Investigation of core closeouts in fiber-reinforced sandwich laminates

by Russell Lee Evertz

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering
Montana State University

Abstract:
Wind is an environmentally friendly renewable energy source that becomes more attractive when composite materials technology is applied; particularly technology associated with fiber reinforced plastics. This technology allows the design of lighter wind turbine blades, which may increase the efficiency of wind turbines, making wind generated electric power less costly. The application of sandwich panel construction can stiffen the blades while keeping overall blade weights low. Due to manufacturing and design parameters, the sandwich panel configuration is only employed in certain areas of the blade, where additional buckling resistance is needed. Although initially thought to be of little importance, the effect that the transition between fiberglass/balsa sandwich panel and the fiberglass laminate may have on the performance of the blade is not trivial.

This research is an investigation of balsa core sandwich panels, thin laminates (which were the facesheets for the sandwich panel), and transitions from sandwich panels to thick and thin laminates. Sandwich panels were tested in tension, resulting in strengths slightly above the thin laminate without the balsa core in place.

A sandwich panel to thin laminate transition can reduce static tensile strength by up to a factor of six when using a 30 degree fillet transition, as discovered in this research through finite element models and experimental tests. Transitions were tested with fillet angles ranging from 5 to 30 degrees. The 5 degree specimens with a transition to a thin laminate reduced strength by only 7 percent, well above the performance of the 10 degree transition, which lowered strength by 48 percent. Finite element models were created for use as a design tool to evaluate the transition behavior, and were validated using experimental data.

A transition from a sandwich panel to a thick laminate was also investigated. Specimens tested included angles of balsa termination of 5, 10, and 90 degrees. The 5 degree termination performed the best, failing at a value that was only 23 percent less than that for a sandwich panel. The 90 degree specimens delaminated at a stress as much as 55 percent less than the sandwich panel alone.

Fatigue performance of the thin laminate, the sandwich panel, and the sandwich to thin laminate transition were investigated. The sandwich panel had fatigue strengths only 1.1 times lower than the baseline thin laminate at one million cycles. The transition had poor fatigue performance, 3.4 times lower than the thin laminate at a million cycles due to delamination in the transition region.

Design and manufacturing guidelines were made based on the results of experiments and models completed through this research. Recommendations for finite element modeling to be used as a design tool were also made.

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APPROVAL

of a thesis submitted by

Russell Lee Evertz

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Dr. Douglas Cairns — Douglas S Cairns (Signature) — 9/22/00 Date

Approved for the Department of Mechanical Engineering

Dr. Vic Cundy — (Signature) — 9/22/00 Date

Approved for the College of Graduate Studies

Dr. Bruce McLeod — Bruce R. McLeod (Signature) — 9-25-00 Date

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Wind is an environmentally friendly renewable energy source that becomes more attractive when composite materials technology is applied; particularly technology associated with fiber reinforced plastics. This technology allows the design of lighter wind turbine blades, which may increase the efficiency of wind turbines, making wind generated electric power less costly. The application of sandwich panel construction can stiffen the blades while keeping overall blade weights low. Due to manufacturing and design parameters, the sandwich panel configuration is only employed in certain areas of the blade, where additional buckling resistance is needed. Although initially thought to be of little importance, the effect that the transition between fiberglass/balsa sandwich panel and the fiberglass laminate may have on the performance of the blade is not trivial.

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A sandwich panel to thin laminate transition can reduce static tensile strength by up to a factor of six when using a 30 degree fillet transition, as discovered in this research through finite element models and experimental tests. Transitions were tested with fillet angles ranging from 5 to 30 degrees. The 5 degree specimens with a transition to a thin laminate reduced strength by only 7 percent, well above the performance of the 10 degree transition, which lowered strength by 48 percent. Finite element models were created for use as a design tool to evaluate the transition behavior, and were validated using experimental data.

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CHAPTER 1

INTRODUCTION

Environmentally friendly, renewable energy alternatives have been investigated for decades [Cheremisinoff (1978)]. In the past ten years, there has been a substantial increase in the interest in wind power as an ecologically sound and renewable energy source. The growing interest can easily be seen in Europe where the wind power industry is flourishing [Gipe (1995)].

Wind power becomes more attractive when composite materials technology is applied, particularly with fiber reinforced plastics. Composites are a combination of reinforcement, such as glass or carbon fibers, and a binder or matrix [Dostal, (1989)]. This technology allows the design of lighter wind turbine blades, which may increase the efficiency of wind turbines, making wind generated electric power less costly. Increases in efficiency includes decreased cost of blade manufacturing and the additional power gained as the mass of the turbine is reduced while the wind gathered remains the same. A popular composite material among wind turbine blade producers is fiberglass-reinforced polyester. As turbines increase in size, blades need increased stiffness and durability. While early, small turbine blades used randomly oriented fiber mats, larger blades use aligned fiber fabrics in their construction [Mayer (1996)].

To make wind turbines more efficient, blades are designed to be as light as possible. Minimizing weight and maintaining blade performance is an ongoing challenge to the designer. The inclusion of sandwich panel construction to resist buckling in blade designs allows designers to reduce weight without sacrificing blade performance. Sandwich construction has been developed for decades, and used as early as the mid 1800's [Allen (1969)]. It consists of three or more layers of material. The outer facesheets or skins are strong, stiff materials, such as fiber reinforced plastics, while the center layer or core is lightweight. The facesheets carry the load, while the core separates the facesheets and carries shear stresses, preventing buckling. Sandwich panel construction is illustrated in Figure 1.1.

