International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 06 June 2024, pp: 101-110 www.ijaem.net ISSN: 2395-5252

A Review on the Development of Lightweight Composite Material for Aerospace Industry

[1]K. K. Sunil, [1,2*]S. Y. Musa, [3]Haruna Abubakar
[1]*Department of Mechanical Engineering, Mewar International University, India*
[2]*Department of Occupational Safety and Health, Federal Ministry of Labour and Employment, Kaduna, Nigeria*
[3]*Department of Mechanical Engineering, Kaduna Polytechnic, Kaduna, Nigeria.*

Date of Submission: 28-05-2024 Date of Acceptance: 06-06-2024

ABSTRACT: The aerospace industry's relentless pursuit of weight reduction and performance enhancement has fuelled the development of lightweight composite materials. This review provides a comprehensive overview of the evolution, current state and future directions of lightweight composite materials for aerospace application. The paper discusses the various types of lightweight materials used in aerospace industry such as aluminium alloys, titanium alloys, magnesium alloys and composites materials including carbon, glass, and natural fibre reinforced composites. Finally, the paper highlights future research directions and technological innovations that will shape the next generation of lightweight composite materials for the aerospace industry.

KEYWORDS: aerospace, composites, lightweight, material development, manufacturing techniques.

I. INTRODUCTION

Composite is defined as an engineered material made from two or more constituent materials with significantly different physical or chemical properties that remain separate and distinct on a macroscopic level within a finished structure (Abdullahi & Umar, 2011)(Dimple et al., 2023). Composites are made up of a matrix constituent (continuous phase) and a reinforcement constituent (fibres or/and particles). The reinforcement phase carries the majority of the load and provides strength and stiffness. Therefore, the reinforcement is harder, stronger, and stiffer than the matrix. The matrix is the continuous phase that surrounds and protects the reinforcement from environmental factors such as abrasion, wear, and chemical attack (Campbell, 2010). Composite materials are immensely more robust than their counterparts, mainly because of their high strength-to-weight ratio (Sahu et al., 2023). Composites, due to their advantageous mechanical characteristics and lightweight, are continually evolving towards products that are the most efficient and least expensive possible. They are widely used in various industries such as the automobile, marine, aerospace, and sporting goods sectors among others (Habibi et al., 2020). Generally, the type of matrix such as polymer, ceramic, and metal classify the composite material.

Polymer matrix composites (PMC) consist of a polymer matrix (resin) and a dispersed phase of reinforcing fibres. PMCs are very popular and widely used due to their low cost, simple processing methods, lightweight, and low density. Over the past few decades, high-strength polymer matrix composites have gradually replaced the widely used metal matrix composites in the aerospace, automotive, automotive, and marine industries (K. et al., 2023). Polymers or resins are classified into two types: thermoplastics [polypropylene (PP), polyethylene (PE), polystyrene (PS), polyvinyl chloride (PVC)], and thermosets (epoxy, phenol formaldehyde, polyester) and they can be reinforced with different types of fibres such as natural (plant, mineral, and animal) and synthetic for various applications (Saxena et al., 2011).

The use of synthetic materials such as Carbon fibre, Kevlar fibre, and Glass fibre allowed the development of a variety of structural components in the aerospace, automobile, and other sectors. However, these synthetic materials have tremendous environmental effects due to their biodegradability (Aravinth et al., 2023). Consequently, the reduction of global warming gases requires lighter materials and lower carbon emissions. Recently, there has been a shift towards using environmentally friendly and lighter materials such as bio-composites, replacing the conventional composite materials developed using synthetic materials (Elfaleh et al., 2023). A lot of natural fibres have been identified and processed for the reinforcement in the matrix. Even though natural fibres have lower strength than synthetic fibres, they offer several advantages such as low cost, simplicity of processing, biodegradability, and abundance (Gholampour & Ozbakkaloglu, 2020).

