A SURVEY ON FEM MODELLING FOR COMPOSITES

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Abstract

FEM modelling methods are increasingly used to simulate and predict the behavior in design, service condition and subsequent damage of composite materials. This paper is intended to capture the recent advancements in the area of modeling and simulation in composite materials. The work provides an extremely useful insight into how modern computational methods can be used to predict damage inflicted upon composite components during events encountered during service. The rapid growth in the usage of composite materials has made it necessary to summarize the progress made in the modeling and simulation fields and thus determine future perspectives.

Keywords: *Composites, FEM, Modelling*

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1. INTRODUCTION

Composite materials are multi-phase materials comprising a matrix reinforced with one or more types of fibers and particles. Their properties are defined by the properties of constituents, reinforcement distribution, and characteristics of the reinforcement-matrix interface. Recent times it has been observed that many composites are developed and in use in various areas like Aircraft, Automotive, civil infrastructure, Electrical and Marine fields. Figure 1 presents an overview of usage of composite materials in civilian aircraft structures for several major aircraft models [1].

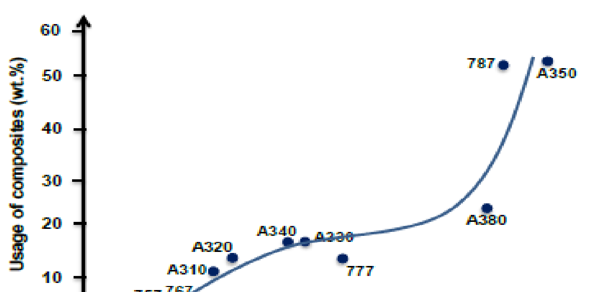

Fig -1: Usage of composite materials aircraft industry.

After the initial surge in the applications of composites in this sector in 1980's, the field saturated in 1990. In recent years, a steep increase in the usage of composites in this sector is observed as the Boeing Dreamliner and Airbus 380 and 350 heavily incorporate composites in their structure. Research and development in a diverse range of fields have contributed to this recent steep increase in the usage of composites. Understanding of fatigue failure, long term environmental damage, combined effects of temperature and mechanical loads, and effect of processing parameters on the quality of the fabricated components are among the factors that have helped composites. In addition, availability of predictive models and improved simulation methods has helped in designing composites as per the requirements of the applications.

The complexity in modeling the behavior of composite materials makes it challenging to develop approaches that can lead to "Materials by Design". In addition, a number of advanced composites have hierarchical microstructures that span from nano to macro-scale, which require considerable advancement of the present modeling and simulation methods. An example is shown in Figure 2,

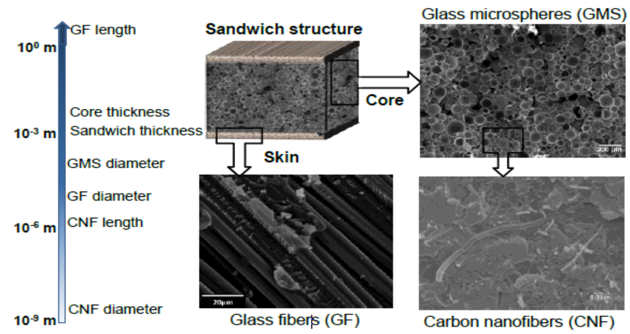

Fig-2 An example of multiscale composite material that has features spanning from a few nanometers to several meters

Where carbon nanofiber toughened resin is filled with glass hollow particles to make a syntactic foam that is used as the core material in sandwich structures. The skins are made of glass fibers. The scale bar included in this figure shows the spread in the dimensions of various materials. Extensive use of carbon nanotubes, carbon nanofibers, and nanoclay requires development of nanomechanics and multiscale modeling techniques.

These challenges are not unique to polymer matrix composites. Metal matrix composites are also striving for similar advancements because their structures may contain grains, precipitates, interfacial phases, and reinforcements across various length scales. Recent developments in simulation methods have been very useful in studying composite materials. Finite element analysis (FEA) methods have been used for the past several decades. Recently, techniques have been developed to incorporate microstructural details in solid models that are used for FEA.

