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# Composite Materials Under Fatigue Loading: General Review

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***Abstract***

Advanced applications, such as aircraft manufacturing, require sophisticated materials. Composite materials are among these advanced materials and offer several advantages, including high strength and low weight. Given that these applications experience repeated loading, studying fatigue in composite materials is essential. This paper provides a comprehensive review of fatigue failure in composite materials, focusing on the types of fatigue loads, the characteristics of composite materials, and the damage mechanisms. Additionally, we discuss modelling and simulation techniques to understand fatigue behavior and the standards necessary for conducting fatigue failure testing in composite materials. The study of fatigue in composite materials is diverse, reflecting the materials' complexity, which varies across scales. Due to composite materials' heterogeneity, numerical modelling can be challenging. It often requires numerous constants that change with various factors, which can only be determined through experimental test. As a result, studying fatigue in composite materials can be costly.

## 1. Introduction

Since the 1950s, numerous studies have examined the fatigue performance of composite materials across various engineering fields, considering different loading and environmental conditions. This includes modelling fatigue to analyze fatigue behavior and predict fatigue life [1, 2].

The composite material consists of two or more substances to give physical properties different from its constituents [3]. Some properties that are improved by making composite material are: strength [4, 5], high fatigue strength because of static strength and its slight decrease with cycle number to fracture [6], stiffness [7], slight decrease with several loading oscillations [6], weight [8], temperature dependent behavior [9], thermal insulation [10], corrosion resistance [11], fatigue life [12], low notch sensitivity, low sensitivity to the frequency of loading [4]. Hence, the increasing popularity of modern high-performance products is not surprising for composite material, even though composite are not recent innovations where the Bible referenced straw-reinforced bricks in the Old Testament [4].

The aerospace industry is the leading field for highly engineered composite applications [13]. The first airplane took its maiden flight no more than a century ago, and composite materials have been used to build structural components for more than half that time. The first usage dates back to 1940, when a main spar on Blenheim aircraft was constructed from flax thread skin infused with Phenolic resin, followed by the first fibrous composite in 1947. After that, they show a steady increase in the usage of composite in aviation, as shown in Fig. 1 for the composite material used in fixed-wing and rotary-wing aircraft industries. Today, most rotary blades are made of composite [14] after being made of metal blades in the sixties of the last century. The use of composite rotor blades lasts at least 20,000 hours, while the use of metallic rotor blades lasts about 1000 hours due to the difference in fatigue performance [4].

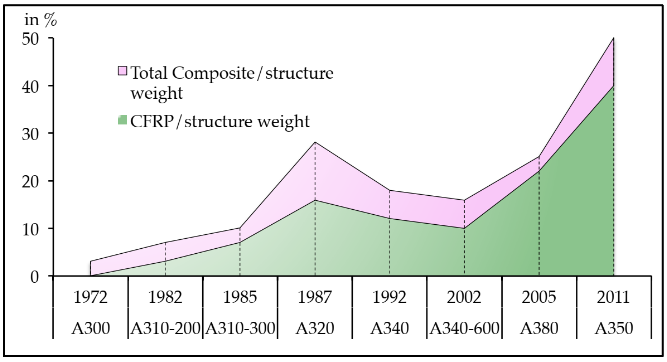


**Fig. 1** Composite usage in airbus aircraft [4].

Many aircraft parts are made from carbon epoxy and aramid epoxy [15], reducing the aircraft's weight and increasing payload and economy. Therefore, composite material is used rather than metal. Furthermore, because the composite material has high fatigue resistance, it enhances the stiffness-to-density and strength-to-density ratios [16]. Table 1 illustrates the specific modulus and strength of materials used in aircraft [17].

The known behavior of composite materials under fatigue loading has evolved significantly with advancements in product designs. Carbon fiber/epoxy, in particular, has demonstrated excellent fatigue resistance [18] from the early stages of composite development, which has been the focus of extensive research. Given that composite materials are anisotropic [19], a stress system that produces only a minor strain in the main direction of the fibers may not significantly influence the formation of strains normal to the fiber/resin interface or the fibers themselves. However, such damage