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Future of New Generation Aluminium and Composites in Aerospace Industry

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ABSTRACT
In this article a performance comparison between two aerospace grade materials, the aluminium and the composite, has been presented. Since the evolution of aerospace industry, the aluminium metal has remained a first choice to aircraft material designers. During the first decade of this century, the composites materials have achieved a greater attention in aerospace industry. A number of fascinating characteristics of composites i.e. good appearance, light weight, better corrosion resistance and high strength properties made their way onto the modern aircraft as an alternative material to aluminium. However, the advancements in aluminium alloys especially the lithium containing aluminium alloys, which are even better and lighter than traditional aluminium, made the choice difficult for aircraft manufacturers. This study showed that aerospace industry is in a transition phase and hanging in-between the metals and the composite materials. Both types of materials have their own inherent unique characteristics, but a few advantages over each other.

Keywords: Aluminium lithium alloys, composites, mechanical properties, aerospace industry, advantages, new generation AlLi.

1. INTRODUCTION
Materials are deployed in the construction of an aircraft or any other application according to their performance requirements during the service life of that component/part. Every material has its unique properties which directly affect the performance and total life of that part including recycling options. Broadly speaking we usually are interested in physical properties, chemical properties and mechanical properties of aerospace materials. In some applications electrical, magnetic and optical properties are also considered as a design part. Among the unique characteristics of aerospace grade materials, mechanical properties are most important and play a decisive role while selecting a material[1-4]. Aircraft designers principally consider properties like weight, strength, toughness, ductility, hardness, elasticity, fatigue resistance, creep resistance, and corrosion resistance[4]. During the production and processing of aerospace materials, the above mentioned properties are controlled according to the demand and area of application[5]. For example during the thermo mechanical processing of aluminium alloys the mechanical properties of these alloys could be enhanced many times by using suitable heat treatment methods. Similarly by altering the chemical composition, as in new emerging aluminium lithium (AlLi) alloys, a small addition of Li metal greatly enhances the alloy properties[6-9].
When designing a new material in aircraft industry, one has to consider multiple factors and these are;

a) Raw material's availability and cost,
b) Required skills and processing technology,
c) Finished component rejection rates and waste recycling,
d) Unknown risks while deciding application area,
e) Uncertainties in performance,
f) Damage tolerance, maintenance frequency & replacement procedures, and
g) Other factors i.e. improvement in profitability and margins.

In this study we would mainly emphasize on the aluminium and composites, two most widely used materials in aerospace industry.

2. MATERIAL BATTLE IN AEROSPACE INDUSTRY
Historically aluminium alloys have dominated during the last century in aerospace industry due to their good strength, low weight, good wear and corrosion resistance and low manufacturing costs[10-11]. Because of the weight to strength ratio of aluminium, it was preferred over steel, titanium, wood and other aerospace grade materials[7-12]. Some of the key characteristics of various aerospace grade materials have been compared in Fig.1. It is evident from this comparison that aluminium has lower density and higher strength than the steel, titanium and magnesium alloys.

Aluminium and its alloys offer a set of properties on affordable prices along with ease in handling to aircraft manufacturers. However, during the last quarter of the 19th century composite materials were appeared aggressively in aerospace industry and looked threatening to the future of aluminium, especially with the introduction of carbon fiber[13-14]. Carbon fiber composites have made tremendous inroad towards commercial aircraft, primarily due to their light weight, high strength and excellent corrosion resistance properties[15-16]. The comparison in Fig.1 shows that, composites are the lightest materials having high strength. The characteristics of various advanced composites have been compared with high strength aluminium in Fig. 2. This comparison suggests that, composites offer high strength

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and great reduction in structural weight to aircraft manufacturers. Though, despite of their fascinating properties, the composite materials are facing many difficulties in their outspread as a structural material for modern aircraft. Recently conducted studies[17-20] have exposed a serious concern about the service life of the composites, and some other factors like higher manufacturing costs and the requirements of dedicated processing technology is a big reason in their slow growth. At the same time, advancement and improvements[21-23] in the new generation AlLi alloys have shifted the balance again towards the aluminium alloys.

