Theoretical researches on the durability of composite materials with metallic and non-metallic matrices

R Caliman
Calea Marasesti 157, “Vasile Alecsandri” University of Bacau, Romania
E-mail: rcaliman@ub.ro

Abstract. The study was designed in the sense of deepening the data on composite materials, examined in terms of their physico-mechanical properties, with particular emphasis on laminated plates subjected to dynamic stresses. The paper aims to address the procedure of solving the finite element system equations system on the "multi-grid" system - called the Fast Finite Element (FFM), developed by Structural Research and Analysis Corporation and currently integrated in the Cosmos software package, having the following advantages that are clear from the specification of a number of features: number of plate elements: 19113; number of nodes: 19650; number of equations: 117900; requiring a low disk swap space.

1. Introduction
Industrial applications of the composite materials require the development of structural analyzes and the application of more complex design methods than in case of the use of traditional metals. The design of complex structures should take into account aspects such as: static resistance, material fatigue phenomena, system instability, standardization of the laminates, the choice of the type of connection between component parts, permanent connection between design and execution, numerical computations softwares used in structure analysis and, last but not least, the cost of manufacturing the structures [1].

For fully determination of the state for the composite load, are applied the general equations, wich define the plane deformation state. These data should be described in a system, imposing a limitation on a matrix of conditions, with which to analyze the phenomenon of tensions. However, it is not enough to demonstrate that under certain conditions a sufficient number of equations can be found to determine the unknowns, it is also necessary to be able to calculate the quantitative variations of the variables when the data of the composite load are changing. That is why a series of parameters are introduced into the system which, when varies, determines the nature of the change of the unknowns, if it is known how to change the parameters [2,3]. This method is actually the one of the static comparator, which purpose to study the variations that occur in a system when it moves from one position to another, without considering the way in wich this passage is done. Using the multi-grid finite element method, can be made a representation based on the processing of the experimental data and the resulted values from the mathematical simulation of a matrix area (figure 1).

The figure below is an example of the stress distribution around the carbon fibers that strengthens the matrix [4].

In this context, the equilibrium refers only to the values of the variables determined by a set of conditions, and it is always possible to develop a system in equilibrium without any real significance. This method of the compared statics is a particular case of the deduction method, according to which the behavior of a system is defined by an ensemble of functional equations determined by the initial conditions [5].

The concept of the equilibrium system is applied for a single variable case as well as in the case with hundreds of variables, named general equilibrium. The notion of stable equilibrium calls for a theory that determines the evolution of all variables over the time, starting from arbitrary initial conditions. This fact is called the principle of correspondence, according to which the dynamic stability of a system, determines theorems for static analysis, but vice versa, known properties of a static system give information about its dynamic characteristics.
Figure 1. The image of the distribution of the stresses around the carbon fibers that strengthens the matrix.

The system makes it possible the dynamically representation and perform the stressed matrix behavior in the reinforcing zones, punctually in the areas adjacent to the carbon fibers (figure 2) [6].

Figure 2. Representation obtained by using the finite element method, using the maximum value for the matrix tension size. The tensioning values was respresentated for tensions between 0.0068 MPa and 0.01378 MPa.

Using the graphic interface of the program thanks to the models generated in Advance can be create linear patterns such as: bars, stakes, beams, variable section beams, circular arcs, surface elements (membranes,
plates, diaphragms). The program can define the objects to be created, any type of load (punctual, linear and surface) can be applied to the model.

2. Results and opportunities that appear in the finite element modeling of composite behavior

Along with other mathematical modeling systems by using the finite element method, the I-DEAS Advanced Durability method provides a set of analytical tools that can predict the calculated life span as a result of cracking aging composites. The load list can be generated from test measurements or analytical methods [7]. The life cycle of the composite can be calculated using the load from the finite element solution. Both uniaxial and biaxial loading are considered the ways to define lifecycle criteria. I-DEAS Advanced Durability provides multiple fracture resistance analysis capabilities.

Crack testing is used to evaluate the durability of a general element finite model when a set of loads is applied simultaneously or sequentially. Linear or nonlinear results can be used for this analysis. A typical application of the resistance is to determine the crack durability of a composite panel subjected to variable loads. In this case, the critical areas of fatigue are normally around the reinforcement points (figure 3).

![Figure 3. Example of crack test used to evaluate composite durability by finite element modeling of matrix behavior in the carbon fiber area.](image)

Also, a set of results, defined in sequential order, can be taken for fatigue calculations. This is useful for fatigue checks, using nonlinear results [8]. May be used, for example, I-DEAS Model Solution, I-DEAS Variational Analysis or external solvers (Nastran, Abaqus or Ansys) to prepare the loads to be used in static fatigue testing. Fatigue tests uses the mode acceleration method or mode display methods to generate tension/effort for fatigue testing. I-DEAS Model Solution or External Solvers can be used to generate modal models for fatigue testing.

