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Laminar composite materials for unmanned aircraft wings

Mala Utami[1*], Jonathan Ernest Sirait[2], Beny Budhi Septyanto[3], Aries Sudiarso[4], I Nengah Putra Apriyanto[5]
[1,2,3] Faculty of Defense Technology, Indonesian Defense University, Indonesia

*Corresponding author E-mail: mala.utami@tp.idu.ac.id

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Abstract

Unmanned Aerial Vehicles (UAVs) have high popularity, especially in the military field, but are now also being applied to the private and public sectors. One of the UAV components that require high material technology is the wing. The latest material technology developed as a material for unmanned aircraft wings is a composite material that has high strength and lightweight. This research aims to identify composite materials that can be used for unmanned aircraft wing structures. The method used in this research is a qualitative method with a literature study approach. The results of this theoretical study show that some of the latest composite materials that have been developed into materials for unmanned aircraft wings are Laminar Composites with a sandwich structure. Laminar and sandwich composites consist of various constituent materials such as Balsa wood fiber-glass and polyester resin, microparticles, Carbon Fibre Reinforced Polymer, polymer matrix composites reinforced with continuous fibers, Polymer matrix composites, E-glass/Epoxy, Kevlar/Epoxy, Carbon/Epoxy, woven fabrics, acrylonitrile butadiene styrenecarbon (ABS) laminated with carbon fiber reinforced polymer (CFRP) and uniaxial prepreg fabrics. Laminar and sandwich composite materials are a reference for developing unmanned aircraft wing structures that have resistant strength and lightweight.

Keywords: UAV Wings, Composite Materials, Laminar Composites, Sandwich Composites

1. Introduction

An unmanned aerial vehicle (UAV) can be defined as a type of aircraft that is not controlled by a pilot, but uses aerodynamic forces with a lift so that it can fly autonomously or be remotely controlled, can be recovered or disposed of, and can carry payloads that can be tailored to the desired task and operation [1]. UAVs are increasing in use for both civilian and military use and are preferred because they are more cost-effective and more versatile. So in the last few decades UAVs have become very popular due to their versatility [6].

Currently, Unmanned Aerial Vehicles (UAVs), or in Indonesia known as unmanned aircraft (Drones) have high popularity so the development of good materials at a low price becomes a goal. Not only that but designing UAVs also requires engineers to design and produce on a large scale with limited time [3]. The development of UAVs in the aviation industry is to find materials or materials that have high speed. The advancement of UAVs is highly dependent on innovations in various technologies such as control systems, computer technology, and communication integration. Innovations in manufacturing techniques and materials are also important to develop and improve UAVs'performances by producing durable and lightweight structures. This can be achieved by applying innovative composite materials with high strength, ballistic and rigid properties. Advanced composite materials are made of fibrous materials embedded in a resin matrix, generally laminated with fibers oriented in alternating directions to form the strength and stiffness of the combined material [3].

Wing development for unmanned aerial vehicles (UAVs) is a multi-stage work such as airfoil selection, geometric calculation, structural design, material selection, numerical analysis, and manufacturing. The main objective in wing development is to design a structure characterized by high strength and low weight. The wing should have a high strength ratio and be supported by lightweight. There will be loads and moments acting on the wing so to overcome the stress due to these loads the wing must have high strength. The weight or weight of the wing must be low because the heavyweight will reduce unwanted efficiency in the engine [3].

With the development of material technology, it is easy to access and purchase composite materials. With the advancement of composite manufacturing technology, to make even complex shaped parts can be made easily in a few days. The use of UAV composite materials is different from that of general aviation vehicles, where most of the structures are made of aluminum and titanium in addition to carbon fiber composites. Whereas almost all UAV structures are made of carbon fiber composites [2], it becomes possible to manufacture a UAV in a laboratory or workshop for 4 or 5 people in a few weeks.

In addition, maintenance and repair of UAVs can also be done quickly and easily because they are assembled from small, cheap, and easy-to-manufacture composite components. Composite materials offer an excellent strength-to-weight ratio with greater manufacturability of complex parts, unique contours, and special features, especially in aircraft applications. One of the basic aircraft components of concern in the application of composite material structures is the wing profile [6].