Natural fibres have superior physical and mechanical properties than wood fibres and they are high in cellulose and crystallinity content and lighter in weight than wood fibres. Some desirable properties of natural fibres include high specific strength and modulus, flexibility during processing, biodegradable, low self-weight, low cost, low density, and substantial resistance to corrosion and fatigue (Faruk et al., 2012), (Vigneshwaran et al., 2020). Recently, researchers have focused on developing composite materials reinforced with natural fibres, as these composites combine good mechanical properties and low density. These compounds offer several advantages, such as cost, availability of renewable natural resources, and biodegradability (Elfaleh et al., 2023). These inexpensive natural fibres can become a viable alternative for expensive and non-renewable synthetic fibres when high elastic modulus is not required. The advancement in composite materials is illustrated in Figure 1.

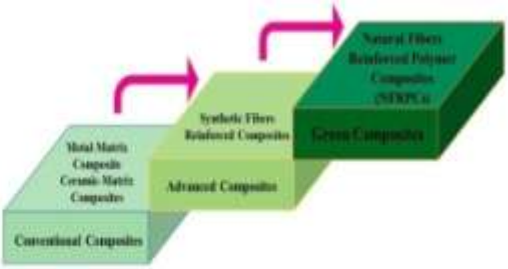

Figure 1: Advancements in Composites Technology (Khalid et al., 2021)

The aircraft market is forecasted to generate around 250 billion dollars between 2016-2025 and this market is characterized by demand and its dynamic and competitive environment. These aircraft manufacturers are pursuing process innovation to attend to the increase in production demands. Continuous improvement and a high level of efficiency together with maximum process reliability is the keynote to success in a highly competitive market (Barbosa et al., 2017). Carbon fibre-reinforced composites have found application in aircraft manufacturing since the late 1960s, displacing the more conventional materials such as aluminium and titanium alloys. It was predicted and argued that fibre-reinforced polymer; especially carbon fibre can and will in the future contribute to more than 50% of the structural mass of aircraft (Soutis, 2005). However, with the growing problems of climate change and global warming, airline companies are actively promoting energy-saving and carbon-reducing measures in an attempt to reduce environmental impacts. A method to lower fuel consumption by reducing the weight of seats in the passenger cabins. Weight reduction is another critical design objective for any aircraft, as it is directly related to fuel consumption and cost. The aerospace industry is currently experiencing an increase in demand for sophisticated composite materials that enable significant weight reduction while retaining structural integrity. Consequently, they adopt a green approach to the weight reduction of aircraft cabin seats by developing novel seats with the help of natural fibre-reinforced composites (Tsai et al., 2014). Polymer matrix composites (PMC) are a substantial component of airframe materials at the moment. Natural fibres have emerged as a potential alternative to synthetic fibres such as E-glass, Carbon fibres, and others in the production of composite materials due to their high strength-to-weight ratio, low cost, and renewability. However, choosing the optimum natural fibre for an aerospace application can be challenging due to the diversity of fibres available in combination with a variety of matrix materials

II. LIGHTWEIGHT MATERIAL FOR AEROSPACE

The selection of aerospace material is crucial as it affects many aspects of aircraft performance from the design stage to disposal. Materials with a high strength-to-weight ratio are the major needs of the aerospace industry. Other properties include mechanical, physical, and chemical properties such as high stiffness, fatigue durability, damage tolerance, low density, and high corrosion and oxidation resistance. The most commonly used commercial aerospace structural materials are aluminium alloys, titanium alloys, high-strength steel, and composites (Zhu et al., 2018).

A. ALUMINIUM ALLOYS

Aluminium alloys and their metal matrix composites (AMMC) are great alternate super lightweight material for aerospace applications and have gained tremendous attention among researchers due to their properties. They are light in weight, cheaper, easily fabricated, and can be treated to become a high-strength material. To develop various enhanced properties, alloying Aluminium with different elements has reported high strength, and observed that, when alloyed with Zinc and Magnesium it has considerably higher strength (Sehgal et al., 2022). Many lightweight aerospace structural applications, such as the fuselage skin, upper and lower wing skins, and wing stringers, favouring advanced aluminium alloys due to their relatively high specific strength and stiffness, good ductility and corrosion resistance, low price, and excellent manufacturability and reliability (Siengchin, 2023).

