driving force for the appearance of radiation effects at the macrolevel [6, 7]. The objective of the present work is to determine the relation between the micro- and macro-deformations, taking account of the differences between the elastic constants and the morphology of the components of reactor graphite.
A macrodeformation of graphite is described by a theory that takes account of the existence of internal stresses in graphite and nonlinear microdeformation of a crystallite [6]. The present article proposes a general approach that makes it possible to understand and describe the contribution of each component of graphite morphology – filler, binder, and ensemble of microcracks – in the formation and evolution of the macroscopic properties of graphite.

Anisotropy of the Elastic Properties of Graphite. The standard approach to the description of the elasticity of polycrystallites ignores the presence of a hierarchical structure of the crystallites and is based on matching the solutions of the equations of the theory of elasticity for neighboring crystallites with a prescribed shape and with a prescribed random orientation of the anisotropy. Because of the strong anisotropy of the elasticity of graphite crystallites, substantial stresses develop on their boundaries; these stresses cannot be described analytically, so that numerical calculations are necessary to take them into account. This approach to the description of graphite texture has only limited application, since the orientations of neighboring microcrystallites are not independent. In the present work, a crystallite with a characteristic scale, at which ordering of the crystalline planes of the microcrystallites is lost is chosen as the structural unit of a polycrystal. The multiscale nature of graphite texture largely determines its constants and moduli of elasticity, a fact that the standard approach neglects.

The present work proposes an analytical theory based on a rough lattice model that ignores the excess information about the exact shape and orientations of the crystallites, which is used in the standard approach. The position of a crystallite is determined only to within its size $R$ and the direction of anisotropy to within the angles of rotation $\pm \pi/4$. To this accuracy on scales greater than $R$, it can be assumed that the crystallites occupy the sites of a regular lattice and are surrounded by the binder matrix, while the axis of their anisotropy coincides with one of the axes of this lattice (Fig. 1). We shall limit attention to microcracks with sizes smaller or approximately equal to $R$.

To describe the elasticity of an anisotropic body, we shall make use of the vector representation of the strain tensor [8], whose first three components $\varepsilon_i = \Delta L_i / L_i$ determine the relative change of the dimensions $L_i$ of the sample in the direction of the $i$ axis, and their sum

$$\varepsilon \equiv \sum_{i=1}^{3} \varepsilon_i = \frac{\Delta V}{V}$$

represents the relative change of the local volume $V$. The three other components equal the corresponding off-diagonal components of the strain tensor – $\varepsilon_4 = \varepsilon_{23}$, $\varepsilon_5 = \varepsilon_{13}$, $\varepsilon_6 = \varepsilon_{12}$. The strain energy density can be represented in the form [5]