# ENGINEERING MECHANICS of POLYMERIC MATERIALS

## Theories, Properties, and Applications

Gabil Garibxan ogli Aliyev, DSc
Faig Bakhman ogli Naghiyev, DSc

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| PA | Polyamid-610 |
| PEHD | Polyethylene of high density |
| PELD | Polyethylene of lower density |
| PP | Polypropylene |
| PS | Polystyrene shock-resistance |

# PREFACE

Large production of polymer materials in the world redoubled attention to the problem on their use in engineering in place of load-bearing structural elements. However, in some applied problems of engineering by using polymer materials, for example, their work in contact with a different kind of corrosive liquid and gassy medium, operational characteristics of industrial constructions made of them sharply deteriorate, and this leads to premature loss of their bearing capacity. This says that the classical methods of mechanical strength stability and dynamics analysis of constructions become unreliable. It should be noted that today, in designing engineering of constructions working in contact with corrosive liquid and gassy medium, the reliable engineering methods for strength analysis of constructions with regard to physico-chemical properties of materials are not available. This is connected with the fact that account of influence of diffusion processes of corrosive media in polymers on strength characteristics of constructions, especially of composite materials, introduces considerable difficulties. In this context, the following principle questions remain open: how do the physico-mechanical properties of polymer and composite materials and also the problem on strength of structural elements made of them depend on physico-chemical changes of the material? In particular, how is the quality and quantity character of dependence of serviceability of different constructions made of polymer materials and also their mechanical properties on the character of their contact with corrosive liquid and gassy media? The joint solution of diffusion equations of corrosive and gassy media to polymers, and the equations of mechanics of deformable body made of polymer and composite material, is a very complicated mathematical problem of connected type. At the same time, such an approach requires to know exact values of initial properties of the material, diffusion factor and boundary conditions of the problem. Otherwise, the physico-mathematical problem may become ill-posed.

In this monograph, theory of strength of laminated and reinforced structures made of polymer materials with regard to changeability of their physico-chemical properties is elaborated upon. To achieve this goal, an experimental-theoretical method on definition of physico-mechanical properties of polymers, composite materials and also polymerized bundles made of fibers with regard to change of physico-chemical properties of the material is suggested. On this basis, Hooke's generalized law with regard to changeability of physico-chemical properties of polymer material is suggested; a criterion of adhesive strength of laminated and sandwich reinforced pipes with regard to physico-chemical changeability of the structure's layers is suggested; stability criterion of one-dimensional structural elements with regard to swelling effect of materials is suggested; new mechanical effects such as changeability of mass force of a polymer material with regard to material's swelling effect buckling of columns under the action of only material's swelling effect were revealed. A mechanical effect, dependence of joint deformability of several polymer materials on the character of layer's swelling was experimentally and theoretically established.

We hope this monograph will be useful for research associates engaged in the problems of designing of construction from polymer and composite materials that are intended to work in corrosive liquid and gassy media. We think that the obtained scientific results may find its reflection in some physico-mathematical problems of biomechanics.

**— Gabil Garibxan ogli Aliyev, DSc**
**and Faig Bakhman ogli Naghiyev, DSc**

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## CHAPTER 1

# INTERACTION OF PHYSICO–MECHANICAL AND PHYSICO–CHEMICAL PROPERTIES OF POLYMER MATERIALS

G. G. ALIYEV and F. B. NAGIYEV

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## 1.1 OBJECTIVE LAWS OF MASS-TRANSFER OF CORROSIVE LIQUID AND GASSY MEDIA IN POLYMER AND COMPOSITE MATERIALS AND SOLUTION METHODS OF DIFFERENTIAL TRANSFER EQUATIONS

The media transfer processes are based on diffusion phenomena, that is, spontaneous travel of atoms and molecules in consequence of their thermal motion. Depending on proceeding conditions of this process, there is an interdiffusion observed in the presence of concentration gradient or in the general case, the chemical potential gradient; secondly, a self-diffusion is observed when the above-mentioned ones are not available. Under interdiffusion, the diffusing particles flux is directed to the side of concentration decrease. As a result, the substances are distributed in the space, and local differences of potentials and concentrations are leveled. The characteristic quantity of such a process is the interdiffusion coefficient $D$. In the case of one-dimensional diffusion, the relation between the diffusing substance flux $f_i$ and the concentration gradient $\partial \tilde{N}_i / \partial x$ in an isotropic medium at rest is described by Fick's differential equation:

$$(J_i)_R = -(D)_p \frac{\partial C}{\partial x} \qquad (1.1)$$

According to this relation, $D$ numerically equals the flux density with respect to the section $R$ under the given concentration gradient. Simultaneously, $D$ may be considered as velocity by which the system is capable to level the unit difference of concentrations.

In this way, we can define the problems that compose the mass-transfer content in the section of physics of polymers.

Firstly, to work out a method of experimental investigation of diffusion process, that is, to study kinetic objective laws of diffusion parameters change: either concentration distribution or the sizes of diffusion zone, or the amount of diffusing substance.

Secondly, to create a method for defining the diffusion coefficients on experimental data and the solution of the inverse problem-prediction of the process course if $D$ and kinetic conditions are known. This group of questions is the subject of phenomenological or mathematical theory of diffusion. If at experimental measurements the physical methods are an instrument in the hands of researchers, then in phenomenological theory the apparatus of mathematical physics is such an instrument. Analytic equations connecting changes of these or other external parameters of registered in the test, of coordinate diffusion, with time, diffusion coefficient, and sample's sizes are obtained with the help of this apparatus.

Since, as a rule, the diffusion factor in these equations is an unknown quantity, then processing of experimental data with their help allows getting quantity information on its value, to establish correctness of the accepted mathematical model to the real process.

Thirdly, analysis of elementary act of translational travel of molecules or macromolecules on the basis of diffusion mechanism and theoretical calculation of partial coefficient of self diffusion of diffusing particle in a polymer medium. This is a problem of molecular-kinetic theory of diffusion.

Fourthly, explanation of some "strange" phenomena known as "negative diffusion" and "ascending diffusion", determination of direction of diffusion fluxes, calculation of thermodynamical parameters of the system by diffusion data.

All above-stated problems and directions are closely connected between themselves forming a united chain of investigations of diffusion processes.

Two fundamental laws of nature: the law of preservation of mass and the law of preservation and transformation of energy are on the basis of above-mentioned section of transfer phenomenon. Directedness of transfer processes is determined by the second law of classic thermodynamics the law of increase of entropy. The most common equations of mass and heat transfer are obtained on the basis of the mentioned laws.

In thermodynamics of irreversible processes, it was established (Grot and Mazur, 1967; Lykov, 1978; Sedov, 1970), that the product of the entropy increases velocity $\frac{dS}{dt}$ by absolute temperature $T$, and equals the sum of products of flux densities $J_i$ by the appropriate thermodynamical moving forces $X_i$:

$$T\frac{dS}{dt} = \sum J_i X_i \tag{1.2}$$