` ISSN No. 2456-0472
The Engineering Journal of Application & Scopes, Volume 2,Issue 1, February 2017

Review on Mechanical Properties of Carbon Epoxy in Context of the Best Material Selection.

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Abstract— Materials are certainly more deep seated in our culture than most of us realize. Housing, communication, clothing, recreation, transportation and food production— virtually every segment of our everyday lives is influenced to one degree or another by materials. The failure in engineering is almost always an undesirable event for several reasons such as causing economic losses, putting human lives in jeopardy and interfering with the availability of products and services. In the era of immense technology and development, in the field of mechanical engineering and material science, there is no space for failure. Amongst the various reasons that may cause failures is the improper material selection. This paper entails the analysis of mechanical properties of epoxy carbon and aluminum. Many researchers in this field accomplished different works and showed positive results. By observing and analyzing these results, epoxy carbon is suggested as the best material. The paper also focuses on the important applications of epoxy carbon as future material because of its high strength-to-weight ratio and rigidity.

Keywords: Epoxy-Carbon, Aluminum, future material, Strength to weight ratio.

I. INTRODUCTION

Carbon fibers, also called graphite fiber or carbon graphite, are a type of high-performance fibers used mainly in structural engineering applications. It consists of very thin strands of the elemental carbon. With high tensile strength, carbon fibers are very strong for their size. In fact, it might be the strongest material because of its high strength-to-weight ratio and rigidity. Carbon fibers have high elastic modulus and fatigue strength than those of glass fibers.

Each fiber is 5-10 microns in diameter. To give a sense of how small that is, one micron (um) is 0.000039 inches. One strand of spider web silk is usually between 3-8 microns. Carbon fibers are twice as stiff as steel and five times as strong as steel, (per unit of weight). The most important factors determining the physical properties of carbon fiber are a degree of carbonization (carbon content, usually more than 92% by weight) and orientation of the layered carbon planes (the ribbons).[1]

Considering service life, studies suggest that carbon fiber reinforced polymers have more potential than agamid and glass fibers.[1]Carbon Fibre Reinforced Polymer (CFRP) is a layer of carbon fibre embedded in a polymer which is often epoxy. A CFRP system consists of the carbon fibre fabric or procured CFRP laminate, the epoxy adhesive and associated primers and sealers. Special features of CFRP are low self-weight, high strength, corrosion resistance, high chemical resistance, low thermal expansion and ease of application. CFRP have been successfully used both internally as an alternative to steel reinforcement and externally as a repairing agent.Epoxy carbon is a CFRP with a layer of carbon fibre embedded in the epoxy polymer. Epoxy resin is the polymer matrix used most often with reinforcing fibers for advanced composites applications. The resins of this class have good stiffness, specific strength, dimensional stability, and chemical resistance, and show considerable adhesion to the embedded fiber. [12] Over the years, many attempts have been made to modify epoxy by adding either rubber particles or fillers to improve the matrix-dominated composite properties.[2] Epoxy resin composites are frequently applied in mould manufactured with rapid tooling technologies, because of their low shrinkage and easy mouldability.[3] Carbon Fiber Reinforced Epoxy is used to make aircraft and spacecraft parts, racing car bodies, golf club shafts, bicycle frames, fishing rods, automobile springs, sailboat masts, and many other components where light weight and high strength are needed.[2] Different materials are tested for several mechanical properties required for choosing the best material for a particular application. Epoxy carbon has given a tough competition to aluminum in various aspects. However, this review seeks to analyze epoxy carbon as the better material than aluminum on the basis of research and analysis accomplished by different researchers in this field.

II. HISTORY

Epoxy resins, the petrochemical byproducts, first became commercially applied in the aerospace industry in the early 1950’s and have rapidly infiltrated almost every industrial sector. The 20th

` ISSN No. 2456-0472
The Engineering Journal of Application & Scopes, Volume 2,Issue 1, February 2017

century saw a roller coaster ride in the demand for carbon fiber. Threats to peace increased the demand for carbon fiber for defense purposes mid-century. A downturn in defense needs results in a reduction in production of carbon fiber toward the close of the century. By the beginning of the 21st century, new applications and new markets sent the production of carbon fibers on an upswing. Despite a downturn in 2007-2008, worldwide demand increased to approximately 40,000 metric tons in 2010. Carbon fibers have revolutionized the technology of materials. It is no wonder that the National Academy of Engineering voted carbon fibers one of the 20 top engineering achievements of the 20th century and the American Chemical Society named the development of high-performance carbon fibers a National Historic Chemical Landmark in September 2003. On the other hand, epoxy resins, the petrochemical by-products, first became commercially applied in the aerospace industry in the early 1950's and have rapidly infiltrated almost every industrial sector. [1]

