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J.H. Sjølund, E. Lund

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Structural gradient based sizing optimization of wind turbine blades with fixed outer geometry

J.H. Sjølund[a,*], E. Lund[a]

[a]*Department of Materials and Production, Aalborg University, Fibigerstræde 16, Aalborg DK-9220, Denmark*

Abstract

In this work the mass of a 73.5 m offshore wind turbine blade is minimized while considering manufacturing constraints, tip displacement, buckling, and static strength criteria when subject to an extreme load envelope consisting of 12 load directions. The gradient based sizing optimization takes offset in the outer geometry and loading from a commercial 73.5 m wind turbine blade where the manufacturing mold should be re-used and hence the outer geometry is kept constant. A solid-shell finite element model of the full blade is used as basis for the optimization. The blade is divided into patches and thicknesses of ply-groups (groups of contiguous plies with the same material and fiber orientation) are used as design variables. The design variables are assumed continuous in the optimization phase. Sequential linear programming (SLP) is used to solve the problem with semi-analytical gradients. In the post-processing phase the lay-up is refined and ply-group thicknesses are rounded to a whole number of plies. The gradient based sizing optimization results in a reduced mass and many active constraints across multiple load directions while the post-processing ensures manufacturability.

Keywords: wind turbine blade structural design, gradient based sizing optimization, manufacturing constraints, laminated composites

1. Introduction

Modern wind turbine blades are complex composite structures. The blades are subject to complicated loading conditions and the materials have many different failure modes. The structure has a variable stiffness with ply-drops present throughout the blade. The ply-drops are accompanied by advanced material transitions between sandwich and monolithic sections, adhesive bonding, bolted connections, lightning protection and many other details. Modern wind turbine blades typically utilize either glass- or carbon-fiber reinforced polymers (GFRP/ CFRP), or even hybrids of these two, as the main load carrying materials. Wind turbine blades can be manufactured in many ways. One method is to place dry non-crimp fabric fiber mats in a mold, layer by layer. A mold exists for both the upwind (UW) side and the downwind (DW) side of the blade. The material is infused with resin in a vacuum-assisted process. Finally, the two halves of the blade are glued together with webs placed in-between. A typical cross section resulting from this process is illustrated in Figure 1. The main laminate (MA), sometimes referred to as the spar cap, is mainly built from unidirectional (UD) layers. The trailing edge (TE) and leading edge (LE) are likewise reinforced by UD layers while core materials are usually covered by biaxial angle plies ±45°. Basically, the main laminate carries the flapwise moment, trailing edge and leading edge laminates carry edgewise moments, sandwich panels in-between prevent local buckling, and the shear webs (SW) carry the shear load. The in-between sandwich panels are referred to as leading edge core (LEC) and trailing edge core (TEC) as shown in Figure 1.

Structural optimization is often applied in the design of wind

*Corresponding author E-mail address: jhs@mp.aau.dk