# Introduction

In the course of the last several decades, the mechanics of composite materials and structural elements fabricated from these materials has evidently become one of the most important and actively developed areas of mechanics. The composite materials industry has seen considerable development as well as intense research and investigation into the many scientific and technical problems associated with both the design and construction of engineering structures and of structures from composite materials and to problems associated with this class of materials.

The problems of mechanics, of applications concerning the design of engineering structures, and of structures fabricated from composite materials are concentrated mainly around three areas: mechanics of composite materials in its proper sense; mechanics of structural elements fabricated from composite materials—methods of investigation, analysis, and design; and problems of mechanics related to the technology of developing the composite materials and structural elements from these materials. It should be noted that problems of mechanics associated with these three lines of research have occurred and still occur in the design and construction of engineering structures fabricated from other materials, particularly from metals and alloys. However, the importance and significance of mechanics in each of these areas in its application to composite materials has increased considerably, so that it has become necessary to revise some obsolete ideas of engineers and scientists. The mechanics in the solution of some problems has become of foremost importance.

To illustrate these considerations, we discuss below some problems associated with specific features, with special properties of composite materials.

1. In their microstructure, composite materials are structural elements (of engineering structure) with laminated, fibrous, or granular structure. Consequently, the total complex of phenomena, related to the statics, dynamics, stability, and fracture of engineering structures and to the structures in general, is valid also in composite material mechanics. In cases when these processes are not only of local character and manifest in the macrostructure, the role of composite materials mechanics becomes still more important. As a result, the role of mechanics increased considerably among other sciences which investigate a broad range of problems related to composite materials only. This situation was not characteristic of traditional materials.

2. In the process of developing the methods of analysis of structural elements, the complete analysis of composite materials microstructure is quite cumbersome, time-consuming, and evidently not very useful (in cases when this analysis could be carried out). In view of this it has become necessary to combine composite materials mechanics, which takes into account the microstructure, with structural element mechanics, traditionally developing within the framework of continual representations. This problem is solved in the process of construction of the theory of determination of normalized properties of composite materials with various structures (laminated, fibrous, granular, and others), describing their behavior taking into account the continual representations. In such a way, the transition is made from the piecewise-homogeneous medium to the homogeneous one. This problem area in mechanics also has not had an analogous importance for traditional materials.

3. In developing design and computational methods for structural elements, specialists currently use certain hypotheses or corresponding algorithms for the reduction of three-dimensional problems to two-dimensional or one-dimensional problems in order to obtain results in a form that is convenient for engineer designers and allows one to carry out optimization of the structural element or the whole engineering structure. The experience in this area was associated with investigations of properties of traditional materials, without accounting for specific properties of composite materials related to their structural characteristics. Among these properties are reduction of shear stiffness, significant decrease of stiffness in various directions, the anisotropy of strength properties, change in damping properties, and others. In this situation it becomes necessary to carry out investigations via improved, more accurate theories and approaches with the purpose of determining the possibilities of using applied theories for description of the behavior of structural elements with a necessary degree of accuracy, as well as determining applicability limits in their dependence on the values of geometrical and mechanical parameters. Only are completion of such investigations may conditions be derived for development of algorithms for analysis and computation of composite material structures. This is essentially the final aim of the investigations.

4. In some cases, during the technological process of the fabrication of structures from composite materials, the complete structure or engineering structure can be produced omitting some stages of design, such as development of materials and the design and construction of structural elements. A situation of this kind occurs, for example, in fabrication by winding structures in the form of revolving bodies. In this case the strength and the deformation properties of structures depend significantly on the applied technological regime. This dependence of structural mechanical properties on this regime is also evident in other fabrication technologies of structural elements and of composite materials structures. Clearly applications of composite materials, the fabrication technology and mechanical properties are closely associated, much more than in the case of traditional materials. The systematic use of the results of mechanics studies allows one to improve significantly structural properties in technological regimes. Consequently, the problems of mechanics related to technological processes are at present of high practical importance and significance.

5. The dependence of mechanical properties of composite materials on time, loading regime (on the speed and the frequency of loading), environmental conditions, and degree of influence of temperature and electromagnetic fields, differs significantly from analogous dependence of traditional materials, for example, metals and alloys. This specific feature requires the revision of traditional ideas on possible uses of composite materials, on the basis of practical experience with metals and alloys.

6. The anisotropy of mechanical, strength, thermophysical, and other properties of composite materials, occurring as a result



 

of marked microstructure, enables one to design and construct structures with prescribed properties, allowing development of structures optimal in some sense.

