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Executive Summary of a Ph.D. Thesis

Nasreen Adeela*

Department of Textile engineering, School of Engineering and Technology, Pakistan

***Corresponding author:** Nasreen Adeela, Department of Textile engineering, School of Engineering and Technology, Pakistan

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Introduction

This executive summary provides an overview of a comprehensive Ph.D. thesis titled "Development and Characterization of Aluminum/CFRP Hybrid Joints for Aerospace Applications. The study focuses on the development and characterization of hybrid joints combining aluminum and carbon fiber hybrid composite, to enhance structural integrity and performance in aerospace applications. This research work was completed in collaboration with the PAC Karma industry, in Pakistan. Ceramics, metals, polymers, and composites are often utilized as engineering materials. For maximum strength and least weight, wood was formerly the first material utilized in the earliest aircraft in the 1900s. Although it can support low loads for some military aircraft, wood deteriorates over time. To improve toughness, damage tolerance, and corrosion resistance in the 1920s, aluminum alloys were heat-treated; nevertheless, frictional heating causes these alloys to soften. Immediately following the First and Second World Wars, magnesium alloys were used. The weight and stiffness of these alloys were found to be lower than those of aluminum. Due to their superior mechanical and temperature-resistant qualities, titanium and super alloys were first utilized in both military and commercial aircraft throughout the 1950s. These expensive alloys are preferred in pressure bulkheads and jet engines. The demand for a high performance-to-weight ratio has led to a substantial expansion in the use of Fiber-Reinforced Polymer Composites (FRPCs) in military and commercial vehicle applications since the 1940s.

For instance, the airframe of the Euro Typhoon uses 80% carbon fiber composite, but the surface area of the Dassault Raffaele uses 70% CFRP. Joining and assembling components made of similar and different materials assures the structure's integrity, and a successful joint design is dependent on the reliability and joining of its components. Mechanical fastening, welding, and adhesive bonding, as well as their hybridization, are often utilized in joining procedures. Conventional hybrid joints are more durable, have higher static and fatigue strength, and are lower in weight than mechanical or adhesive joints. However, certain problems in the creation of traditional hybrid joints exist, such as research work limited to small overlapping areas, single bolts, limited load transference via bolts, and stiff adhesives. Aluminum/G-CFRP dissimilar junctions are widespread in aircraft structures, but these joints are not focused on customized surface modification technologies, specialized adhesive, and unique hybrid joint designs for increased performance.

Objectives

The primary goals of current research are to develop novel hybrid joints such as optimizing surface pre-treatment of aluminum and G-CFRPs for improved adhesion, modifying and characterizing polymeric adhesives for improved properties between aluminum and G-CFRPs, optimizing mechanical joints, and developing novel hybrid joints for improving structural integrity and performance of hybrid joints in the aerospace and aeronautical sector. The study's goal is to assess the benefits and drawbacks of such joints in terms of their practical applicability in the aerospace sector.

Methodology

The research effort entails a rigorous, multi-step method that begins with the selection of acceptable resources. Carbon fiber tow (AS4,12K) and woven glass fabric (E glass) were employed as reinforcement materials in the first phase, while LY 564/Ardur 22962 (low viscosity resin) was used as the matrix. To attach the aluminum and glass-carbon hybrid composite (G-CFRP), Al 7075-T6 aluminum was utilized as a metal adherend and Aremco 2310 glue was employed as an adhesive. Woven Nylon Peel ply, sand, and potassium permanganate were used to clean and change the surface of composites, while the phosphoric solution was utilized to anodize and activate the surface of aluminum before adhesive bonding. Glass-carbon hybrid composite (G-CFRP) was developed by combining 20 plies of CFRPs and 2 plies of GFRPs. The prepregs were created using a solvent dip process, and the composite (G-CFRP) was cured on a compression molding machine. The mechanical characteristics of composites were as follows: Thickness (2.8 mm), tensile strength (400 MPa), tensile modulus (57 MPa), and short beam shear strength of about 9 MPa. The tensile strength of aluminum alloy was roughly 500 MPa. The unique G-CFRP composite was created to eliminate galvanic corrosion difficulties between aluminum and CFRP surfaces in joints. The surface of composites and aluminum alloys was then modified. The aluminum/G-CFRP dissimilar adhesive joint was then constructed and characterized. Composite and metal adherends were modified to successfully bond them.

