ANALYSIS OF COMPOSITE LAMINATES FOR WIND TURBINES

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TO MY PARENTS

ANALYSIS OF COMPOSITE LAMINATES FOR WIND TURBINES

by

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THESIS

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ABSTRACT

The aim of this thesis is to develop easy to use analytical tools to analyze composite structures and suggest a suitable fabricating technique for fabrication of a wind turbine blade root. Two analytical tools for analyzing composite laminates were presented. This is done with the intention of undertaking a feasible blade root design. In one analysis classical plate theory is used and a computer code was developed, with the output signalling the user about the ply failure conditions. This will help the user to arrive at the appropriate lay up schedule for a given loading condition. The other tool is based on finite element techniques and the analysis was done using 3D modelling. The main aim is focussed on modelling cylindrical objects and analyzing them for stresses. Anisotropy associated with composites has been taken into account. Both of the above tools were tested with existing classical solutions and were found to give good results. In addition to the above, a preliminary blade root design was suggested, fabricated and tested. A suitable fabrication procedure was outlined based on the experience thus far gained.

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CHAPTER 1

INTRODUCTION

Glassfiber Reinforced Plastic (GRP) is an interesting material for manufacturing of wind turbine blades offering a number of advantages:

- Good moldability to obtain desired aerodynamic shape
- Low specific weight compared to other materials meaning other components of the wind turbine can be made lighter
- High specific stiffness, (E/ρ) and high specific strength (σ/ρ)
- Comparatively easy manufacturing
- Corrosion resistant
- Good mechanical properties

These properties have made GRP a popular material for the blades of small wind turbines. Also large Wind Turbine blades have been built using GRP.

1.1 General Nature of the Problem

Recently the wind energy industry has suffered a large number of blade failures. These failures are mainly caused by failure at the blade root, and has made the industry focus on this critical part of the design. A blade root failure normally means the loss of the blade. In some cases the blade

can be repaired. For both cases the rest of the blade needs an expensive inspection for damage at a high cost. For a large system, the cost of a blade is very high and a blade failure would cause a severe economic loss. It is doubtful if the system would even survive the loss of a blade, since a large wind turbine system would probably not be designed for this unbalanced load case. Besides, the loss of a blade would hazard the life and limb of those nearby and would lead to a loss of confidence in wind energy as a reliable energy source.

The basis for GRP design for these applications, however, is far from complete. Results from other fields of GRP research are not applicable due to the large number of load cycles during the lifetime of a wind system. The situation is further complicated by the fact that the strength of a GRP structure not only depends on the materials it is made up from but also on the design principles and manufacturing method.

The disadvantages with GRP can be summarized as:

-problems at transition pieces such as blade roots

-limited knowledge of long term properties e.g. ageing

-non-availability of easier analytical tools

-variation of mechanical properties based on the manufacturing techniques

1.2 Objective of Study

The objective of the study is aimed at developing simple

analytical tools at analyzing structures made of composite laminates. Emphasis is placed on analyzing Cylinders, the most common type of the turbine blade spar, made of composite layers, using both closed form and finite element methods. An attempt is made to suggest a design criterion for interfacing the composite laminate with metallic hub. A feasible and effective manufacturing technique is suggested based on the limited testing results, to ensure better joint fabrication.

The scope of the thesis is limited to and encompasses the following areas:

-Development of a computer program to analyze composite laminate structures (cylinders and plates) using classical closed form approach. First ply failure conditions are determined using maximum stress failure criterion and also strength ratios are determined using the Tsai-Wu criterion. Empirical formulas as given in [5] are used to determine the buckling failure conditions. This program is primarily used to determine the no. of layers required in the spar to take up the loads.

-Development of a computer program to analyze composite laminate cylinders based on finite element methods. The method is similar to the analysis of an isotropic material in all respects, except for the fact that the elastic constants are different as it involves

transverse isotropy. Part of the above program is utilized in this in calculating the equivalent elastic constants.

-Suggest one of the feasible blade root designs and its manufacturing technique, based on the experiments thus far conducted to ensure ease in fabrication and repeatability of results. This is not to say it is the only possible design for this configuration, but is one of a possible alternative. Also this is not very radically different from the existing designs, but is a variations of one of the suggested alternatives which is yet to be tried. In this context, it may be mentioned that, two designs were under active consideration, however since one of the wind energy harnessing firm M/s Zond Systems has taken up the first one on experimental basis, only the second one has been taken up for study.