There are some other specific, striking features of composite materials, and the role of mechanics in their analysis and investigation is steadily increasing. However, the information mentioned above shows the practical importance and the advisability of investigating composite material mechanics accounting for microstructure to some degree; this accounting at various levels is one of the main (or perhaps the principal) trends in development of the whole complex of areas of composite material investigations.

On the basis of these considerations, in the following the term "micromechanics of composite materials" may be applied to all investigations on composite materials mechanics in which the existence of microstructure is consequently accounted for and which deal with analysis of mechanical phenomena in microstructure. It may be assumed that micromechanics of composite materials investigates the stresses and deformation fields (and other fields) which change significantly at distances of the order of structural geometric parameters or lower; in these investigations, attention is concentrated on a sufficiently exact description of these fields. Micromechanics is an essential part of composite material mechanics, since the occurrence of mechanical phenomena in macrovolume could be predicted from the results of these investigations. These phenomena are caused by mechanical processes in the microvolume, which may lead to fracture of the total composite. This is the principal sense of investigations within the framework of composite materials mechanics. In view of this, the results obtained within the framework of the composite materials micromechanics should be highly realistic and accurate. Inaccuracies and errors may be contained in the results on composite materials micromechanics for following three reasons:

1. Insufficiently accurate description of separate, single mechanical properties of the filler (the reinforcing elements) and the binder (the matrix). To eliminate the inaccuracies of this type, it is necessary to use other models that more adequately describe separately the mechanical properties of reinforcing elements and the matrix. In this case, the improved, more accurate results are obtained essentially as in mechanics of traditional materials, which does not account for microstructure.

2. Insufficiently accurate description of phenomena on the interfaces of reinforcing elements and the matrix (it is necessary to take into account various kinds of adhesive phenomena). Inaccuracies of this type are usually caused by the fact that investigations were carried out in specific (in some cases, too much idealized) boundary conditions on interfaces of the reinforcing elements and the matrix. To eliminate these inaccuracies, investigation and analysis may be made at different boundary conditions on interface boundaries providing two-way evaluations of results at real boundary conditions. For example, investigations may be mentioned in the case of complete contact and contact with slip on the boundaries of interface properties. An analogous approach is used in mechanics of structural elements fabricated from traditional materials, for example, in studies on structural element stability at conditions of hinged support and of rigid fixation allowing one to obtain two-way evaluations for the case of elastic fixation.

3. The use of approximate computational schemes (hypotheses and algorithms) in descriptions of stress and deformation fields (and other fields) in reinforcing elements and in the matrix with application in investigations on composite material micromechanics. In these cases, inaccuracies arise as a result of application of various two- and one-dimensional theories of shells, plates, and rods (as a result of using other approximate computational schemes) for description of phenomena in the composite microstructure. This is the most frequent source of computational inaccuracies, since, in strict application of three-dimensional theories, considerable difficulties occur; in this situation, in numerous publications, approximate theories of such type are used. It should be pointed out that it is evidently not logical to use applied two- and one-dimensional theories within the framework of the micromechanics of composite materials in general. These theories are inadequate, they do not allow description of fields that change significantly at distances of the order or less of structure parameters.

For effective elimination of errors and inaccuracies caused by the third source mentioned above, three-dimensional equations may be applied for describing and representing statics, dynamics, stability, and fracture phenomena with application to reinforcing elements and the matrix. It may be concluded that the application of three-dimensional equations allows adequate description of statics, dynamics, stability, and fracture processes micromechanics of composite materials. The results, obtained within the framework of three-dimensional formulations (separately for reinforcing element and matrix), allow not only accurate descriptions of phenomena related to the micromechanics of composite materials, but they also serve as model results for various approximate approaches. These specific features prove the high effectiveness and advisability of investigations on micromechanics of composite materials in a three-dimensional formulation.

At present, a considerable number of publications has appeared on micromechanics of composites in three-dimensional formulation. The main results are obtained on statics for fibrous and laminated materials with infinite fibers of circular cross section and with layers of constant thickness. Also, results are obtained on dymanics for laminated materials with infinite layers of constant thickness.

In the last years essential new results have been obtained on the stability of fibrous and laminated materials as well as on statics of this class of materials with curved, bent structures. This special issue of *Applied Mechanics Reviews* contains review articles on micromechanics of composite materials with application to recent new results on statics, dynamics, and stability of fibrous and laminated composites. All results considered in these articles are obtained in three-dimensional formulation, so that these papers differ substantially from numerous publications. Most of the results presented were obtained in the course of investigations in preparation of doctorate theses in the Department of Dynamics and Stability of Continua at the Institute of Mechanics of the Academy of Sciences of the Ukrainian SSR. Additional information may be obtained from four monographs published in Russian in Kiev.[1,2]

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## REFERENCES

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