In recent years, aluminium-copper-lithium (Al-Cu-Li) alloys have been highlighted as one of the most promising alloys for structural applications within the aviation and aerospace industry. Arbo et al., (2022) evaluated the weldability of aerospace grade Al-Cu-Li alloy AA2065 and the result of the study showed the potential of utilizing AA2065 wires for welding purposes without excessive formation of pores or cracks. Helal Miah et al., (2023) conducted research and illustrated the impact of the combined welding parameter for the friction stir lap welding process for two Al-Mg-Si Al-Alloy plate joints. From the result, it is evident FSW process is one of the most effective ways to solve the challenges of the welding process of modern aerospace companies. Vasanthakumar et al., (2019) reviewed studies on the effects of SiC and Gr on the microstructure, mechanical, and wear properties of powder metallurgy-based aluminium alloy composite for aerospace applications. They concluded that the porosity, hardness, and tensile strength of the composite increases by increasing the SiC content whereas an increase in Gr content leads to a decrease in porosity, hardness, and tensile strength.

Awate et al., (2023) used stir casting to fabricate graphene nanoplates reinforced aluminium Al6061 composites for aerospace and automobile applications. The microstructure and tensile properties of the nanocomposites were analysed using FESEM and UTM respectively. The tensile testing results revealed enhancement in ultimate tensile strength which is required for use in a variety of aviation applications. The potential of rare-earth compounds as anticorrosion pigments for the protection of aerospace AA2198-T851 alloy was studied by Gad et al., (2023). Their findings indicate that these inhibitors may potentially provide new options for the corrosion protection of aerospace Al-Cu-Li alloys. Anandan & Manikandan (2023) studied the effect of welding speed of friction stir welding between dissimilar aerospace grade AA7050-T7651 and AA2014-T6 aluminium alloys. Microstructural characterization and mechanical testing were performed to determine the tensile strength, microhardness, and residual stress. They reported that proper material mixing and finer grains were obtained at a weight speed of 65 mm/min which resulted in good mechanical and metallurgical properties compared to other welding speeds.

Pazhani et al., 2023 synthesize and characterized graphene reinforced AA 2014 metal matrix composite using squeeze casting method for lightweight aerospace structural applications. The research focuses on the development of isotopic composite materials and reported that a successful isotropic composite material is created and can be used in aerospace and space exploration application. Akinwade et al., 2023 fabricated a 7068 aluminium/ lightweight high entropy alloy as aero material. They characterized the specimens where the results of the tensile and compressive tests at 10 wt% showed significant enhancement and optimal performance achieved for aerospace application. Finally, Lahbari et al., 2024 studied the homogenization heat treatment influence on microstructure evolution and mechanical properties of aluminium alloy for lightweight aerospace application. They concluded from their work that the best hormogenization time is 26hr as a process proceeding rolling.

B. TITANIUM ALLOYS

Titanium alloys are widely recognized for their excellent properties, which makes them suitable for aerospace applications. These alloys have many advantages over other metals such as high specific strength, high stiffness, good fracture toughness, fatigue resistance as well as very good corrosion resistance, heat resistance, cryogenic embrittlement resistance and low thermal expansion (Zhu et al., 2018). A variety of aerospace components are built with TiAl6V4 material. Titanium has superior properties like low density, good strength, and better corrosion resistance and is perfectly suited for aerospace components (Sehgal et al., 2022). The machining performance of TiSiN (Ag) coating on tool inserts during dry turning of TiAl6V4 aerospace alloy was conducted by Cavaleiro et al., (2021). They found out that TiSiN showed better tool life when a lower cutting speed was applied. Their work shows the potential use of TiSiN(Ag) coatings for machining TiAl6V4 aerospace alloy under dry conditions. Kamal et al., (2023) joined C/SiC niobium alloy with titanium alloy (TiCuAg) for aerospace applications. They studied the microstructural and mechanical properties of the joint and concluded that an optimal Ti content of the alloy is necessary that minimize the formation of a brittle phase without compromising the joint strength.