The new AlLi alloys are significantly lighter[24] than the traditional aluminum, have considerably improved corrosion resistance, and are lower in cost than composite materials. The structures made of new generation AlLi alloys would provide 10 percent weight savings comparative to composites, thus seesaw battle will shift again in favor of aluminium alloys. One of the major benefits of AlLi is their high corrosion resistance and damage tolerance[21-25], so the time between major overhauls of airplanes would increase from eight to 12 years.

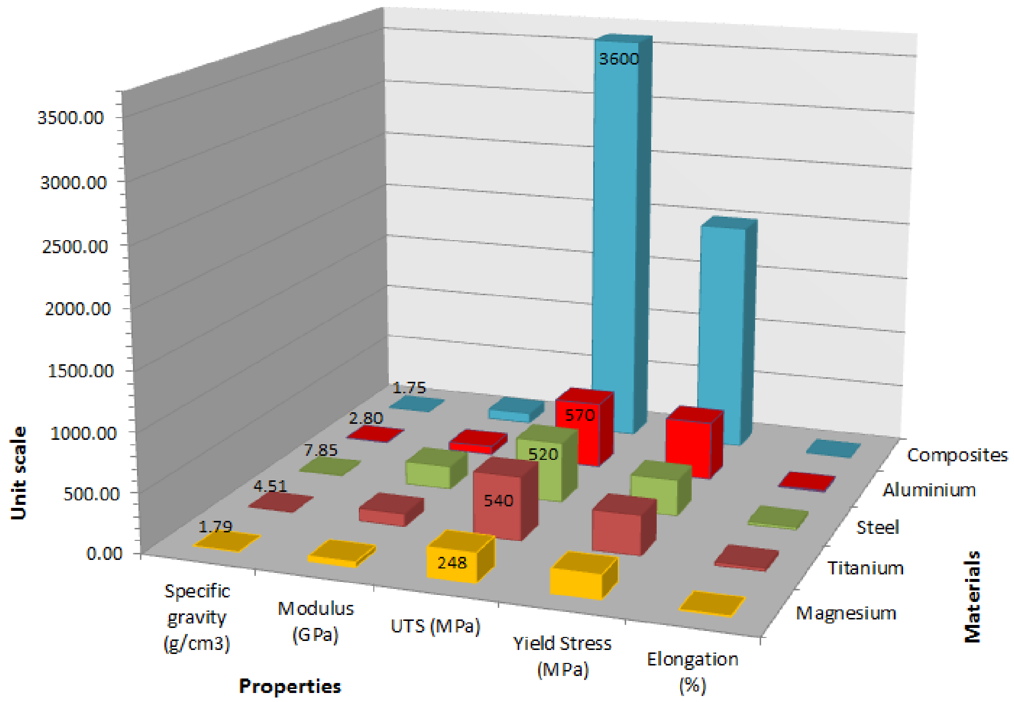

Fig-1: Mechanical properties of various aerospace grade materials

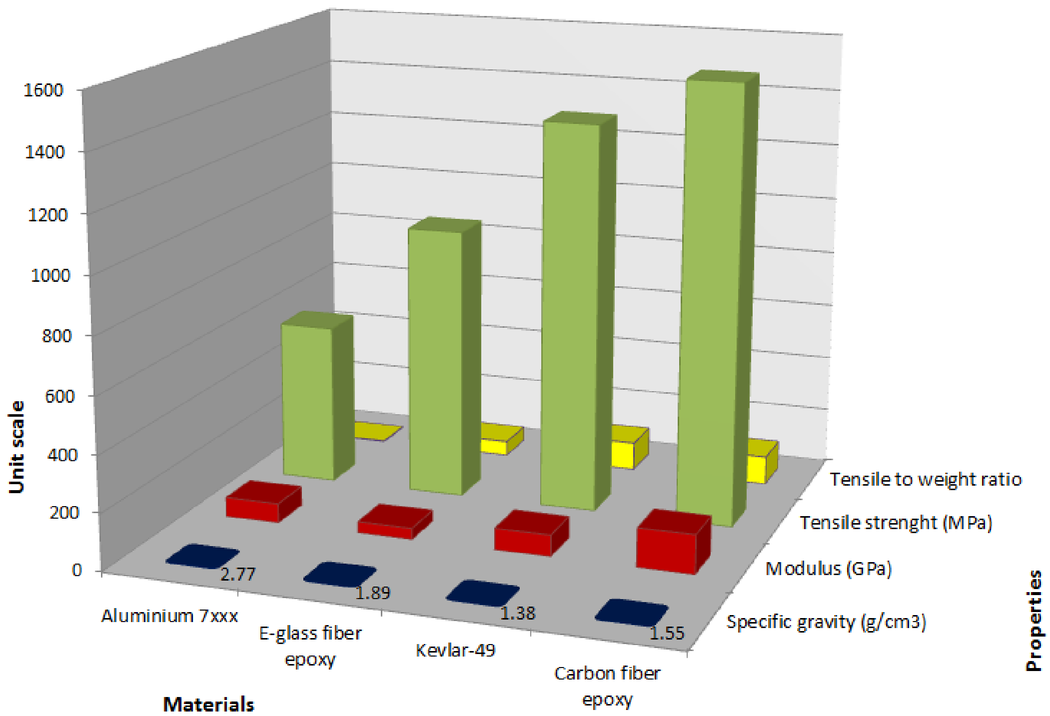

Fig-2: Mechanical properties of composites compared to high strength aluminium

In the succeeding paragraphs we have discussed the characteristics of the two materials and their advantages over each other.

3. ADVANTAGES OF COMPOSITES OVER ALUMINIUM:

Table-1 presents an overview of the benefits by which the composite materials have beaten the supremacy of most popular and dominant aerospace material of the last century.

The composite material containing desired properties are made by combining two or more distinct materials with predefined characteristics. Principally composites have just two phases; one is the matrix, and the other one is the dispersed phase. The properties of the composite material largely depend upon the properties of the phases involved, the geometry of the dispersed phase and the quantity of each phase[13-26]. On the basis of the phase distribution, three main classes of composites have been evolved i.e. particle reinforced, fiber reinforced and structural or laminates. A common sequence to all polymeric composite processes is the combining of a resin, a curing agent, some type of reinforcing fiber, and in some cases a solvent[27]. Heat and pressure are used to shape and cure the mixture into a finished part. The resin acts to hold the fibers together and protect them, and to transfer the load to the fibers in the fabricated composite part. The curing agent or hardener acts as a catalyst and helps in curing the resin to a hard plastic[28]. The reinforcing fiber imparts strength and other required properties in the composite[16-29].

Table-1: Advantages of composites materials over Al alloys in aerospace applications

Elements	Remarks