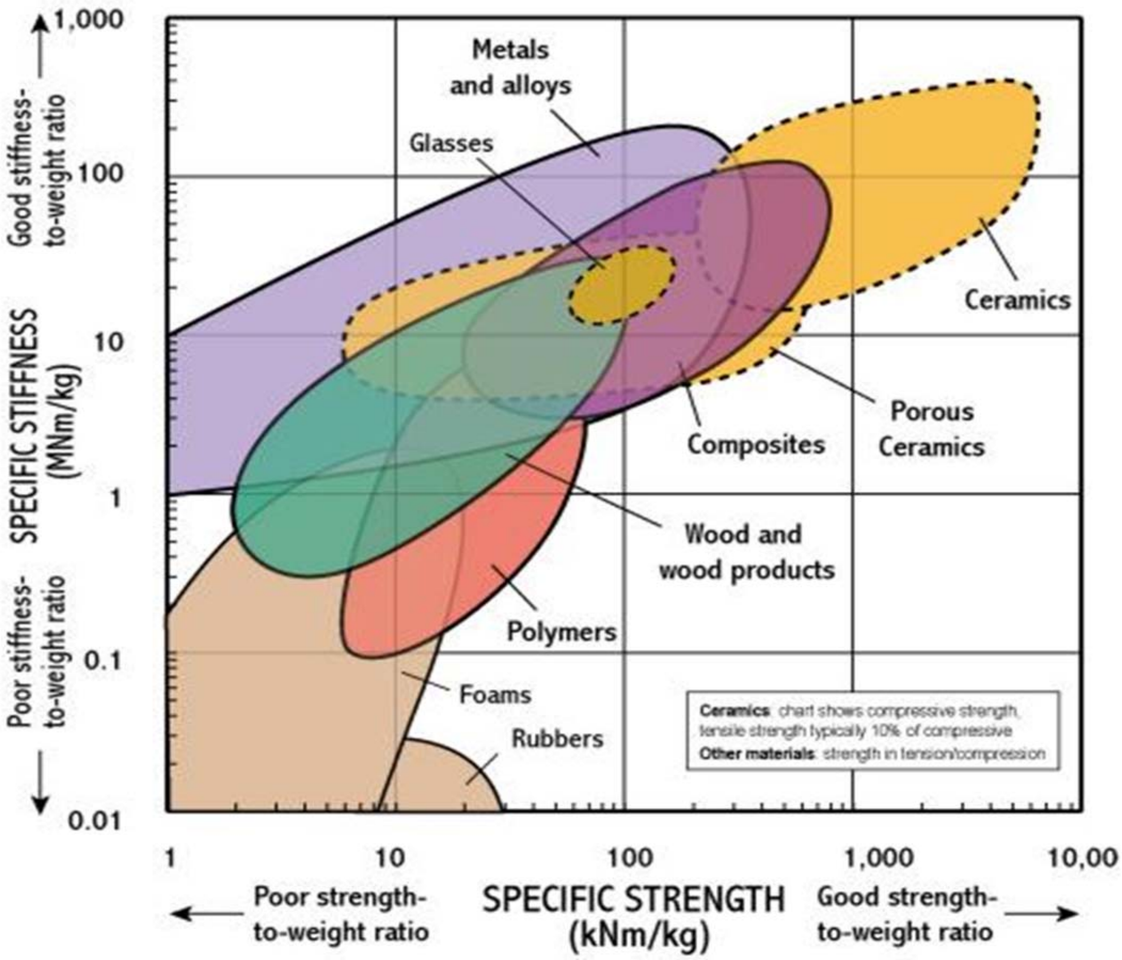

Figure 1. Comparison of stiffness and strength with a weight between composite materials [4]