Veera Ajay et al., (2020) conducted experimental studies on single point incremental forming (SPIF) of Ti-6-Al-4V alloy for aerospace applications. Zhao et al., (2022) reviewed the application of high-strength titanium alloy for the aerospace industry, where several positive achievements have been realized for technological exploration. Although numerous high-strength titanium alloys have been developed, the designing approaches mainly rely on the Al/Mo equivalents. Pathania et al., (2021) researched the use of directed energy deposition techniques for the refurbishing of Ti6Al4V components used in aero-engine. They concluded that DED is the best-suited cost-effective technique that imparts the repaired components' highly functional and mechanical properties. Xia et al., 2024 prepared a lightweight titanium dioxide/ carbon nanotube composite using ALD method for microwave absorption. Their study provided a novel idea for preparing efficient and lightweight microwave absorbing materials for aerospace applications.

C. LIGHTWEIGHT COMPOSITE

Synthetic fibres like glass, carbon, and Kevlar have been extensively used in airplanes for weight reduction when compared to aluminium alloy. A lot of research has been carried out on the development of a variety of high-performance composites such as fibre-reinforced polymer and fibre metal laminates (FML), competing with the major lightweight aerospace materials such as aluminium alloys. Research by Bhavya et al., (2021) evaluated the performance of E-Glass reinforced epoxy composite laminate as an aerospace material. Tensile, flexural, shear, and impact properties of the fabricated laminates with a variation in the hardening agent used were studied. The tensile and shear properties of the two samples do not show much difference results whereas there was significant improvement observed in the flexural strength and hardness values of the two samples. They concluded that the material studied qualified as a potential and good electromagnetically transparent material to be used for the mechanical covering of antenna systems of aircraft. Tahir et al., (2022a) developed a hybrid biocomposite from Sterculia Setigera Delile fibre and Pterocarpus Erinaceus wood dust epoxy for aerospace applications. They optimized the mechanical properties and found that its properties have better biodegradability, lighter in weight when compared to other formulations of the composites.

Lakshmi Kala & Prahlada Rao, (2022) fabricated a carbon fibre-reinforced Aluminium sandwich composite laminate using the compression moulding method. Aluminium 2024-T3 and carbon UD fibres 200gsm were selected for the fabrication of CRFP/Al/CRFP sandwich laminates. The fabricated laminates were examined to assess their properties such as tensile, flexural, and impact strength, and were found to have properties applicable to the aerospace industry. Naik et al., (2022) developed a lightweight three-layer functionally graded composite material using a spark plasma sintering route for aerospace applications. The raw materials for the development are commercially available B_4C and ZrB_2 powders. The powder mixtures for each layer composition were mixed separately in a tumbler mixer using Zirconia balls and heated at 150°C in an oven to remove moisture. The density, microstructure, and hardness of the sintered samples were measured and the results showed that the composites had a relative density of 96% and were free from defects such as cracks and delamination at the interlayer regions.

Sunith Babu et al., (2023) fabricated GFRP/ epoxy composite laminates using a vacuum bagging process with varying thicknesses. A 200gsm bi-woven GFRP cloth was used to prepare four laminates with different ply counts of 6, 10, 14, and 18. An impact test was conducted on different laminate thicknesses using an instrumented drop-weight testing machine. The defects on the laminates subjected to the testing were identified using visual inspection for both the front and rear portions. They concluded that the laminate thickness plays a significant role in the performance of the material subjected to low-velocity impact. Shao et al., (2023) researched how to suppress delamination and improve the interlaminar strength of composite laminate. RTM moulding process was used to design, woven, and laminate a new double-sided two-dimensional (2D) woven laminated composite (DWLC). The tensile, compressive, interlaminar shear mechanical properties and damage behaviour of the DWLC were experimentally and numerically investigated. The maximum error between the numerically and experimentally measurements is 8.6% and concluded that the simulated strength and modulus of DWLC under tensile loading are in good agreement with the experimental results.

