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HIGH CYCLE FATIGUE OF WIND TURBINE BLADE MATERIALS

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ABSTRACT

Results will be reported from an on-going study of the high-cycle fatigue behavior of fiberglass composites for wind turbine rotors. Wind turbine rotors are expected to experience 10^8 to 10^9 fatigue cycles at varying load levels over their 20 to 30 year design lifetime. There currently exists only very limited data and experience with composites of any type in this cycle range, and an improved basis for both fatigue design and materials selection (and development) is needed.

Composites in fatigue usually experience a progressive process of stable damage development and accumulation, which may finally result in failure by one of several basic modes. Some damage modes may never produce failure directly, but result in significant constitutive property changes and load redistribution within the material. A variety of models have been proposed for the fatigue behavior composites, but these have not generally been applied in the high-cycle regime, where lifetime trends often begin to show nonlinearities under some conditions. The objectives of the present study are to explore a variety of generic material forms and substructures in the high-cycle range. Damage development and constitutive relationships are determined throughout the lifetime, and failure modes and lifetime trends are established..

To date over 250 tests have been conducted on ten materials supplied by blade manufacturers. While most tests have been at moderate stresses and lifetimes, many have been carried out to 10^7 to 10^8 cycles, with longer tests planned. Load conditions have included tensile fatigue, compressive fatigue, and reversed loading. Materials have included unidirectional and triax (0^o and $\pm45^o$ fibers) with polyester and vinylester matrices; all materials have used E-glass fiber reinforcement. Some tests have incorporated ply terminations and joints to simulate actual structures.

Results to date show the behavior of unidirectional materials in tension to be approximately as expected from the literature out to 40×10^6 cycles, with some effects of the less precise fiber alignment associated with blade manufacturing as compared with aerospace composites. The addition of $\pm45^o$ layers results in a significant decrease in fatigue resistance as compared with expectations. Tensile fatigue failure strains become dominated by the off-axis, ±45 layers as opposed to the more structural 0^o layers. Lifetime trend extrapolations to 10^9 cycles depend greatly on the extrapolation model used, but the triax materials tested to date show much poorer strain tolerance than expected over the entire lefetime range. The presence of ply terminations or joints can result in delamination of layers, but lifetime trends are not greatly affected. Compressive fatigue behavior is thickness and test method dependent, and in some cases appears more critical than tensile fatigue. Reverse loading tends to follow either tensile or compressive dominated behavior. Very little effect of matrix material is observed. Damage development during the lifetime has also been monitored, as well as decreases in stiffness. The latter range from the order of 10% for unidirectioonal materials to 30 - 40% or more for triax, over typical specimen lifetimes.

Future work will focus on testing to higher cycles. An attempt will be made to develop test methods using representative small volumes of material to allow higher frequences with reduced hysteretic heating. The application of coupon-type tests to real composite structures will also be investigated through studies of representative substructures and correlations with full scale blade tests.