To modify the surface of G-CFRPs, three techniques were used: Peel ply, peel ply plus sandblasting, and peel plyplus chemical etching. While the metal surface was modified by utilizing two techniques: mechanical and anodizing. Surface morphology, contact angle testing, and lap shear strength testing were performed after surface modification of both adherends to optimize joint roughness, wettability performance, and adhesion strength. Commercial epoxy was blended with un-vulcanized EPDM rubber in the second phase using a GPS silane coupling agent to increase its capabilities as an adhesive and compatibility with joining substrates such as G-CFRP composites and Al 7075-T6. The mechanical and thermal properties of modified and commercial adhesives were investigated. The lap shear static strength of joints made with commercial Aremco adhesive and unmodified epoxy was compared to that of G-CFRP and aluminum substrate surfaces before bonding with the modified epoxy glue. The performance of several mechanical joint designs was tested and their lap shear strength was analyzed in the final phase. As adherend materials, 390 MPa tensile strength composite material and 500 MPa tensile strength aluminum alloys were utilized. Two types of Hex head steel mechanical fasteners, as well as Nylock nuts and steel flat washers, were employed. To impart clamping force to mechanical couplings, a computerized torque wrench was used. Hybrid joints were developed based on the findings of surface treatments, adhesive modification, and mechanical joint designs. Based on the number of bolts, adhesive materials, and attachments, a total of eight hybrid joint configurations were created. Four configurations were labeled as standard hybrid joints, while the remaining four were labeled as new due to the addition of connection on both sides of overlapping sections of hybrid joints.

Results and Findings

First, the mechanical properties of G-CFRPs and Al 7075-T6 were determined, demonstrating the enormous potential of employing these materials in aeronautical applications. Pretreatments of composite/metal adherends using sandblasting/anodizing and chemical etching/anodizing approach created micro-level roughness on adherend surfaces, reduced contact angle, improved hydrophilicity, and increased the adhesion strength of composite/metal adhesive bonded joints. Aremco adhesive had the best impact strength and metal adhesion strength, LY 564 adhesive had the best thermal resistance, and LY 564/EPDM adhesive transferred the most load in hybrid joints. Mechanical joint performance improves with changes in mechanical fastener size and adherend material, however, there is no gain in joint performance when mechanical fasteners are arranged in a constant overlap area. Mechanical joints performed the least well. Bonded joints performed better than mechanical joints. Conventional hybrid joints were lighter in weight and served as a failsafe design. While innovative hybrid joints transferred the most weight, they were discovered to be complex and labor-intensive.

Applications and Practical Implications

The finding of this research holds immense applications for the aerospace industry. The development of hybrid joints can potentially revolutionize aircraft design and manufacturing processes. The reduced weight of these joints contributes to improved fuel efficiency and reduced emissions, aligning with the industry's growing focus on sustainability and environmental responsibility. Moreover, the enhanced structural performance and static strength of hybrid joints elevate aircraft safety, reliability, and longevity. The applications of these joints in key structural components, such as wings, fuselage sections, and control surfaces, could lead to

Recommendation

A novel joint design was proposed based on the findings of adherend surface modification, adhesive surface modification, and joint design studies and displayed reliable and improved performance. To further advance the field, it is recommended that future research explores the joints' long-term durability, including their resistance to environmental factors such as temperature variations, humidity, and chemical exposure. Additionally, further investigation into the fatigue behavior of the hybrid joints under cyclic loading would provide a comprehensive understanding of their performance in real-world applications. Moreover, conducting an economic assessment to evaluate the manufacturing cost and scalability of the hybrid joints compared to the conventional joints would facilitate their commercial adoption in the aerospace industry. Collaboration with aircraft manufacturers and relevant regulatory bodies would help validate the joints' performance in full-scale applications and potentially lead to their incorporation in future aircraft design standards. In conclusion, the thesis on the development and characterization of G-CFRP/Al 7075-T6 hybrid joints for the aerospace industry presents a critical contribution to the aerospace engineering field. The research emphasizes the immense potential of hybrid joints in improving structural performance and safety setting a path for future advancements in aerospace designs and manufacturing practices. The comprehensive investigation into novel hybrid joint design offers valuable insights that can inform the aerospace industry's overall performance, thus furthering the field of aerospace engineering.

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