Considerable difficulties have been encountered in determining the material properties of the commercially available materials. The variations in the analytical results from the experimental values can mostly be attributed to this and also to the variations that will be induced during manufacturing process. However, these are expected to give a starting point to further probe into the intricacies of the design.

CHAPTER 2

BASIC THEORY

The word "composite" means "consisting of two or more distinct parts". Thus, composites can be considered materials consisting of two or more chemically distinct constituents, on a macroscale, having a distinct interface separating them. The word macroscale is important here. It means "visible to the naked eye" [1].

Composites consist of two or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the reinforcement material, whereas the continuous phase is termed the matrix. The primary function of the reinforcement material is to carry the loads, whereas for the matrix is to protect the composite from the environment and to maintain the reinforcing material together.

With respect to the current work, the matrix is an Epoxy Resin and the reinforcement material is commercial grade woven fabric glass.

2.1 Types of Composites

Many different materials can be used in composites. The possible combinations are limitless, but there are only five basic types of composites. Figures 2.1 and 2.2 illustrate the

form of the material within the composite and the five composite types respectively [2].

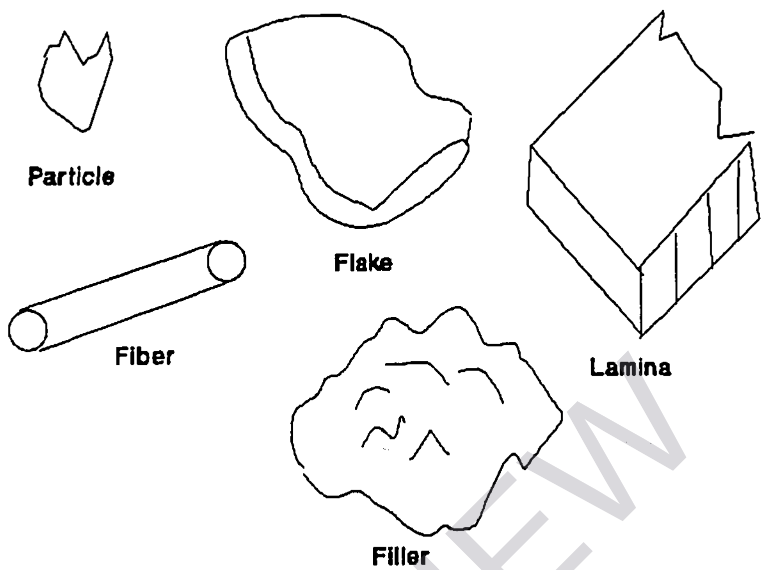

Figure 2.1 Constituent Forms in Composites [2]

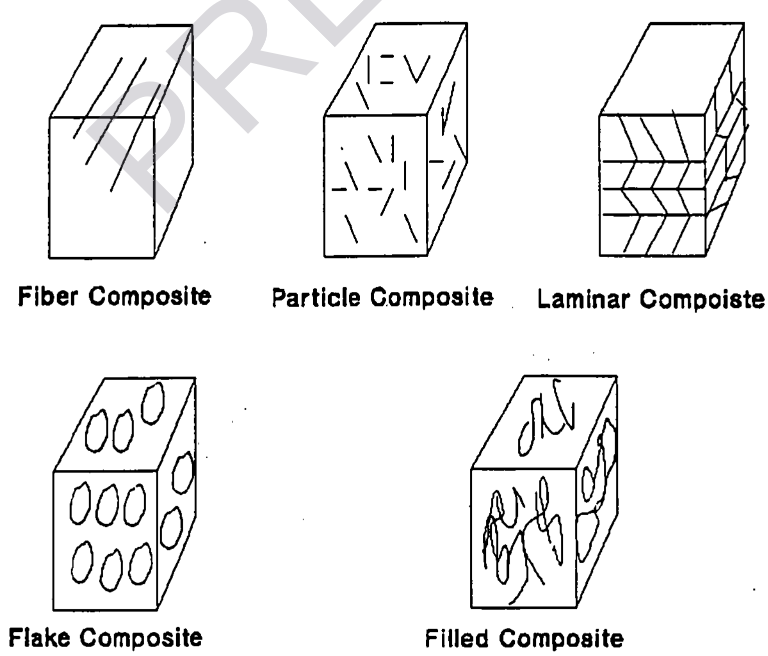

Figure 2.2 Classes of Composites [2]

The five types are:

-Fiber composites, made up of fibers

-Particle composites, made up of particles

-Flake composites, made up of flat flakes

-Laminar composites, made up of two or more layers of material

-Filled composites, made up of a skeleton matrix filled with a second material

2.2 Classification

In describing a composite besides specifying the constituent materials and their properties, one needs to specify the geometry of the composite. The geometry of the reinforcement may be described by the shape, concentration, size and orientation. Shape may be approximated by lamina, particles, whiskers and fibers. Concentration is usually measured in terms of volume or weight fraction. Size and concentration control the texture of the material. Orientation in continuous fiber-reinforcement composites can be either unidirectional, cross-ply or angle-ply. Figure 2.3 represents a commonly accepted classification scheme for composite material [3].