In the selection of composite materials for UAVs that have high criteria, it means that the selected material must have resistant strength and be lightweight. For example, polymer matrix composites reinforced with continuous fibers are a good choice. These materials are characterized by Young's Modulus values twice as high as those of aluminum alloys and twice as lightweight [5]. The difficulty of using composite materials lies in the structure, the use of composite materials requires knowledge of material constants and mechanical properties. Correctly defining the characteristics of the composite material will guarantee that the material can be a good structure and have the desired reliability of results. The use of composites in aircraft is increasing day by day, especially in military aircraft. Composite materials have the advantages of high strength and lightweight which are very well applied to complex parts, unique contours, and special features, especially as aircraft materials. One aircraft component that is very suitable for using composite materials is the wing profile. Therefore, this paper raises the issue of the use of composite materials in unmanned aerial vehicles (UAVs), especially on the wings. This paper is a theoretical study that aims to increase the knowledge of authors and readers in material engineering technology and its application in the military.

2. Research method

This research uses a qualitative method with a literature review approach. The discussion or analysis is carried out based on the works of research results related to the topic and the results of thoughts that have been produced by researchers and practitioners. The literature review is one of the techniques that can be used in research. A literature review has its own difficulties when compared to other research techniques. As it requires a high understanding of the researchers in conducting a study of a problem to be solved related to the theory to be used, and the model or method to be carried out. The stages in this literature review research are as follows.

a. Finding and determining relevant literature, this activity requires high focus and shrewdness in finding data sources, especially secondary data. Journals, articles, and books are the main sources in this research, the more sources used, the better the results obtained.

b. Conducting literature screening, at this second stage, the researcher must be able to filter the selection of sources that have been obtained to be used in problem-solving. Of the many sources obtained, they are evaluated to adjust to the objectives of the research to be achieved.

c. Strengthening the topic with the sources that have been obtained, at this stage, this is the level of difficulty in the literature review because it must be able to strengthen existing theories with sources and discuss gaps in the form of advantages or disadvantages of each source.

d. Conclude based on the outcome of the discussion so as to reach a solution to the problem raised.

3. Results and discussion

The definition of composite material is a material consisting of two or more phases with significantly different properties (physical and chemical). Combined together to form a new material with different characteristics from its components. The resulting composite material properties are beneficial properties that cannot be achieved with one phase/component alone. And what is unique is that each component remains separate in the finished structure [3]. One of the most common examples of composites is fiber-reinforced composite materials that consist of high-strength and modulus fibers in a matrix material. Reinforced steel bars embedded in concrete provide an example of fiber-reinforced composites. In a composite, the function of the fiber is to carry the load exerted on the composite structure and provide stiffness, strength, thermal stability, and other structural properties. While the matrix material serves as a component that binds the fibers together, transfers fiber loads, and provides protection to reinforce the fibers against chemical attack, mechanical damage, and other environmental effects such as moisture and others [6].

The composite industry has grown rapidly with the advent of better plastic resins and good reinforcing fibers. As DuPont developed the aramid fiber known as Kevlar, it has become a standard in armor due to its high ductility. In addition, carbon fibers were also developed so since this time composites have become a substitute for metals as a new material. At present, of course, the composite industry continues and is still growing, its growth as a metal replacement material as an aircraft material, especially in unmanned aircraft [7]. Composites have unique advantages over other monolithic materials such as high strength properties, high stiffness, durable life, low density, and adaptability to the structure being created. In addition, recent composite materials are exploring improvements such as corrosion resistance, wear resistance, appearance, temperature-dependent properties, thermal stability, thermal insulation, thermal conductivity, and acoustic insulation. The basis that makes composite materials have superior structural performance lies in the high specific strength (strength to density ratio) and high specific stiffness (modulus to density ratio) and the anisotropic and heterogeneous character of the material. The anisotropic and heterogeneous character also provides the freedom to design structures with optimal configurations to obtain certain functions [8].

Composite materials can be classified into several types, namely [9]:

a. First classification, based on matrix constituents. Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs), and Ceramic Matrix Composites (CMCs). The term organic matrix composites are generally assumed to cover two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.

b. The second classification refers to reinforcement. Fiber reinforced composites, laminar composites, and Particulate Composites.

c. Fiber Reinforced Composites, are composites in which fibers as reinforcement are embedded in the matrix material. These composites are called discontinuous fiber composites or short fiber composites with properties that vary depending on the length of the fiber.

d. Laminar Composites, composites consisting of material held together by a matrix. Sandwich structures fall under this category.

e. Particulate Composites, composites consisting of particles distributed or embedded in the matrix body. The particles are in the form of flakes or powders. Article board, concrete, and wood are examples.

