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Use of KEVLAR ® 49 in Aircraft Components

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Abstract

Aircraft industry is also finding its way to adapt on the increasing demand not only considering aircraft safety and customer requirements, but also on the increasing legislative requirements in terms of resource efficiency and gas emissions. This document explores Kevlar 49's application on aircraft components and why this material is specifically selected for such applications above any other Kevlar type of materials. Its functions, properties, advantages and disadvantages are discussed together with some alternative materials in lieu of Kevlar 49. In order to provide credible information, literature search was conducted using significant keywords in Google Scholar and journal repository Deepdyve. Kevalr ® 49 is considered an exceptional material for reinforcement to produce aircraft components. It has high tensile strength, lightweight, inert on some conditions, stiff, and resilient. However, Kevlar's has poor compressive strength, workability and is overly stiff for some applications. Another disadvantage is its cost, though it was shown to belong to a middle ranged material relative to carbon fiber and Boron. But overall, there are extensive applications in aircraft components that are now continuously using this material as reinforcement with other materials like carbon and boron to arrive on an ideal blend of product.

Keywords: aircraft industry, customer requirements, Kevlar 49, resource efficiency

1. Introduction

Not only in automotive industry, aircraft commerce is also finding its way to adapt on the increasing demand not only considering aircraft safety and customer requirements, but also on the increasing legislative requirements in terms of resource efficiency and gas emissions. In this context, Lightweighting in aircraft industry is also the emerging direction leading researchers to focus on its strategic material selection mostly for weight reduction leading to lesser fuel consumption and greenhouse gas emissions. This strategy dwells on the principle that light materials require lesser energy to accelerate resulting to higher potential for increasing fuel efficiency (US Department of Energy, 2015).

Kevlar is a material belonging to the advanced composites making up an estimate of fifty per cent of an airplanes structure like the Boeing 787. USA's Department of Defense (2002) stipulates the ideal properties of aramid fibers: "low density, high tensile strength, high tensile stiffness, low compressive properties (nonlinear), and exceptional toughness characteristics". Therefore, aircraft industries are identifying as much applications or combine it with other materials to achieve a more desirable blend.

This document will explore Kevlar 49's application on aircraft components and why this material is specifically selected for such applications above any other Kevlar type of materials. Its functions, properties, advantages and disadvantages will be discussed together with some alternative materials in lieu of Kevlar 49.

2. Review of Related Literature

Versatility is what makes Kevlar® fiber as one of the chosen advance composite materials for aircrafts. But other than consideration on the properties of the material, the mother legislation followed by aircraft industry tends to keep the selection process confined in some guidelines. Examples are FAR 25.613 (Material Strength Properties), FAR 25.615 (Design Properties), FAA AC 20-107A, JAR 25.613/25.615/25.603, and many more. The selection process is therefore critical and complex considering not only the design and properties needed to be met but also the compliance on these requirements.

In mid-1960's, desired properties like tenacity and modulus levels from renowned fibers like nylon and polyester were not achieved due to the complexity of the process producing products with such characteristics (Dupont, n.d). Dupont (n.d) detailed the discovery of Kevlar as scientist Du Pont "discovered a new method of producing an almost perfect polymer chain extension. The polymer poly-b-bensamide was found to form liquid crystalline solutions due to the simple repetitiveness of its molecular backbone". Consecutive reconfiguration of molecular structures eventually leads to the birth of Kevlar. The figure below shows the polymeric structures of aramid fibers.

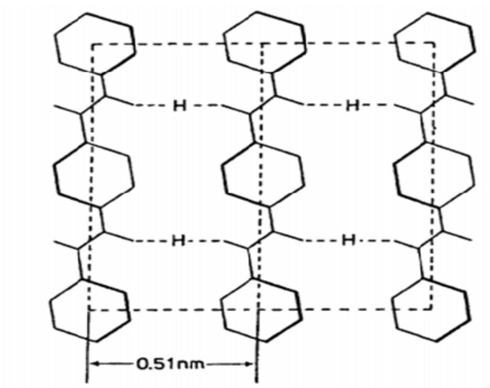

Figure 1. Polymeric structures of aramid fibers (Baker, Dutton, & Kelly, 2004)

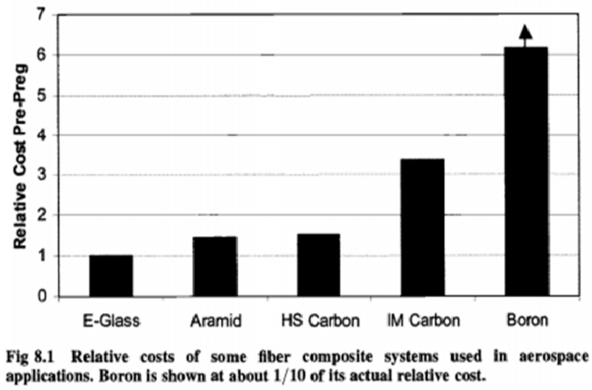

Figure 2. Aramid's relative cost compared to other composite materials (Baker, Dutton, & Kelly, 2004). Note: Cost for Boron presented is 1/10 of its actual cost