Structural flexibility and optimization	The fibers in composite materials can be oriented in preferred directions that can provide even higher strength and stiffness in a particular direction. On the other hand, metals have same properties in all directions.
Fatigue and corrosion resistance	Composites can withstand natural or corrosive environmental effects, and have high resistance to fatigue damage. These properties make their life fairly large than metals.
Weight to strength ratio	Composites are light weight and have a lower density than most metals. But composite aircraft has almost same and comparable weight to that of metal aircraft; because a larger amount of material is required in achieving better structural stability, stiffness and soundproof construction.
Aerodynamics and appearance	Composite can provide fine design and superior aerodynamics by utilizing lenience in production of complex and curved structures with lesser joints, seams and rivets. These structures enhance appearance and aesthetics of the aircraft.
Simplicity in design	Composites can make aircraft assembly more simple and compact; because many small parts, fastenings, joints can be replaced with larger and more integrated structures.

Composite materials have been successfully used for aerospace applications, due to their structural flexibility, high specific strength and stiffness. From graph in Fig.1, it is obvious that the specific gravity of a standard composite laminate is in the range of 1.5 compared to aluminium alloy of 2.7 or steel of 7.8. The strength to weight ratio of these novel composites is many times that of steel. Composite are extremely beneficial material in a corrosive environment and also resists the attack of a wide range of chemicals. These offer benefits in design and aerodynamics along with translucency and color choices further add to their aesthetic advantages.

Apart from their advantages there are a number of disadvantages of composite materials, and the same have shifted the balance towards the historic metal, the aluminium (Table-2). The manufacturers of composite materials face two significant challenges that are the low production rates and recycling of defective parts[30-31]. There is actually less industrial waste than traditional aluminum alloy production, but the materials are generally more hazardous and difficult to recycle as compared to aluminium alloys which are easily recycled. The specialized technology like autoclaves is very costly and so is the production process[18].