In its application as a leading material in UAVs, especially wings, ceramic materials used are various as described above.

Based on research conducted by Lamaini et al., [10] the sandwich structure made consists of Balsa wood, fiberglass, polyester resin, and microparticles used to close the pores of the Balsa wood surface. The results of the mechanical properties analysis of the UAV wing structure can be seen in that the sandwich structure can be used in UAV applications. The developed UAV wing weighs 800 grams, 20 mm camber thickness with a length of 20 mm and a span of 70 mm. Tensile, compressive, and flexural tests have been carried out on the sandwich structure. The results of the average tensile and compressive properties of the composite can compete with existing composite materials. The lay-up method can cost production and can also be used in large-scale production. So it can be concluded that Balsa wood-based sandwich composites can be used as UAV wing structures.

All main components in the aircraft are made of CFRP (Carbon Fibre Reinforced Polymer) composite material consisting of woven and uniaxial prepreg fabrics. Uniaxial prepreg fabrics aim to ensure volume consistency and will provide a smooth overlap. A low-cost manufacturing process can be achieved by reducing the number of parts and a fabrication process that does not require costly autoclaving. The characteristics obtained from the test results of the UAV wing structure with composite materials are the shaker-table approach to simulate the wing on the UAV. The shaker-table method produces a signal of greater magnitude with less noise when compared to data obtained from a full aircraft configuration [11].

Table 1 shows previous research on material utilization for UAV wings, with authors, titles, methods and type of composite materials given.

Table 1. Previous research on material utilization for UAV wings

Author (year)	**Title**	**Methods**	**Composite Material**
Lamani, Shivaji., Stanvil Dsouza, Dane Hubert Saldanha, Granvil Dsouza and Madhurima R Londhe. (2020) [10]	Analysis, Fabrication and Testing of a Sandwich Composite for an UAV Wing	Hand lay-up technique	Sandwich Composite (fiber-glass and polyester resin and microparticles)
J. Simsiriwong & R. Warsi Sullivan. (2012) [11]	Experimental Vibration Analysis of a Composite UAV Wing	The form of woven and uniaxial prepreg fabrics	Carbon-fiber reinforced polymer (CFRP) composite
Basri, E. I., Sultan, M. T. H., M., F., Basri, A. A., Abas, M. F., Majid, M. S. A., Ahmad, K. A. (2019) [12]	Performance analysis of composite ply orientation in aeronautical application of unmanned aerial vehicle (UAV) NACA4415 wing	Ply combinations	Carbon Fiber Reinforced Polymer (CFRP) laminated composite
Grodzki, W., & Łukaszewicz, A. (2015) [3]	Design and manufacture of unmanned aerial vehicles (UAV) wing structure using composite materials.	-	Polymer matrix composites reinforced with continues fibers, Polymer matrix composites (Laminates and sandwich structures)
Tah'ir Turgut (2007) [6]	Manufacturing And Structural Analysis Of a Lightweight Sandwich Composite UAV Wing	Vacuum Bagging Method with curing at room temperature	Laminated composite and sandwich structure (E-glass/Epoxy, Kevlar/Epoxy, Carbon/Epoxy)
Sasi Kirono (2015) [13]	Mechanical Properties of Unmanned Aircraft Composite Materials	A comparison of the mechanical properties of composite materials is carried out by tensile strength testing.	Front Fuselage Components Upper skin with three layers of carbon fiber, honeycomb, and glass fiber
Vasić, Zoran, Stevan Maksimović, and Dragutin Georgijević (2018) [15]	Applied Integrated Design in Composite UAV Development	Pyrolysis of an organic precursor such as rayon or Poly-acrylonitrile, or petroleum pitch	Graphite fibers, glass, carbon and graphite, Kevlar, boron and Carbon fibers

According to research conducted by Basri et al., [12], the ACP (ANSYS Composite Preppost) module is used to apply composite materials with various thicknesses and angles. Which is applied to wing skins, spars, and ribs. Laminate Composite is prepared according to the Classical Laminate Theory (CLT) to investigate the behavior of composite sandwich structures subjected to internal influences from applied loads. In ANSYS, the model of a wing structure is interpreted in the form of shell elements (lamina). The effect of ply orientation on the NACA 4415 UAV wing composite laminate was evaluated. Analytical predictions show that the stress state developed in the variation of fiber orientation with ply-angle has a significant influence on the strength. Finite element analysis studies show the total displacement values obtained are within the acceptable range.