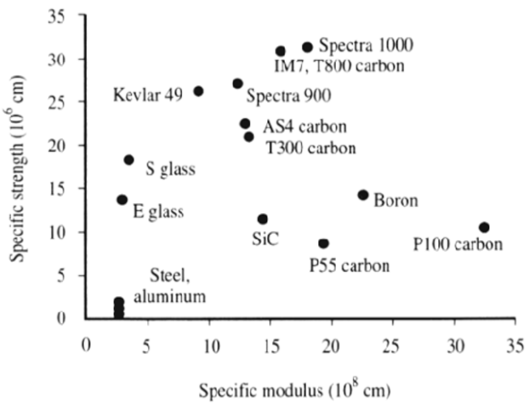

Figure 3. Strength/Specific Modulus of material components of aircraft (Cairns, 2010)

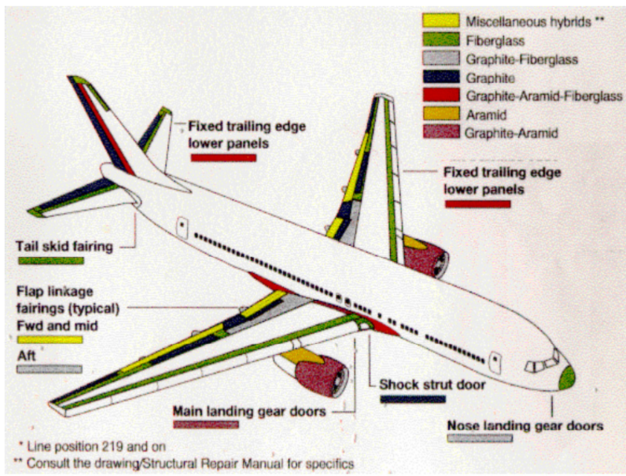

Figure 4. Aircraft Components and Materials (Cairn, 2010)

Kevlar are aromatic polyamides, belongs to the family of nylon and is actually a thermoplastic with degradation temperature lower than its glass transition temperature (Campbell, 2004). The starting point in the process of producing Kevlar is the formation of aramid or the polyparaphenylene terephthalamide by reacting paraphenylene diamine and terephthaloyl chloride in an organic solvent followed by mechanical process of extrusion, stretching, and drawing (Campbell, 2004). The polymer is then washed and sulfuric acid is used to dissolve the resulting aramid with the solution extruded in spinnerets or small holes for orientation of fiber before wounding it up (Campbell, 2004).

When weight savings and determined properties are critical coupled with cost consideration just like in the production of aircraft components etc., Kevlar composite is a choice. The Figure below shows the relative cost of Aramid Fiber including Kevlar 49 as compared to other composite materials of choice. It is explicitly shown that Aramid fiber cost is considered to be middle ranged compared to Carbon and Boron.

For example, Yeung and Rao (2014) have known that "Boron-polyester composite (with Kevlar 49) provides the best performance in terms of cost per unit tensile properties whereas Boron-polyimide composite (with Kevlar 49) provides the best performance in terms of cost per unit compressive and flexural properties. Another example is the wing-to-body fairing panels of Lockhead L-1011 aircraft which showed excellent performance after five years of flight as audited by flight service evaluation plus with a weight reduction of 363 kg per aircraft relative to its counterpart alternatives like aluminum and fiberglass composite structures (Watts 1980).

The figure below shows the position of Kevlar 49 in terms of its specific strength relative to specific modulus of all aircraft materials compared to other materials used.

It is shown that although Kevlar 49 is not on the extreme side of the x axis which is the specific modulus aspect, Kevlar 49 provides a balance between specific strength and this specific modulus. This balance is critically deliberated in parallel with the cost to be entailed, safety, and other considerations.

3. Recommendation

Kevlar is an aramid fiber primary utilized as reinforcement for polymeric organic matrix composites aircraft components, electrical applications, and may other manufactured materials (Langston, 1985). As early in the 80's, Kevlar fiber particularly Kevlar 49 had already been a standout in any applications as Langston (1985) described it as "a material with an outstanding combination of high strength and high modulus per unit weight. It is also inherently flame resistant, does not melt and has a high useful temperature range". The table below shows the basic properties of Kevlar 49 showing high tensile strength which was the basis of the statement that this material is five times stronger than steel. Additionally, Kevlar 49 is lightweight at 1.44 g/cm^3 density therefore the material strength/weight ratio is high. Department of Defense (2002) added that this "density is 40% lower than glass and 20% lower than commonly used carbon". In addition, it is also impact and abrasion resistant plus it does not expand when heated.