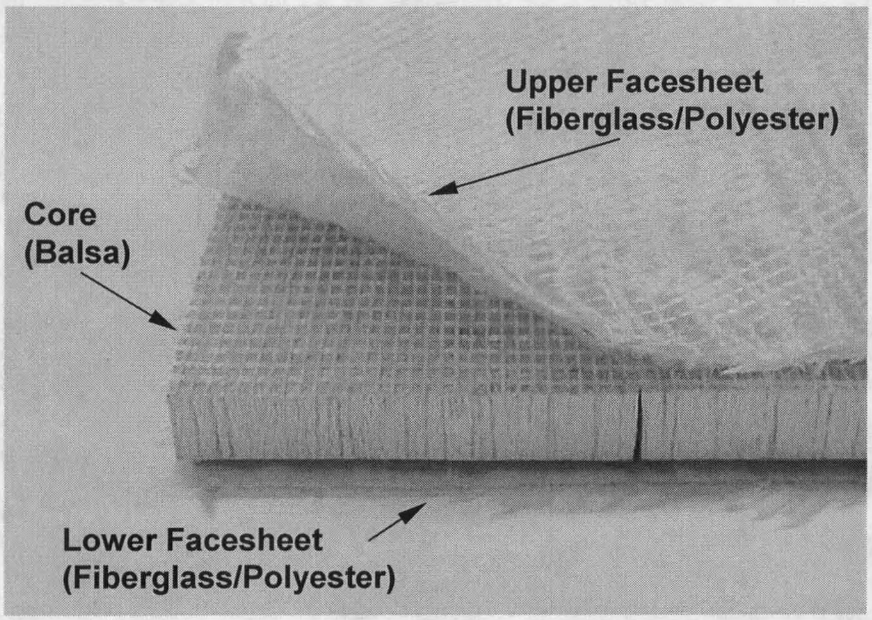

Figure 1.1 Sandwich panel construction (polyester matrix has been omitted for clarity.)

The application of sandwich construction can increase local buckling resistance by at least an order of magnitude with little increase in weight [Gere &

Timoshenko (1990)]. Since sandwich panel construction is only employed in local areas of the blade, the termination of the sandwich panel into a thin laminate is inevitable in an efficient design. Insert info about load introduction

A discontinuity in any composite system should be examined carefully to ensure it does not substantially reduce the overall strength of the design. Several design details that introduce discontinuities are discussed by Mandell et al. (1998). Although initially overlooked, the transition between a fiberglass/balsa sandwich panel and the fiberglass laminate may be significant after reviewing the stress concentrations of other structural details such as ply drops, surface indentations, and locally high fiber contents.

The main objective of this research was to investigate the transition zone between the fiberglass/balsa sandwich panel and the fiberglass laminate. The parameters of interest are the static and fatigue strengths of the transition area, compared with the strengths of thin laminates as well as sandwich panels. The study has evaluated a variety of transition region parameters, using both experiments (after extensive test development) and finite element models. The results were used to develop design and manufacturing guidelines for designers to use when developing turbine blades containing fiberglass/balsa sandwich panel construction.

CHAPTER 2

BACKGROUND

Motivation

A wind turbine blade design has been developed as part of the Montana State University Wind Program for the AOC 15/50 wind turbine [McKittrick et al. (1999)]. The blade design consists of two skins separated by a spar. A diagram of the blade is shown in Figure 2.1. The top and bottom sections are secondary bonded to the spar; they are also secondary bonded at the leading and trailing edges. Secondary bonds are accomplished with high strength adhesive, joining parts manufactured in two or more pieces.

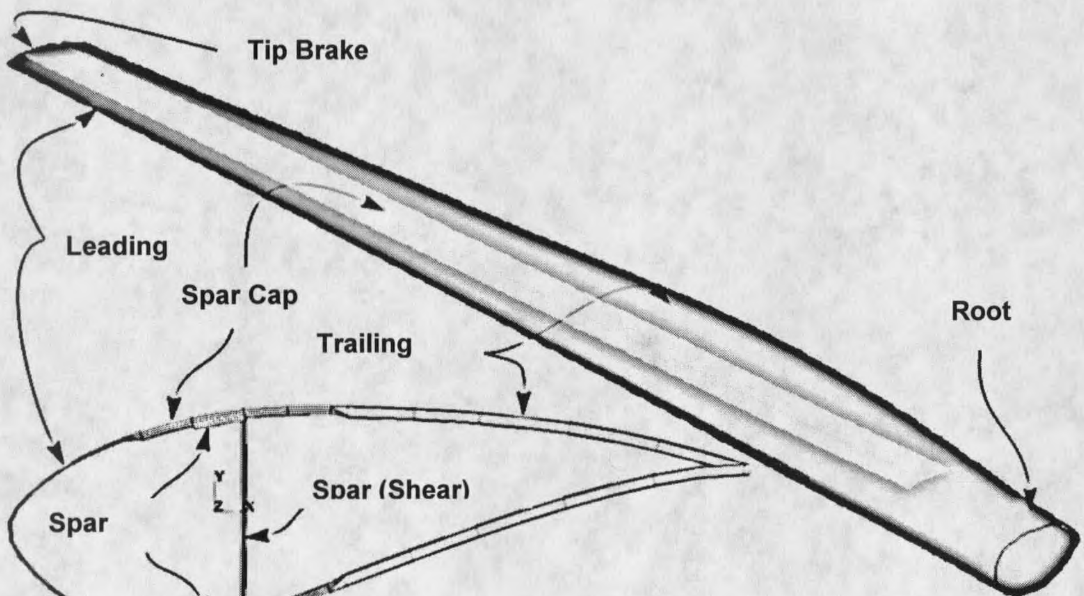

Figure 2.1 Diagram of blade design for the AOC 15/50.