Utility of FEA at the nanoscale is debatable because of increased contribution of molecular level interactions. Methods that can work across length scales, computationally efficient algorithms, and availability of powerful computer hardware are key components in the future development in the area of simulation methods. Experimental studies on composite materials under extreme environments, such as high speed automobile crashes, bomb blasts, radiation, and long term environmental damage can be very expensive and technically challenging. Such fields can especially benefit from the development in modeling and simulation methods.

2. MODELLING APPROACH

2.1 Basics

The basic design characteristics of modern aircraft are the use of complex software packages, in both design and service. Most of these software's are based on the Finite Element Method (FEM). With the help of these programs, it is possible to determine the accurate number of measurable places on the structure, with increasing stress values. This enables optimization of necessary measure equipment, which is integrated on aircraft and directly contributes to shorten the time of testing and project price reduction. The same kind of procedure provides an opportunity for tracking defects in structures during their service life within maintenance procedures. Structural analysis is the process by which the relevant data for the structure are obtained. These data can be the following: stresses, deformations, displacements, oscillations, etc [7]. It can be said for structural analysis that it presents an integral and important part of the design.

Methods for structural analysis are divided into: analytical, numerical and experimental. In modern design a wide range of software packages are used, such as CATIA, PRO/Engineer, Solid Works, Inventor, and others that enable fast work on different projects.

Finite Element Method (FEM) is a numerical method of structural analysis [8]. The basic idea of this method is a physical discretization of a continuum. This implies a dividing accounted domain (some structures) on the finite number of small dimensions and simple shapes, which represent the basis for all considerations. This makes a mesh of so-called '"finite elements"'. Over discretization of a continuum, one type of finite elements or combination of several types may be used. The finite elements are connected by common nodes, so that they make the original structure. Mesh generation is the division of a certain area on nodes and finite elements. Commercial software packages have a built automatic division of the areas for the purpose of obtaining one faster as well as qualitative solutions. This is of big importance in large or very complex engineering tasks [10].

2.2 Approach

The main task of stress analysis on composite structure consists of three parts [2]:

- Finite element modeling
- Finite element analysis
- Computer aided detail stress analysis

The FEM is used to find out: stresses and deformations in the complex and unusually shaped components; conditions of fluid flow around buildings; heat transfer through gases and in other applications. A complete model takes into account geometry components, used materials, load conditions, boundary conditions and other significant factors. Appropriate use of FEM permits that component is tested before it is made. Consecutive iterations of that part would be modified, in order to attain the minimum weight with supply of an adequate strength. To view the basic equations in the FEM, various methods are used [9]. Commercially available FEA software is as below (Miracle & Donaldson, 2001)

Table 1: Commercially available FEA software (Miracle & Donaldson, 2001)

Code	Company	Web address
Codes with built-in pre- and postprocessors for composites		
ABAQUS	Hibbitt, Karlsson & Sorensen, Inc., Pawtucket, RI	http://www.abaqus.com/products/
ALGOR	Algor, Inc., Pittsburgh, PA	http://algor.com/homepag2.htm
ANSYS	ANSYS, Inc., Canonsburg, PA	http://www.ansys.com/
CATIA/Elfini	IBM and Dessault Systemes, Newark, NJ	http://www.catia.ibm.com/prodinfo/cov.html
COSMOS	Structural Research & Analysis Corp., Los Angeles, CA	http://www.srac.com/products.html
EMRC-NISA II	Engineering Mechanics Research Corp., Troy, MI	http://www.emrc.com/webpages/composite/compov.html
ESI-SYSPLY	ESI Group, Paris, France	http://www.esi.fr/products/sysply/overview.html
ESRD-StressCheck	Engineering Software Research and Development, Inc., St. Louis, MO	http://www.esrd.com/CompositeAnalysis.htm
Pro/MECHANICA	PTC, Needham, MA	http://www.ptc.com/products/proe/sim/structural.htm
SDRC-IDEAS	Structural Dynamics Research Corp., Milford, OH	http://www.sdrc.com/nav/software-services/product-catalog/lamcomp.pdf
Codes using separate pre- and postprocessors		
LS-DYNA	Livermore Software Technology Corporation, Livermore, CA	http://www.lstc.com
MSC-NASTRAN/DYTRAN	MSC Software Corp., Costa Mesa, CA	http://www.mechsolutions.com/products/patran/lammod.html
VR&D-GENESIS	Vanderplaats Research & Development, Inc., Colorado Springs, CO	http://www.vrand.com/genesis_fact.htm
Pre- and postprocessors		
PATRAN	MSC Software Corp., Costa Mesa, CA	http://www.mechsolutions.com/products/patran/patran2000.htm
HyperMesh	Altair Engineering, Inc., Troy, MI	http://www.altair.com/