4. ADVANTAGES OF NEW GENERATION ALUMINIUM OVER COMPOSITES

Table-2 has enlisted the key features of new generation aluminium alloys (AlLi) and highlighted the weakness in their competitors, the composites.

The AlLi has appeared as an alternative material to standard aluminum used in aircraft manufacturing industry. Aluminium alloys manufacturers are claiming that the advancement in the third generation AlLi alloys will be even better and can save weight up to 10 % over composites in new airplane designs. In addition to the weight savings, the new generation aluminum alloys will provide better passenger comfort. The AlLi is lighter than traditional aluminum alloys, more durable, less susceptible to corrosion and would require larger gap between major maintenance overhauls[21-33]. And off course it is easy to recycle via the same procedures already established for conventional aluminium alloys.

Irrespective of their outstanding properties and many advantages over traditional aluminium alloys, the AlLi alloys could not make an extraordinary growth, mainly due to certain handling problems during the fabrication of these alloys. Lithium (Li) is a highly reactive metal, which poses a great difficulty while adding in molten aluminium during alloying[34-35]. Further, it quickly oxidizes when comes in contact with air or moisture and can produce violent explosions[36-39]. Although the processing route of AlLi is the same as that of traditional aluminium alloys, but still we need appropriate melting and casting technology to handle Li metal additions i.e. melting and casting under vacuum or inert gas environment[40-41]. Due to these facts production of low cost and stable AlLi material for modern commercial aircraft has not yet been outspread. This is one of the reasons that, aircraft manufacturing companies may not switch completely towards the AlLi alloys because the processing technology is just enough different from that of traditional aluminium alloys, and that would add complexity and cost to the current tooling and methods.

Table-2: Advantages of new generation Al alloys over composites in aerospace applications

Elements	Remarks
Manufacturing processes	Composite materials require different manufacturing processes i.e. curing in ovens or autoclaves, thus need especial manufacturing technology and assembly methods as compared to traditional aluminum alloys. On the other hand, new generation AlLi alloys passes through same processing route used for conventional Al alloys, which are well known and long established, though technology enhancement is in progress.
Cost and durability	The production cost of composite materials is higher than that of aluminum alloys, due to expensive raw materials, especially technical needs and low production rates. Durability of composites in aircraft structures has yet to be established because it requires a set time and several protocols to confirm. On the other hand, performance of new aluminum alloys in the aerospace environment is predictable through their well-known history.
Structural integrity and life assessment	Structural integrity and life assessment analysis are well established for Aluminium alloys; damage can be easily determined through inspection, and straightforward repairs can be made using scab patches of additional material. Whereas the material characterization and life assessment methods are difficult and require extra time and large frequency for composites materials[42-44].
Material recycling	New generation aluminium alloys are fully recyclable like any other conventional aluminium alloy. Carbon fiber composites include carbon fibers, as well as a metallic mesh to protect against lightning strikes, encased in cured resin. The high strength carbon fibers and metallic mesh are difficult to extract from the material, making recycling difficult.
Safety issues	The performance of aluminum alloys and composite components vary significantly in a crash event. Aluminum is less rigid than carbon fiber composites and tends to crush and absorb impact during a crash. On the other hand, carbon fiber composites tend to shatter on impact, and may get separated from the resin on high impact. In the case of fire, composites would become toxic material and may generate poisonous gases which could be a potential threat to passengers' safety.

5. CONCLUSIONS

This article review about the future of aluminium material in comparison with advanced composites materials in aerospace industry and concludes the following points;

a. The advanced aluminum alloys are fighting back by offering fascinating properties to aircraft manufacturers and making their choice more difficult. However, the aluminium industry has to manage the handling problems during the fabrication of AlLi alloys to compete with advanced composite materials.
b. The structural flexibility of composite materials helps in designing efficient structures for an aircraft. But on the other hand the problems such as delamination, impact damage, repair and recycling, and internal flaws assessment is a set back and need further attention and research.
c. In the coming future the aircraft would be a hybrid type, that is the, there may be no full aluminium or full composite aircraft. Though, the maintenance frequency is still a major concern when using the two materials together, especially at the fusion interface of composite and aluminium. The joining/welding of these materials is an important area for researcher's working on aerospace materials.

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