



Literature review on imperfection of composite laminated plates



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ARTICLE INFO

Article history:

Received 29 September 2016

Received in revised form 7 November 2016

Accepted 12 January 2017

Available online 1 February 2017

Keywords:

Composite laminates

Imperfections

Delamination

Fiber

Matrix

ABSTRACT

A composite material can be defined as a combination of two or more materials that gives better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The two constituents are reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness combined with low density when compared to classical materials. Micromechanical approach is found to be more suitable for the analysis of composite materials because it studies the volume proportions of the constituents for the desired lamina stiffness and strength.

It is found that the manufacturing processes are responsible of many defects which may arise in fibers, matrix and lamina. These defects, if they exist include misalignment of fibers, cracks in matrix, non uniform distribution of the fibers in the matrix, voids in fibers and matrix, delaminated regions, and initial stress in the lamina as a result of its manufacture and further treatment.

The above mentioned defects tend to propagate as the lamina is loaded causing an accelerated rate of failure. The experimental and theoretical results in this case tend to differ. Hence, due to the limitations necessary in the idealization of the lamina components, the properties estimated should be proved experimentally.

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1. Introduction

Composites were first considered as structural materials a little more than half a century ago. From that time to now, they have received increasing attention in all aspects of material science, manufacturing technology, and theoretical analysis.

The term composite could mean almost anything if taken at face value, since all materials are composites of dissimilar subunits if examined at close enough details. But in modern materials engineering, the term usually refers to a

matrix material that is reinforced with fibers. For instance, the term “FRP” which refers to Fiber Reinforced Plastic usually indicates a thermosetting polyester matrix containing glass fibers, and this particular composite has the lion’s share of today commercial market.

Many composites used today are at the leading edge of materials technology, with performance and costs appropriate to ultra-demanding applications such as space craft. But heterogeneous materials combining the best aspects of dissimilar constituents have been used by nature for millions of years. Ancient societies, imitating nature, used this approach as well: The book of Exodus speaks of using straw to reinforce mud in brick making, without which the bricks would have almost no strength. Here in Sudan as stated by

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<http://dx.doi.org/10.1016/j.jmau.2017.01.001>

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Table 1
Properties of composite reinforcing fibers.

Material	E (GN/m ²)	σ_b (GN/m ²)	ϵ_b (%)	ρ (Mg/m ³)	E/ ρ (MN.m/kg)	σ_b/ρ (MN m/kg)
E-glass	72.4	2.4	2.6	2.54	28.5	0.95
S-glass	85.5	4.5	2.0	2.49	34.3	1.8
Aramid	124	3.6	2.3	1.45	86	2.5
Boron	400	3.5	1.0	2.45	163	1.43
H S graphite	253	4.5	1.1	1.80	140	2.5
H M graphite	520	2.4	0.6	1.85	281	1.3

Where E is Young's modulus, σ_b is the breaking stress, ϵ_b is the breaking strain, and ρ is the mass density.

Osama Mohammed Elmardi [1], people from ancient times dated back to Meroe civilization, and up to now used *zibala* (i.e. animals' dung) mixed with mud as a strong building material.

As seen in Table 1 below, which is cited by David Roylance [2], Stephen et al. [3] and Turvey et al. [4], the fibers used in modern composites have strengths and stiffnesses far above those of traditional structural materials. The high strengths of the glass fibers are due to processing that avoids the internal or external textures flaws which normally weaken glass, and the strength and stiffness of polymeric aramid fiber is a consequence of the nearly perfect alignment of the molecular chains with the fiber axis.

These materials are not generally usable as fibers alone, and typically they are impregnated by a matrix material that acts to transfer loads to the fibers, and also to protect the fibers from abrasion and environmental attack. The matrix dilutes the properties to some degree, but even so very high specific (weight – adjusted) properties are available from these materials. Polymers are much more commonly used, with unsaturated Styrene–hardened polyesters having the majority of low to medium performance applications and Epoxy or more sophisticated thermosets having the higher end of the market. Thermoplastic matrix composites are increasingly attractive materials, with processing difficulties being perhaps their principal limitation.