III. DATA ANALYSIS

Mechanical Properties [4]

- Tensile strength, Ultimate[11]

Aluminum alloy	70-750 MPa
Carbon-epoxy	50-2100 MPa

- Tensile Strength, Yield [11]

Aluminum alloy	69-730 MPa
Carbon-epoxy	4.62-2650 MPa

- Modulus of Elasticity

Aluminum alloy	67-73 GPa
Carbon-epoxy	6.6-520 GPa

- Shear Modulus

Aluminum alloy	25-27.6 GPa
Carbon-epoxy	3-5 GPa

- Shear Strength

Aluminum alloy	50-400 MPa
Carbon-epoxy	30-120 MPa

- Elongation at break

Aluminum alloy	1-25 %
Carbon-epoxy	0.50-11.0 %

- Compressive Yield Strength

Aluminum alloy	372-530 MPa
Carbon-epoxy	50-1720 MPa

- Compressive Modulus

Aluminum alloy	70-72.4 GPa
Carbon-epoxy	8.2-138 GPa

Other Properties [4]

- Density

Aluminum alloy	2.72-2.89 g/cc
Carbon-epoxy	1.15-2.25 g/cc

- Electrical Resistivity

Aluminum alloy	0.0000029-0.0000059 ohm-cm
Carbon-epoxy	100-1.3e+13 ohm-cm

- Specific Heat Capacity

Aluminum alloy	0.856-0.96 J/g-C
Carbon-epoxy	1-1.2 J/g-C

- Thermal Conductivity

Aluminum alloy	115-222 w/m-k
Carbon-epoxy	0.22-400 W/m-k

Comments On The Basis Of Data Analysis

- Epoxy carbon has High Strength to Weight Ratio (also known as specific strength)

Aluminum alloy	222
Carbon-epoxy	785

- Rigidity or stiffness of a material is measured by its Young Modulus. Carbon Epoxy is stiffer than aluminum.
- Carbon Epoxy has a better Tensile Strength.
- It can be said, Fatigue Resistance of Carbon-Epoxy is good.
- Carbon Epoxy is less electrically conductive than aluminum.
- Carbon epoxy is less thermally conductive than aluminum.
- Carbon Epoxy has a low coefficient of thermal expansion.

IV. PERFORMANCE ANALYSIS

` ISSN No. 2456-0472

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1. **Performance Analysis of Carbon Fiber with Epoxy Resin Based Rocket Shell** [7]

The various reasons that may cause case failures are the improper material selection and improper design and analysis. SATURN V LAUNCH VEHICLE [9] rocket model is designed using CATIA v5 tools, meshing with Hypermesh and Analysis with Ansys 10, where different materials like Aluminum and Epoxy-carbon are selected. The results proved that the rocket shell designed when an advanced material such as Carbon-Epoxy is considered in spite of aluminum is suitable for mission requirements and more effective.

Results of analysis:

Fig. 1. Deformation when aluminum is considered [7]

Fig.2.Deformation when carbon-epoxy is considered [7]

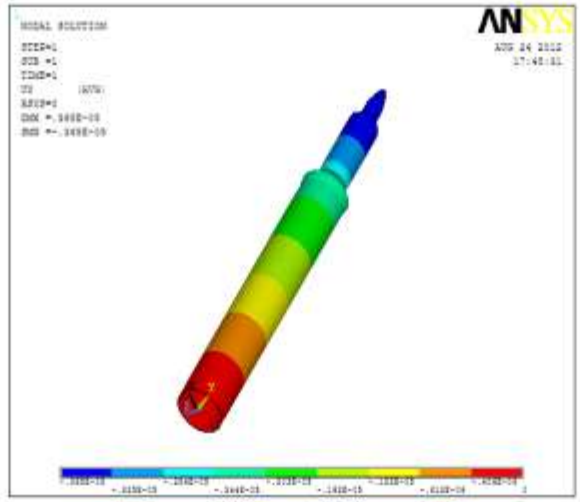

Fig.3.Nodal solution when aluminum is considered [7]