It can be said that the FEM solution process consists of the following steps:
• Divide structure into piece elements with nodes (discretization/meshing);
• Connect (assemble) the elements at the nodes to form an approximate system of equations for the whole structure (forming element matrices);
• Solve the system of equations involving unknown quantities at the nodes;
• Calculate desired quantities (e.g., strains and stresses) at selected elements.

The FEM is used in deformable bodies' mechanics to solve various static and dynamic problems. There are linear and nonlinear FEM analyses. Linear FEM analysis is based on a few basic assumptions: theory of small deformation, material is linear elastic. Nonlinear analysis takes into account the material nonlinearity and geometrical nonlinearity (large deformations) of a considered system.

3. RESEARCH ON COMPOSITE MODELLING

Considerable progress has been made in recent times in modeling and simulation of composite materials. The present thematic topic is an attempt to capture the present state of the art in these areas through research and review articles related to a wide variety of composite materials, loading conditions, and problem solution methods. The topic is sponsored by the Composite Materials Committee of Structural Materials Division of TMS [1]. A brief overview papers that appear under this topic is presented below

3.1 Molecular Dynamic (MD) Methods

Variety of problem sets including mechanical and thermal analysis in polymer and metal based systems. The MD simulation methods have enabled both quantitative and visual understanding in the behavior of individual atoms and interatomic bonds present in the system.

3.2 Composite Dynamic Behavior under High Strain Rate Deformation.

Solve a complex problem of fluid-structure interaction when shock waves interact with a composite plate and to microstructure effects on the properties of composites.

3.3 Multiscale Models

Multiscale models are very useful in constructing approaches that can predict the materials properties across length scales. Such methodologies are gaining more importance due to the recent surge in the use of composites in structural applications.

3.4 Mechanics Based Modeling Approaches

These models are theoretically grounded and can provide predictions of mechanical, thermal, and electrical properties of composite materials. A review paper presents available theoretical models that can predict thermal conductivity of hollow particle filled polymer matrix composites called syntactic foams.

3.5 Finite Element Analysis (FEA)

Finite element analysis (FEA) is a widely used simulation method. The capabilities of this method in understanding structural, thermal, magnetic, and other properties ex: wear of composites have been well utilized in the published literature.

4. CONCLUSIONS

In current scenario there is a tendency to develop software packages, which could predict conditions on the constructions & structural health monitoring. These programs for structural analysis are mainly based on the finite element method (FEM). With these program packages on a formed model realistic conditions that construction was subjected to during service life can be simulated. Rapid growth of Modeling and simulation in composite materials field has been encouraging and is expected to continue in the near future, particularly with regards to the microstructure based simulation technique and multiscale modeling methods to study structural health monitoring of composites.

One composite material is chosen and appropriate models are formed, which are composed of only a single layer or Multilayer or Hybrid composites. Simulation testing of the models on tension, shear, pressure and other parameters like wear etc are done. By using appropriate program, stress distributions on the model were achieved.

The results of simulations offer the possibility of tracking and analysis of critical positions in construction during the design process, but also during its exploitation. In order to determine material properties Ex: stresses, wears in the composite materials, software packages (any of the suitable software listed in table 1) are used. On the basis of the results from the tests of these programs, potentially critical locations in model structures are determined, due to the existence of maximum stress/wear, and accordingly possible occurrence of damage and fracture. Obtained data can be used for further testing and analysis of damage present in these locations on the real constructions. With a particular probability, the model behaves almost the same as the actual construction. However, these facts have to be proved and confirmed by experiments. In that way, we can get accurate insight into the structure state because of damage, with the maximum optimization in terms of time and cost of testing the same.

It has been found after analyzing various papers on simulation modeling of composites that very few works has been done correlation between the computational model and the experimental analysis of composite materials. Similarly correlation can also be extended to many software packages available in the market and can be compared with experimental results.

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