2.3 The nature of fiber-reinforced composites

Glass fiber reinforced composites are light and strong constructional materials with weather resistant

characteristics. They are easily fabricated into complex shapes. The glass fibers enhance the stiffness, strength and creep resistance of the composite matrix.

On the basis of strength and stiffness alone, fiber reinforced composites do not have a clear advantage over metals, particularly when it is noted that their elongation to fracture is much lower than that of the metals. Table 2.1 shows the mechanical properties of steel and fiberglass

Property	Medium Carbon Steel	Fiber Glass
Modulus of Elasticity (psi)	27600000	7395000
Density (lbs/cu. in.)	0.28	0.1
Elongation to Fracture (%)	12 - 28	1.8
Resistance to Corrosion	Low	High

Table 2.1 Comparison of Typical Properties of Steel and Fiberglass

The advantage of composites appear when the modulus per unit weight (specific modulus) and strength per unit weight (specific strength) are considered. The higher specific modulus and specific strength of composites mean that the weight of components can be reduced. This is a factor of great importance in moving components especially in all forms of transport, where reductions in weight result in greater efficiency and energy savings. The major advantages may be

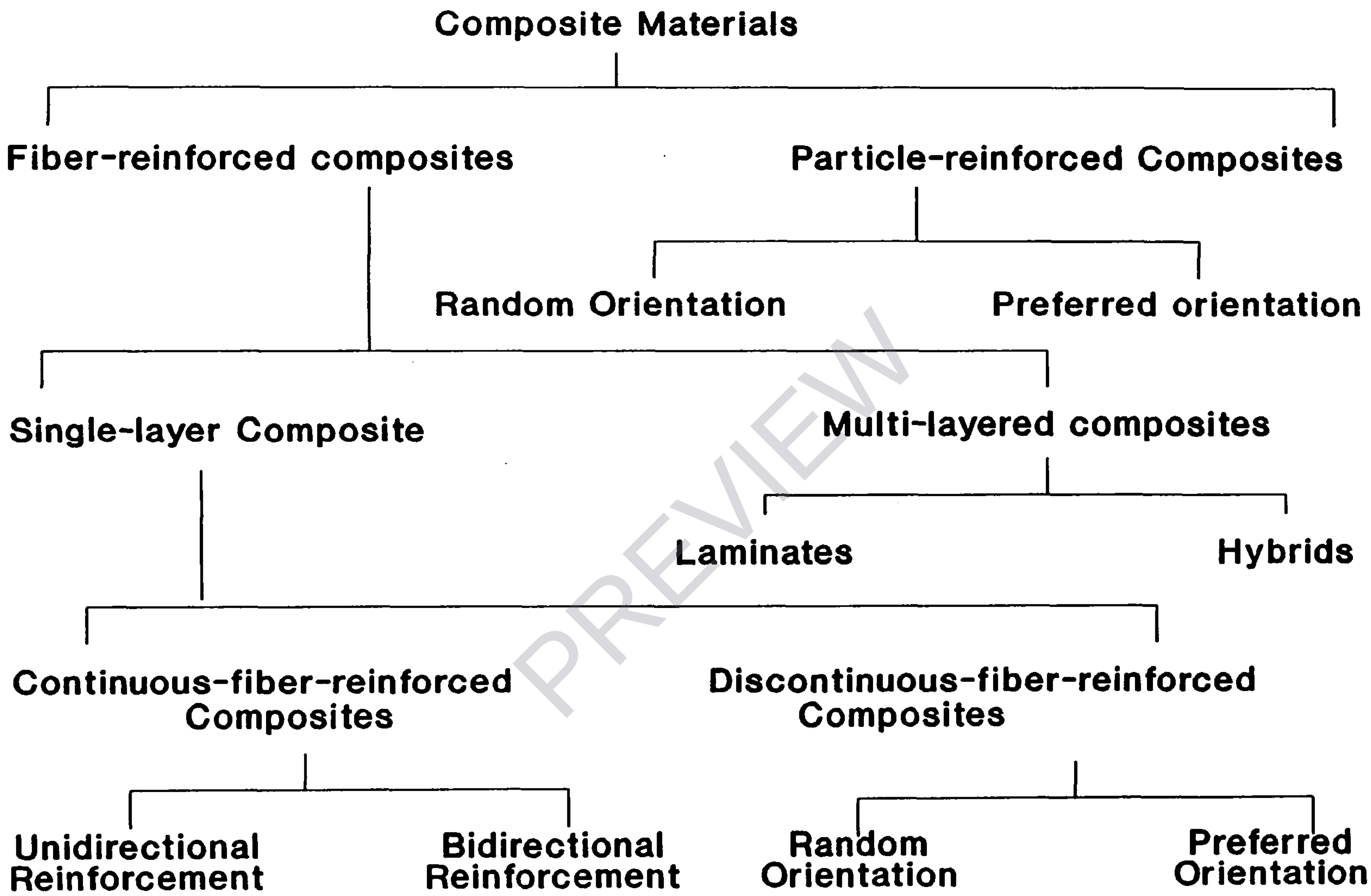

Figure 2.3 Classification of Composite Materials [3]

summarized as follows [1]:

- -High strength to weight ratio
- -Light weight and easy to handle
- -Easy to maintain and fabricate complex shapes
- -Excellent corrosion resistance in a wide range of adverse environments
- -Good thermal and electrical insulation
- -Good surface weathering properties

The essence of composite material technology is the ability to put strong and stiff fibers in the right place, in the right orientation and in the right proportion.

2.4 Behavior

A typical unidirectional (UD) composite is shown schematically in Figure 2.4. A unidirectional composite

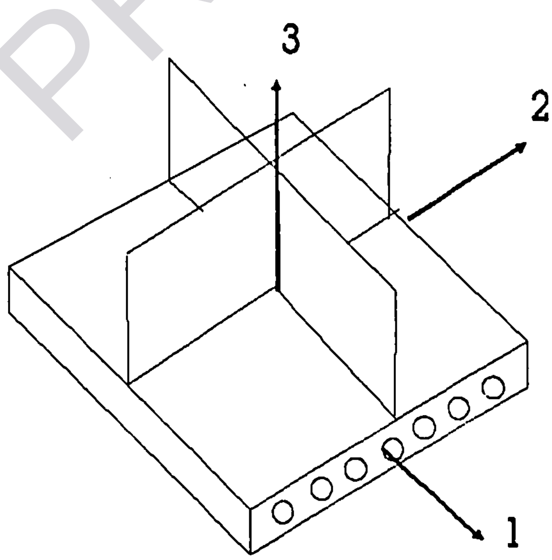

Figure 2.4 Three Planes of Symmetry for UD composite

consists of parallel fibers embedded in a matrix. Several

