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**Effect of Saltwater on Multiaxial Cyclic Fatigue of Carbon Fiber/Epoxy
Composite Material**

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Abstract

Carbon/epoxy composites have been used for a variety of high-performance engineering structures. In general, all engineering composite structures are subject to a multiaxial stress state. Also, carbon/epoxy composites are susceptible to environmental degradation from long-term saltwater exposure. Understanding the long-term effects of saltwater on the multiaxial fatigue behavior of these composites is important, however, little information is presently available.

The objective of the study is to investigate the long-term saltwater effects on multiaxial fatigue degradation, failure modes, and stress-life relationship. A series of tension-torsion fatigue experiments were conducted on hoop-wound carbon/epoxy tubes in a variety of saltwater environments.

Results indicate that the composite elastic properties degrade slightly during cycling. Long-term soaking in saltwater provides the most significant reduction in fatigue life, modulus, and monotonic strength. Two distinct fatigue failure modes are found to govern the cyclic stress-life relationship under various combinations of axial and shear fatigue loading.

1. INTRODUCTION

Long-term cyclic fatigue of fiber composite materials is an important, and sometimes elusive, engineering issue. Many researchers have studied polymer-matrix composite fatigue life and strength. But most of them have been conducted with experiments in a uniaxial loading condition. The laminate layups used in these experiments usually would force a fiber-dominated behavior. However, it is recognized that even in a composite laminate subject to uniaxial loading, individual plies generally possess combined axial, transverse, and shear stress, i.e., in a multiaxial loading condition. Understanding the matrix-dominated fatigue behavior becomes necessary for design, performance evaluation, and reliability assessment of the composite structures. In addition, many composite structures in service are exposed to seawater. Thus the effects of seawater sorption and cycling while immersed need to be understood.

In this research filament-wound composite materials are considered as they are most commonly used in many offshore and marine structures. Tubular specimens are used to conduct the experiments. These tubes are subjected to simultaneous, cyclic axial and torsional loading. Using the tubular specimens also offers the following desired advantages:

1. Any individual or combined state of shear and transverse stresses can be easily applied.
2. The same filament-winding process used to make actual marine structures can be employed for fabricating the experimental specimens.
3. Tubular specimens eliminate edge-stress concentrations, a problem that plagues many coupon specimens.

Basic concepts and procedures used in this study to determine ply stresses and deformations, and account for composite failure modes in multiaxial cyclic fatigue follow the original work in [1] and its subsequent development [2]. The focus of this research is to investigate the effect of seawater on the fatigue life of the carbon/epoxy composite system. Saltwater is used to simulate the seawater. Two different saltwater absorption processes are studied: (1) cycling the composite specimen in saltwater without pre-conditioning, and (2) pre-soaking the composite specimen followed by cycling in saltwater.

In the next section, a brief review of the relevant literature on the subject is conducted. The objectives and scope of the work are given in Section 3. The experimental program, including the development of the experimental equipment and test methodology is described in Section 4. The recently developed physical-mechanism based fatigue theory used in the study is reviewed in Section 5. Application of the theory to the current results obtained from the multiaxial experiments of the filament wound composites is given in Section 6. Important conclusions, drawn from the research are made in Section 7.