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Comparison of Materials for Unmanned Aerial Vehicle

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Abstract: This paper emphasis and gives detailed study about the comparison between the materials used in structuring the Unmanned Aerial Vehicle. The requirements of these materials on Unmanned Aerial Vehicle are with respect to their physical and mechanical properties. The paper shows us the theoretical approach to the result by comparing the properties like, strength to weight ratio, ease of shape ability, low corrosion, less inflammable, endurance limit, low thermal gradient, and high performance. In order to satisfy these requirements, the materials compared in this paper are metal alloys like Aluminium alloys, Steel alloys and Titanium alloys with composite such as Carbon Fiber, and Glass Fiber.

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1. Introduction

The recent improvement in Unmanned Aerial Vehicle (UAVs) technology has remoulded industries such as surveillance, agriculture, and logistics. UAVs are high innovative forms of target drone and remotely piloted vehicles used by the military of many countries in the decades after World War II. Nowadays UAVs are critical assets for the modern military. The first prototype of the machine was linked to the American Elmer Sperry, who created an aircraft that was fully controlled by autopilot the test flights were taken place around 1917 [1]. The redevelopment of systems, design and materials usage for the manufacture took place to make it more efficient. Wide variety of materials came into consideration for the building the structure precisely with accurate physical and mechanical properties. Metal alloys are extensively used in Aerospace industry because of its extremely light and can hold high load or high-stress conditions. Also, the composites are used for their exceptional lightweight and high strength properties. They can reduce the UAVs structure about 30-40% which can increase the endurance of the flight [2]. As you can see the UAV design reference taken in figure (Fig 1) below, exhibits the weight distribution throughout the structure. The detailed design of the UAV, usage of material and its weight distribution ensures the efficiency and performance of the structure. Selecting suitable materials for manufacturing UAVs is a concerning matter. Materials used for building UAVs are mostly metals like aluminium and titanium which are expensive and weighted materials compared to composites. The usage of composite materials is expanding in industry due to their better mechanical properties, and quick availability in addition to the low cost compared to metal alloys [3,4]. The material can be investigated for designing UAV by the use of the method Dynamic Mechanical analysis. The Dynamic Mechanical analysis helps to determine the mechanical properties of the materials used like Elastic modulus for stiffness value, Energy dissipation and Damping [5].

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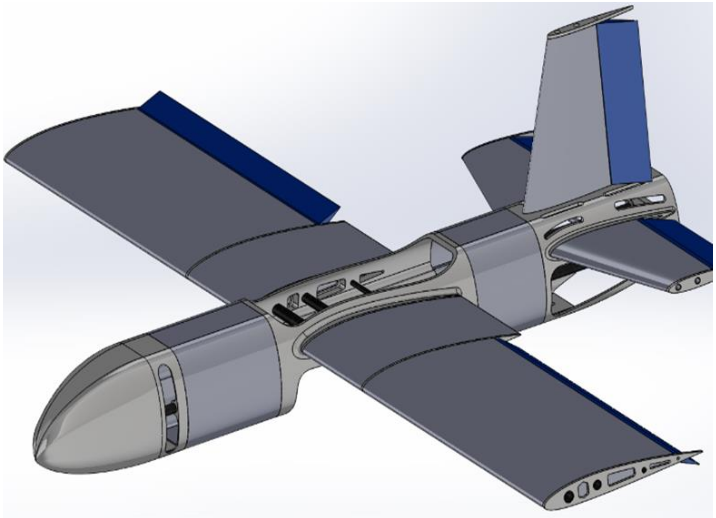

Figure-1 UAV Drone Cad Model [6]

2. Materials Selection

Metal Alloys

a. Aluminium Alloys

Alloys of Aluminium metal are very famous in the Aerospace Industry since the introduction of metal skinned aircraft. The alloys are lighter, have durability and high strength. Aluminium is paired with other elements like copper, manganese, magnesium, zinc and silicon to enhance the mechanical properties. One of the most used aluminium alloys is 7075 alloys for its high strength which contains zinc as the primary alloying element [7]. Used for the construction of the fuselage and wings. Another commonly used alloy is 2024 known for its outstanding fatigue resistance [8]. Alloys like 6061 and 6063 offer a better balance of strength, corrosion resistance, and efficiency.

Table-1 Types of Aluminum alloys and their strength

Alloys	Elements	Yield Strength (MPa)	Ultimate Strength (MPa)	Modulus Of Elasticity (GPa)
7068	ZINC	683.3	400.0	70.0
7075	ZINC	503.4	551.6	78.0
6061	MAGNESIUM	234.0	248.0	66.0
6063	MAGNESIUM	179.0	220.0	69.0
2024	COPPER	483.0	385.0	73.1
5052	CHROMIUM	211.6	257.8	64.2

b. Steel Alloys

Steel is not usually used as the key material for the UAVs structure like other materials such as aluminium, titanium and composites but steel alloys still play a critical role because of its strength, durability, cost effectiveness and corrosion resistance properties. Some of the steel alloys mostly used for manufacturing UAVs are:

- 301 (Austenitic Stainless Steel)- A lower cost alternative with nickel as the other element. This combination highlights the properties like formability and corrosion resistance which make it suitable for molding and trim [9].
- 410 (Martensitic and Ferritic Stainless steel)- These Chromium Stainless Steel alloys with different carbon levels influencing properties like high strength with good ductility and heat resisting [9].
- 13-8 (Precipitation Hardening Stainless Steel)- These alloys have properties like high strength, excellent fatigue properties and resistance to corrosion cracking [10-11].