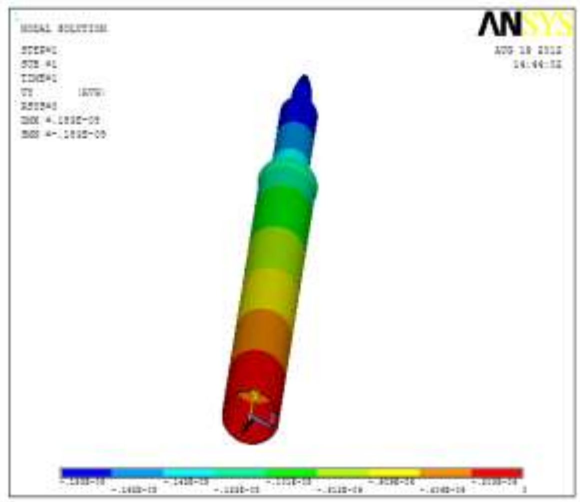

Fig.4.Nodal solution when carbon-epoxy is considered [7]

Conclusion of this analysis:

The results of this study show that Carbon epoxy can be able to perform better over that of aluminum as noted from the results of analysis, the deformation occurred is less for the carbon epoxy compared to aluminum when applied the same loading. It is recommended that further research be undertaken in developing the composite materials (eg: Carbon Epoxy) for the rocket casing as they consists of high strength and they are reusable. [7]

2. Performance Analysis of Carbon Fiber with Epoxy Resin-Based Composite Leaf Spring [8]

In the present work, existing mono steel leaf spring of a light vehicle is taken for modeling and analysis. A composite mono-leaf spring with Carbon/Epoxy composite materials is modeled and subjected to the same load as that of a steel spring. Compared to mono steel leaf spring the laminated composite mono-leaf spring is found lesser stresses and weight reduction of 22.15% is achieved.

In order to improve their processing and product performances and to reduce cost, various fillers are introduced into the resins during processing. Epoxy resins are the most commonly used thermoset plastic in polymer matrix composites. Hence from the above-listed advantages of epoxy resin, it has been selected for the study.

Conclusion of this analysis:

A steel leaf spring used in the rear suspension of light passenger cars was analyzed by analytical and finite element methods. The study demonstrates that the composite can be used for leaf spring for the light vehicle and meet the requirement, together with the sustainable weight reduction. [8]

Sr.No	Parameter	Value
1	Tensile modulus -X direction Ex, MPa	123000
2	Tensile modulus -Y direction Ey, Mpa	7.7
3	Tensile modulus -Z direction Ez, MPa	4.2
4	Tensile strength, Mpa	1841
5	Compressive strength, MPa	920
6	Poisons ratio	0.282
7	Density, Kg/m3	1400

Table 1. Properties of Carbon/Epoxy leaf spring [8]

Sr.No	Parameter	Value
1	Density (×1000 kg/m3)	7.7-8.03
2	Poisson's Ratio	0.27-0.30
3	Elastic Modulus (GPa)	190-210
4	Tensile Strength (Mpa)	1158
5	Yield Strength (Mpa)	1034
6	Elongation (%)	15
7	Reduction in Area (%)	53
8	Hardness (HB)	335

Table 2. Properties of EN47steel leaf spring [8]

Result of this analysis:

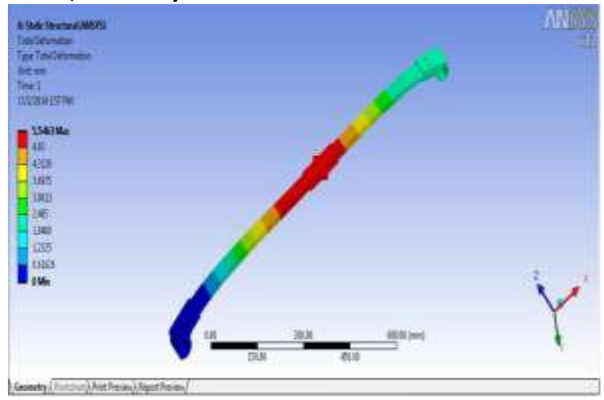

Fig.5. Total deformation-composite leaf spring [8]