Unmanned aerial vehicle (UAV) wings according to their purpose vary in airfoil shape, thickness, chord dimension, span, surface area, and geometry. Despite the differences, the design concept is similar to all types of structures. Due to the high requirements of modern UAV (high-strength-low-weight) composite materials, especially polymer matrix composites reinforced with continuous fibers are the most appropriate choice. To transfer such loads, composite structures have been designed. The first proposed structure is a laminated composite consisting of glass cloth (outer) and unidirectional carbon cloth (inner) reinforced with balsa wood ribs for proper shape. The construction made is a type of sandwich structure, since the upper and lower layers of fabric are separated with balsa wood ribs. The second analysis structure is characterized by an additional foam core separating the glass-carbon fabric layers.

Numerical analysis of composite structures based on the same boundary conditions showed that the sandwich structure is characterized by the deflection of the foam core layer under the load of 11.34 mm - 3 times smaller than the carbon fiber laminate deflecting 32.16 mm considering the same weight. Lightweight composite structures based on carbon, glass fibers produced by the vacuum bag technique minimize the creation of voids (bubbles and wrinkles) and allow to obtain of high fiber content which translates into higher strength of the created structures [3]. According to research by Vasić et al [15] composites with graphite fiber materials are the strongest and stiffest materials widely used in unmanned aircraft structural systems. Placing fibers in graphite composites, it will increase the strength and stiffness of the composite material.

Tensile testing of coupon specimens was conducted to obtain the modulus of elasticity of the composites used in the UAV. The elastic properties obtained from the mechanical tests were used in the elemental analysis of the UAV wing. The woven fabric was modeled as a 2-D orthotropic layer in the analysis. In addition to mechanical testing, elastic properties were also obtained by two other methods. One method is the composite micromechanics approach. In this approach, the properties are obtained based on the volume fraction of the constituents and their respective mechanical properties. The woven fabric is modeled as a biaxial cross-ply laminate in the analysis. Another method used to derive elastic properties is the approximate approach. This approach is based solely on the rule of mixtures. In this case, the woven fabric is also modeled as a 2-D orthotropic layer. It can be concluded from the results of the full-wing analysis that the three material definitions used to give consistent and acceptable results. Moreover, if the displacement results are observed, it is clear that they are almost the same [10].

Research has been conducted by Galatas et al [16] using the latest sandwich composite structure consisting of acrylonitrile butadiene styrenecarbon (ABS) laminated with carbon fiber reinforced polymer (CFRP) layer with ABS/CFRP/ABS arrangement. A series of tests were conducted with tensile measurements for 3D printed samples with varying filler densities and CFRP layers. The results showed that the ABS/CFRP/ABS sandwich structure during the tensile tests exhibited brittle properties while it was ductile for the monolithic ABS samples.

4. Conclusions

Laminar Composites type composite material with sandwich structure is the latest composite material and is widely applied as a UAV wing structure. Laminar composites and sandwiches consisting of various materials such as Balsa wood fiberglass and polyester resin, microparticles, Carbon Fiber Reinforced Polymer, polymer matrix composites reinforced with continuing fibers, Polymer matrix composites, E-glass/Epoxy, Kevlar/Epoxy, Carbon/Epoxy, woven fabrics, acrylonitrile butadiene styrenecarbon (ABS) laminated with carbon fiber reinforced polymer (CFRP)and uniaxial prepreg fabrics. This laminar-type composite material with a sandwich structure has good test values and can be used as a UAV wing structure material.

Declaration of competing interest

The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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