Table-2 Types of Steel alloys and their strength

Alloys	Elements	Yield Strength (MPa)	Ultimate Strength (MPa)	Modulus Of Elasticity (GPa)
301	NICKEL	205.0	1965.0	212.0
410	CHROMIUM	1225.0	1525.0	200.0
13-8	CHROMIUM	1434.0	1551.0	203.0

c. Titanium Alloys

Titanium alloys are splendid choice for the manufacturing of Unmanned Aerial Vehicles due to their extraordinary properties, like strength-to-weight ratio, superior resistance to corrosion, temperature tolerance and resistance. Titanium alloys are comparatively having higher strength and higher temperature stability than aluminium and steel alloys only with half of its weight of most of the steels [12]. Some of the alloys used for the construction of the structure of the UAVs are:

- Ti-6Al-4V – Most widely used titanium alloy in the industry. This alloy has a good combination of mechanical properties with a wide temperature range for system working and can be highly weldable [13].
- Ti-54M – Titanium alloy shows superplastic forming properties than other titanium alloys which allows it to form into complex shapes.
- Ti-6-2-4-2 – This alloy is known for its good strength and its resistance towards oxidation at elevated temperatures which allows it for high temperature applications like the engine parts [14].

Table-3 Types of Titanium alloys and their strength

Alloys	Yield Strength (MPa)	Ultimate Strength (MPa)	Modulus Of Elasticity (GPa)
Ti-6Al-4V	880.0	950.0	114.0
Ti-54M	600.0	650.0	105.0
Ti-6-2-4-2	830.0	900.0	110.0

Composite Fibers

a. Carbon Fibers

Carbon Fibers has incredible properties making it ideal for the usage in UAV Engineering. Its combination with resin to form a composite, to make the structure light and rigid also known as Carbon Fiber Reinforced Polymer. Carbon Fibers are advanced materials which are composed of thin, strong crystalline filaments of carbon, woven together. One of the main advantages of Carbon Fiber composites is its high strength-to-weight ratio. The combination of Epoxy resin and woven type Carbon fiber is the most popularly used in industry. The Carbon fiber used in woven twill type HDC-522-3K, by the brand name AMP-07 [15]. These crucial properties mentioned in the table (Table 4) below for UAV manufacturing allow the structure to be light without compromising structural integrity. Lighter UAVs have less fuel consumption which leads to improved efficiency and longer flight times. Carbon Fiber composites also flaunt excellent corrosion resistance and withstand extreme temperatures [16]. Carbon Fiber can be molded into complex shapes with great flexibility in creating aerodynamic and efficient structures.

Table-4 Properties of Carbon Fiber

Sr.No	Properties	Values
1	Shear Strength	90MPa
2	Compressive Strength	570MPa
3	Density	1.6g/cm^3
4	Shear Modulus	5GPa
5	Tensile Strength	3000MPa-6000MPa
6	Modulus of Elasticity	70GPa

b. Glass Fibers

Glass Fibers play an important role in the manufacturing of UAVs because of their impressive properties. The main advantage of selecting Glass Fiber composite as the material for manufacturing UAVs is their excellent strength-to-weight ratio. UAVs can achieve higher altitudes and longer flight duration due to the lightweight nature of the glass fibre which influences its application in surveillance services [17,18]. Glass Fiber shows a high resistance to wear and corrosion which ensures the longevity and performance of the UAVs. Because of these properties it reduces maintenance costs and extends the machine life. Thermal insulation is another beneficial property of Glass Fiber which allows the UAVs structure to withstand extreme temperature conditions without any damage to the sensitive components of the UAV. In the manufacturing of UAVs, the type of Glass Fiber mostly used is E-Glass (Electrical glass) [19,20]. E-Glass is usually composed of silica-based glass with boron oxide and alumina which gives an extraordinary combination of mechanical properties displayed in (Table 5) below.

Table-5 Properties of Glass Fiber (E-Glass)

Sr.No	Properties	Values
1	Shear Strength	27MPa
2	Compressive Strength	90.380MPa

3	Density	2.6g/cm^3
4	Shear Modulus	30.32GPa
5	Tensile Strength	2000MPa-5000MPa
6	Modulus of Elasticity	72GPa

3. Method Approach

Storage Modules

The storage modulus is to measure the stored energy in a material during deformation and shows the elastic behavior of the material. A high storage modulus depicts material stiffness and will be able to maintain its shape under stress.