Recently, composite materials are increasingly used in many mechanical, civil, and aerospace engineering applications due to two desirable features: the first one is their high specific stiffness (stiffness per unit density) and high specific strength (strength per unit density), and the second is their properties that can be tailored through variation of the fiber orientation and stacking sequence which gives the designers a wide spectrum of flexibility. The incorporation of high strength, high modulus and low-density filaments in a low strength and a low modulus matrix material is known to result in a structural composite material with a high strength to weight ratio. Thus, the potential of a two-material composite for use in aerospace, under-water, and automotive structures has stimulated considerable research activities in the theoretical prediction of the behavior of these materials. One commonly used composite structure consists of many layers bonded one on top of another to form a high-strength laminated composite plate. Each lamina is fiber reinforced along a single direction, with adjacent layers usually having different filament orientations. For these reasons, composites are continuing to replace other materials used in structures such as conventional materials. In fact composites are the

potential structural materials of the future as their cost continues to decrease due to the continuous improvements in production techniques and the expanding rate of sales.

It is important to recognize that, with the advent of composite media, certain new material imperfections can be found in composite structures in addition to the better-known imperfections that one finds in metallic structures. Thus, broken fibers, delaminated regions, cracks in the matrix material, as well as holes, foreign inclusions and small voids constitute material and structural imperfections that can exist in composite structures. Imperfections have always existed and their effect on the structural response of a system has been very significant in many cases. These imperfections can be classified into two broad categories: initial geometrical imperfections and material or constructional imperfections.

The first category includes geometrical imperfections in the structural configuration (such as a local out of roundness of a circular cylindrical shell, which makes the cylindrical shell non – circular; a small initial curvature in a flat plate or rod, which makes the structure non – flat, etc.), as well as imperfections in the loading mechanisms (such as load eccentricities; an axially loaded column is loaded at one end in such a manner that a bending moment exists at that end). The effect of these imperfections on the response of structural systems has been investigated by many researchers and the result of these efforts can be easily found in published papers [5–29].

The second class of imperfections is equally important, but has not received as much attentions as the first class; especially as far as its effect on the buckling response characteristics is concerned. For metallic materials, one can find several studies which deal with the effect of material imperfections on the fatigue life of the structural component. Moreover, there exist a number of investigations that deal with the effect of cut – outs and holes on the stress and deformation response of thin plates. Another material imperfection is the rigid inclusion. The effect of rigid inclusions on the stress field of the medium in the neighborhood of the inclusion has received limited attention. The interested reader is referred to the bibliography of Professor Naruoka [5].

There exists two important classes of material and constructional–type imperfections, which are very important in the safe design, especially of aircraft and spacecraft. These classes consist of fatigue cracks or cracks in general and delamination in systems that employ laminates (fiber – reinforced composites). There is considerable work in the area of stress concentration at crack tips and crack propagation. Very few investigations are cited, herein, for the

sake of brevity. These include primarily those dealing with plates and shells and non-isotropic construction. Some deal with cracks in metallic plates and shells {[30–33]}. Others deal with non-isotropic construction and investigate the effects of non-isotropy {[34–39]}. In all of these studies, there is no mention of the effect of the crack presence on the overall stability or instability of the system.

2. Delamination of Composite Structures

Delaminations are one of the most commonly found defects in laminated structural components. Most of the work found in the literature, deals with flat configurations.

Composite structures often contain delamination. Causes of delamination are many and include tool drops, bird strikes, runway debris hits and manufacturing defects. Moreover, in some cases, especially in the vicinity of holes or close to edges in general, delamination starts because of the development of interlaminar stresses. Several analyses have been reported on the subject of edge delamination and its importance in the design of laminated structures. A few of these works are cited {[40–46]}. These and their cited references form a good basis for the interested reader. The type of delamination that comprises the basic and primary treatise is the one that is found to be present away from the edges (internal). This delaminating could be present before the laminate is loaded or it could develop after loading because of foreign body (birds, micrometer, and debris) impact. This is an extremely important problem especially for laminated structures that are subject to destabilizing loads (loads that can induce instability in the structure and possibly cause growth of the delamination; both of these phenomena contribute to failure of the laminate). The presence of delamination in these situations may cause local buckling and/or trigger global buckling and therefore induce a reduction in the overall load – bearing capacity of the laminated structure. The problem, because of its importance, has received considerable attention.

3. Conclusions

In most of the previous studies, the composite media are assumed free of imperfections i.e. initial geometrical imperfections due to initial distortion of the structure, and material and/or constructional imperfections such as broken fibers, delaminated regions, cracks in the matrix material, foreign inclusions and small voids which are due to inconvenient selection of fibers/matrix materials and manufacturing defects as it is explained in Refs. [26,28,29]. Therefore, the fibers and matrix are assumed perfectly bonded.

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