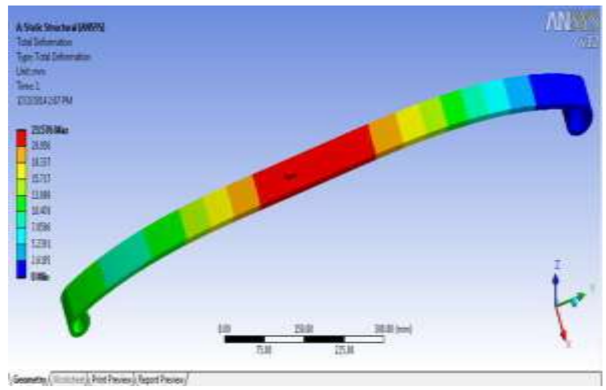

Fig.6. Total deformation-steel leaf spring

Sr.No	load (W) N	Bending stress (σ) MPa	Deflection (δ) mm
1	100	28.38	2.77
2	500	141.93	13.83
3	1000	283.86	27.65
4	1500	425.79	41.48
5	3400	965.14	94.02

Table 3. Bending stress and Deflection of steel leaf spring [8]

Sr.No	load (W) N	Bending stress (σ) MPa	Deflection (δ) mm
1	100	10.13	0.83
2	500	50.68	4.16
3	1000	101.37	8.31
4	1500	152.06	12.47
5	3400	344.67	28.26

Table4. Bending stress and Deflection of Carbon/Epoxy leaf spring [8]

V. APPLICATIONS

- Structural engineering applications: Several structural engineering applications utilize carbon fiber reinforced polymer because of its potential construction benefits and cost effectiveness.[1] The usual applications include strengthening structures made with concrete, steel, timber, masonry, and cast iron; Retrofitting to increasing the load capacity of old structures like bridges; to enhance shear strength and for flexure in reinforced concrete structures. Other applications include a replacement for steel, prestressing materials and strengthening cast-iron beams.[6]

- Aerospace industry: It has gone to the moon on spacecraft, but it is also used widely in aircraft components and structures, where its superior strength to weight ratio far exceeds that of any metal. 30% of all carbon fiber is used in the aerospace industry. From helicopters to gliders, fighter jets to microlights, carbon fiber is playing its part, increasing range and simplifying maintenance.

- Sports goods: Its application in sports goods ranges from the stiffening of running shoes to ice hockey stick, tennis racquets, and golf clubs. ‘Shells’ (hulls for rowing) are built from it, and many lives have been saved on motor racing circuits by its strength and damage tolerance in body structures. It is used in crash helmets too, for rock climbers, horse riders, and motorcyclists – in fact in any sport where there is a danger of head injury.

- Military: The applications in the military are very wide ranging – from planes and missiles to protective helmets, providing strengthening and weight reduction across all military equipment. It takes energy to move weight – whether it is a soldier’s personal gear or a field hospital, and weight saved means more weight moved per gallon of gas.[1]

- Medical: The use of carbon epoxy to strengthen of damaged cruciate ligaments in the knee is being researched, but probably the most well-known medical use is that of prosthetics – artificial limbs. It is used widely in imaging equipment structures to support limbs being X-rayed or treated with radiation.[1]

- As costs come down, carbon epoxy is being more widely adopted in automobiles. Supercar bodies are built now, but its wider use is likely to be on internal components such as instrument housings and seat frames.

VI. LIMITATIONS

- The presence of UV radiation in polymeric composites could lead to changes in chemical structures which ultimately deteriorates their properties.[7]
- These composites are viscoelastic in nature.[10]
- Epoxy carbon is very expensive.[1]
- Heat could also lead to can also deteriorate the chemical structure, hence the material failure.[5]

VII. CONCLUSION

Carbon epoxy has high stiffness, high tensile strength, low weight, high chemical resistance, and one of the most popular materials in engineering. The results of this study show that Carbon epoxy can be able
to perform better over that of aluminum as noted from the results of analysis, the deformation occurred is less for the carbon epoxy compared to aluminum when applied the same loading. The study also demonstrates that the composite can be used for leaf spring for the light vehicle and meet the requirement, together with the sustainable weight reduction. It has more applications in engineering, military, sporting goods, in medical, in the automobile industry, etc. so use of carbon fiber is always effective and provides high strength to the material.

VIII. FUTURE ASPECTS

- **Alternate Energy** — Wind turbines, compressed natural gas storage, and transportation, fuel cells.
- **Fuel Efficient Automobiles** — Currently used in small production, high-performance automobiles, but moving toward large production series cars
- **Construction and Infrastructure** — Lightweight pre-cast concrete, earthquake protection
- **Oil Exploration** — Deep Sea drilling platforms, buoyancy, umbilical, choke and kill lines, drill pipes

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