Table 1. Kevlar 49 Material Properties (Matweb, 2015)

Mechanical Properities	Metric
Tensile Strength, Ultimate	3000 MPa
	3620 MPa
Elongation at Break	2.4%
Tensile Modulus	112 GPa
Tenacity	2.08 N/tex
Poissons Ratio	0.36
Thermal Properities	Metric
Specific Heat Capacity	1.42 J/g °C
	@ Temperature 25.0 °C
Thermal Conductivity	0.0400 W/m-K
Maximum Service Temperature, Air	149-177 °C
Shrinkage	<= 0.100%

These properties led Kevlar 49 to be a material choice not only in aircrafts but also in aerospace industry like air ducting, launch tube reinforcement etc. The table below was adapted from the book of Langston and though the year of the book's publication was 1985, the application still holds true nowadays with some added applications like composite landing gear doors, wing flaps, consoles, access doors and lightweight radome (Watts, 1980). The integration of Kevlar 49 can reduce an approximate mass decrease of 20-35 per cent and eventually translates to some advantages like increased payload and fuel efficiency (Watts, 1980).

Table 2. Sample application of kevlar 49 in aircrafts and aerospace industry (Langston, 1985)

Aircraft: Exterior
Wing-to-body fairings
Landing gear doors
Leading and trailing edges of wings and control pancls
Access panels
Radomes
Engine nacelles, cowlings, and pylons
Helicapter blades
Propellers
Aircraft: Interior
Window reveals
Overhead and side panels
Cargo liner panels
Floors
Partitions, lavatories, galleys, and bulkheads
Pressure bottles for escape slides
Air ducting
Passenger seat pedestals
Misslles and Space
Filament-wound rocket engine cases
Pressure bottles
Air ducting

Watts (1980) added that this material can be "combined with graphite or glass in hybrid composites to achieve a more desirable blend of composite properties than when used as the sole reinforcement". Other potential candidate materials aside from Kevlar are fiberglass and carbon fiber material. The figure below shows these three materials and their physical attributes:

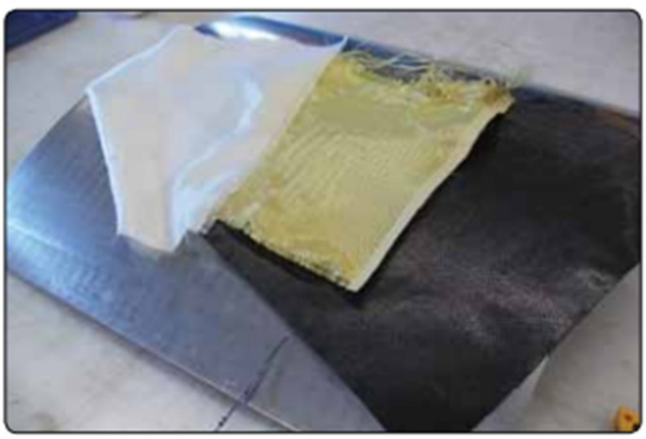

Figure 7-7. *Fiberglass (left), Kevlar® (middle), and carbon fiber material (right).*

Figure 5. (Chapter 7: Advance Composite Materials, n.d.)

Other advantage of this material is its inert nature when exposed to arctic and cryogenic conditions and shows no embrittlement or any decomposition or degradation during such exposure (Department of Defense, 2002).

Though tensile strength of this material is highly impressive, there are still drawbacks that pose constraints in its universality. The main disadvantages lie on its non-compressible and hygroscopic nature, workability especially in drilling and cutting, too stiff for some applications, relatively costly, and instability over a period of time especially at elevated temperatures (Chapter 7: Advance Composite Materials, n.d.; Department of Defense, 2002). Poor compression strength as aramid fiber becomes unstable during this condition after undergoing linear deformation at strain levels of around 0.5 per cent (Baker, Dutton, & Kelly, 2004). In terms of hygroscopy, reports indicated an absorption percentage of eight per cent (weight in water) for Kevlar materials making it sensitive to any moist environment. In addition, the difficulty of working with Kevlar in general also poses a disadvantage as fibers fray during the cutting process and this may mean increased wear and tear of cutting tools (Chapter 7: Advance Composite Materials, n.d.). Another thing, this material is unstable and degrades at certain acidic, basic, and hypochlorite conditions over a long period of time or when exposed to higher temperatures (Department of Defense, 2002). Lastly, when this material is burned, $CO2$ and NO are emitted with some toxic gases produced at a minute amount depending on the burning conditions (Dupont, n.d.).

4. Conclusion

Kevlar fiber particularly Kevlar 49 had already been a standout in any applications since its birth in the mid 1960's and had established its capability in the 1980's. Langston (1985) described it as a material with an outstanding combination of high strength and high modulus per unit weight. Currently, developments are paving its way on the maximum utilization of Kevlar's properties not only in aircraft industry. It is one of the promising composite materials making up 50 per cent of some aircraft man had manufactured like the Boeing 787. However, there is a significant point for development on Kevlar's properties especially its poor compressive strength, workability and overly stiffed characteristic. Another disadvantage is its cost, though it was shown to belong to the middle ranged material in terms of this aspect, cost is still a significant factor especially if the consideration boils down to this sole aspect and the other possible alternative costs lower.

But regardless, there are some applications in aircraft components that are now continuously using this material as reinforcement with other materials like carbon and boron to arrive on an ideal blend of product. The material is still superb in terms of strength and lightweighting capability, five times stronger than steel and can reduce up to 40% of weight on aircrafts if some materials like aluminum are replaced instead.

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