For Tensile or Compressive deformation.

$$E= \frac{\sigma 0}{\varepsilon 0} \cos\delta \tag{1}$$

Where,
σ_0 is the stress amplitude.
ε_0 is the strain amplitude.
δ is the phase angle between stress and strain.

Damping Parameter

The Damping Parameter represented as “tan δ” measures the energy dissipation in the material. It shows the ratio of energy loss in the form of heat to the energy stored in the material during the cycle of deformation. As UAVs are exposed to various vibrations during flights caused by aerodynamic forces, engine operations or external disturbances, a material with good damping properties can take in these vibrations, reducing the stress on the UAVs structure.

Formula

$$\tan \delta = \frac{E\prime}{E} \tag{2}$$

Where,
E’ is the loss modulus
E is the storage modulus

Strength to Weight Ratio

The strength-to-weight ratio is also called specific strength, measures the material’s strength relative to its weight. It plays an important parameter in material selection, taking weight is in consideration. It is the ratio of material’s strength to its density. As strength-to-weight ratio is an important factor for the selection of material. A high strength-to-weight ratio of a material shows how capable the material is of handling more stress without adding more weight and can take impacts without compromising structural integrity.

Formula

$$\text{Strength-to weight ratio} = \frac{Strength}{Density}$$

$$\sigma_s = \frac{\sigma t}{\rho} \tag{3}$$

4. Results in Focus: Discussion and Implications

As we can see the materials taken into consideration for the selection of materials for UAVs manufacturing have many different and similar mechanical properties. Considering the similar mechanical properties, we can get some outcome such as the strength-to-weight ratio. While comparing the strength of the above-mentioned materials it became clear that the composite materials like carbon fiber and glass fiber outperform the metal alloys in the figure (Fig 2) shown below.

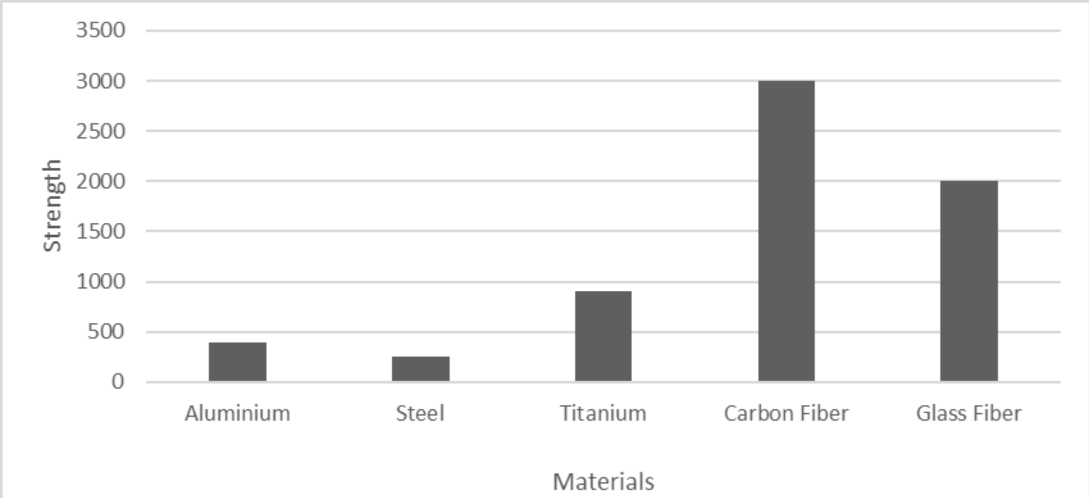

Figure-2 Graph representing the strength of the Materials

Tensile Strength of the Materials

- Aluminium Alloys: 200 to 400 MPa.
- Steel Alloys: 250 to 2000 MPa.
- Titanium Alloys: 600 to 900 MPa.
- Carbon Fiber: 3000 to 6000 MPa.
- Glass Fiber: 2000 to 5000 MPa.

The theoretical approach to the result for the strength of the materials clearly shows how much strength 1000 grams of each material have. Carbon Fiber shows incredible strength properties than other materials. This detailed comparison shows the importance of choosing material based on their properties and performance. Each Materials have their own strengths and limitations.

5. Conclusion And Future Scope

The material selection of UAVs structure is a critical decision that influences the UAVs performance, efficiency and durability. Metal alloys and Composite Fibers are the most widely used materials with their own set of advantages and disadvantages. Metal alloys is known for their machinability, cost-effectiveness and strength to weight ratio its types like 6061 aluminium alloy and Ti-54M Titanium alloy are widely used frames and propellers. However, Metal alloys are heavier than Composites fiber which is also highly resistant to corrosion and can go through extreme temperatures. The future scope from here is to explore suitable material and do experiments according to the needs to get desirable results. Additionally, measurement of coefficient of lift, drag and pressure to check the durability of materials during flying conditions and other parameters such as density, effects on velocity and efficiency of the material in terms of experiment.

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7. Conflict of Interest

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