The crack evaluation is used to estimate life cycle and wear for variable loads, and the maximum failure due to a varied use cycle. Durability results are displayed as graphs. The effort and stress generation functions used in the evaluation can be saved and reused in other analyzes or tests, in the same application or in external applications. Load axes can be determined statistically, randomly, or through a critical (load) plan [9].
Generating the grid, more precisely constructing the grid from elements that describe rigidity of the structure, is the most expensive activity, both time and effort, from finite element analysis. In addition, selecting the element type and corresponding grid density are required to ensure the accuracy and efficiency of the analysis. 1-DEAS FEM offers high capabilities for automatically generating the grid, highlighting the following qualitative aspects [10]:

- automatically generates a user-controlled grid distribution for surface and solid geometry;
- automatically generates the grid for geometries created in 1-DEAS Master Modeler;
- uses the surfaces defined by an unlimited number of curves and solids with unlimited number of faces;
- generates an unlimited number of elements on a single surface or volume;
- allows automatic definition of admissible distortion for tetrahedron elements before generating the grid;
- recognizes reference geometry;
- allows definition of geometry and its generation;
- automatically defines the grid width according to geometry curvature, user defined values for points, curves or surfaces;
- associates the grid with geometry so that it updates with the basic model.

At a basic level, Section Meshing allows to define and generate a grid on a many surfaces and not just on one itself. On a more advanced level, it is possible to exclude elements that are not important in the finite element analysis. Linear or nonlinear results can be used for this analysis. A typical application of resistance is that of determining the durability of the composite subject to variable loads. In this case, the critical areas of fatigue are normally around the reinforcement points (figure 3). Also, a set of results defined in sequential order can be taken for fatigue calculations. This is useful for fatigue checks using nonlinear results. 1-DEAS Model Solution, 1-DEAS Variational Analysis or external solvers (Nastran, Abaqus or Ansys) can be used to prepare the loads to be used for static fatigue testing [9].

A complete library of finite elements will be allowed, in the most efficient way, to perform several types of analysis and modeling. A plurality of elements is provided, including parabolic or linear forms of solids, axial-symmetrical solids, beams, springs, etc.

The I-DEAS Material Data System (MDS) is a robust base that contains all material characterizations, offering possibilities for adding, searching, deleting, and updating material attributes. Properties that do not depend on other variables can be specified as constants. Properties with variable characteristics can be represented by mathematical functions or tabulated according to certain parameters. Analysis of an error model can consume a lot of time and money, most of the time, errors are not detected even after analysis.

In order to composite fissure analysis to influence the design decisions, the results must be presented in a coherent form. I-DEAS FEM offers graphical and data manipulation capabilities that focus on the critical data it provides for presentation and usage. It can calculate displacements, stresses, forces, reaction forces, kinetic energy, temperature and heat flow, displays results and contour loads, displays deformed geometry, animates motion, displays results in 2D or 3D graphs, displays table data [9].

Integrity is maintained through the associativity of data between model building, solving and interpreting the results. I-DEAS Electronic System Cooling is coupled with I-DEAS TMG Thermal Analyzes, providing advanced modulation for both conduction and radiation [10].

3. Conclusions
The general characteristic of the composite materials is that through their combined analysis at the micro- and macro-mechanical level can lead to the "cutting" of the global material in the idea of an optimal response to a large number of distinct requirements specified by the user (to whose command is designed material). It should not be neglected that this guided design also allows for the minimization of the waste of materials, as the maximum values of the properties are ensured only in those directions where the highest operating requirements are recorded.

This very special property makes the composites irreplaceable for applications with complex requirements in terms of physico-mechanical properties of materials. Breaking of non-isotropic composites due to fatigue is accompanied by massive damage, in contrast to the minor and localized ruptures accompanying isotropic composites. Fatigue rupture is accompanied by the combination of the four possible types of damage: layer breakage, layer breakage, fiber breakage and fiber-matrix interface stripping. Any of these effects or combinations of these results leads in reducing the strength or the stiffness.

Breakage of the layer takes place in the sequence from the weakest to the strongest. The first rupture occurs in the 90° layers, and if the voltage increases, other damage occurs in the adjacent layers at 45°, continuing with
the +45°/45° interface; if tension continues to increase, the laminate breaks out. Sometimes, some laminates reach a maximum crack density, after which no more are produced after the final rupture. If the interfacial bond is strong, the damage will continue in the matrix, resulting in a slow rupture of the surface in the cross-sectional direction of the laminate. If the interfacial bond is weak, the rupture is more likely to occur along the fibers at the interface with the matrix. Due to the fact that, in the most advanced composites, the matrix remains elastic until near the breakage of the laminates, damage to the fiber-matrix interface is negligible, except where the fiber has yielded. Consequently, the modulus of elasticity and the specific strength of unidirectional laminates subjected to fatigue stress along the fibers do not decrease much until the break. Therefore, composite design becomes a complexity problem based on matrix formulations that require step-by-step solving and a large number of data processed at the same time. Therefore, the optimal design cannot be imagined in the absence of using computers, and their current development is a determining factor in achieving more advanced composites.

4. References

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