unidirectional layers can be stacked in a specific sequence of orientation to fabricate a laminate that will meet design strength and stiffness requirements. Each layer of a unidirectional composite may be referred to as a layer, ply or lamina.

Fiber-resin composites, in general, exhibit orthotropic behavior. These planes coincide with the 1, 2, 3 axes in Figure 2.4. These axes are also referred to as the material axes. The direction parallel to the fiber is called the longitudinal direction (axis 1). The direction perpendicular to the fibers is called the transverse direction (any direction in the 2-3 plane).

All design procedures involve a comparison of the actual stress field with the allowable stress field. For isotropic materials, this usually means comparing principal stresses with the allowable stress for the material using an appropriate failure criterion. In the case of orthotropic or anisotropic materials the strength varies with the direction, and the direction of the principal stress does not coincide with that of the maximum strength. Thus the highest stress may not be the stress governing the design and comparison of the actual stress field with the allowable stress field is required.

There are five characteristic values of strengths for a unidirectional composites:

-Longitudinal tensile strength

-Longitudinal Compressive strength

-Transverse tensile strength

-Transverse compressive strength

-In-plane shear strength

A unidirectional composite has the strongest properties in the longitudinal direction. The interfacial bond between the matrix and the fibers is another important factor influencing the mechanical properties and performance of composites. The interface is responsible for transmitting the load from the matrix to the fibers, which contribute to the greater portion of the composite's strength. Thus, the composite strength is affected by the interfacial condition.

The modulus of a fiber reinforced composite defines an average property of a volume of a material containing large number of fibers. However, the strength of such a material is intrinsically related to the mechanics of individual fiber/matrix interactions. Extensive literature is available relating the properties of the micro constituents of the composites to the properties of the lamina, which is being dealt with in Chapter 3.