Another research by Jensin Joshua et al., (2023) evaluated the quasi-static strength of hybrid intra-woven composite laminate. The novelty of their work is the weaving methods used and the pattern in which it is intertwined. The base material in their work is Kevlar whereas basalt and Glass (fibre) are the materials with which the Kevlar is woven. First, the Kevlar and basalt are intra-woven by placing one fibre of Kevlar and one fibre of basalt, one over the other to form a ‘1x1’ configuration. Similarly, “3x3” and “5x5” configurations were done. The same pattern was followed for Kevlar and glass fibre and all six configurations of fibres were woven using the manual handloom weaving method and moulded using the compression moulding technique. The quasi-static impact testing on Kevlar/basalt and Kevlar/glass fibre intra-woven composite laminate was experimentally investigated. They concluded that Kevlar/basalt fibre KB3x3 intra-woven composite laminate is observed to be an apt material for aerospace applications and ballistic operation.

Sharma et al., (2019) developed a rare earth particulate reinforced hybrid aluminium matrix composite via stir casting route. They varied the weight percentage of the formulation of composites and studied their tribological and mechanical properties. They reported that the properties of the hybrid composites significantly improved with the addition of the rare-earth particulates. Kanok et al., (2023) studied the effect of banana and glass fibre with epoxy resin as a matrix. The hand lay-up method was utilized in the development of the hybrid composites and samples were cut according to ASTM standards for testing the tensile, flexural, hardness, impact, and SEM analysis. They concluded that the treated 40% wt hybrid composite is better to be used in various convenient household and industrial applications.

Kudva et al., (2023) investigated the mechanical properties of bamboo and carbon fibre-reinforced hybrid composites through tensile, flexural, and Izod tests. The fibres were treated in a 10% NaOH solution for 48 hours and concluded that combining natural and synthetic fibre led to the development of composite material with acceptable mechanical performance. Paladugu et al., (2022) fabricated a hybrid composite using a hand lay-up process. Natural fibres such as banana, coconut, jute, and cotton fibre were used with polyethylene at different weight proportions. They conclude that water absorption is less in the hybrid composite with coconut and cotton fibres as reinforcement and gains mass of 5grm and 7grm. Guo et al., (2023) developed aeronautical multi-fibres hybrid composites corrugated structures consisting of Carbon, Glass, and Kevlar and studied its crashworthiness and failure mechanism using quasi-static axial crushing tests. They concluded that fibre hybridization is a very useful method of improving the structural failure mode to regulate and control crashworthiness. Another research by Karaboga et al., 2024 on the mechanical response of carbon fibre reinforced epoxy composite parts for aerospace application is reported. The study provided guidance at the preliminary stage of an aerospace platform, which in return might reduce costs. It concluded that for enhanced aero structure applications, titanium or steel rivets can be advantageous due to their high strength and corrosion resistance.

Wu et al., (2023) prepared a basalt-glass hybrid fibre-reinforced polymer composite bar. They studied the mechanical properties and failure mechanism of the prepared composite by conducting tensile tests and finite element analysis respectively. They concluded that the defects of basalt fibre such as low ductility and poor tensile properties of glass fibre can be remedied through the mixture of basalt and glass fibre. Nuryanta et al., (2022) investigate the effect of stacking sequence on moisture absorption of natural and hybrid composites consisting of glass fibre under varying layers of natural fibres. Jute, Agel, and bamboo are used as the natural fibre reinforcements, whereas glass fibre and epoxy resin were used as the synthetic fibre and matrix respectively. They reported that hybridization of natural fibre with glass fibre can reduce the water content of hybrid composites and concluded that minimizing surface exposure can increase the moisture resistance of the composites.

Irina et al., (2015) investigate the mechanical properties of three different arrangements of hybrid composites fabricated using the vacuum-assisted transfer moulding method. They concluded that the hybrid composite with lighter weight and higher strength is paramount in modelling the shortage of petrol fuel as well as reducing the environmental burden of automotive vehicles and aerospace structures. Bhoopathi et al., (2014) fabricated a banana-hemp-glass fibre reinforced hybrid composite using the hand lay-up method and evaluated their mechanical properties such as tensile strength, flexural strength, and impact strength. They observed from the results that the banana-hemp-glass fibres reinforced hybrid epoxy composite exhibited superior properties and can be used as an alternate material for synthetic fibre materials.

Rana et al., (2017) investigated the effects of sisal fibre loading on the mechanical properties of a hybrid composite developed using two fixed layers of glass fibre reinforcement on an epoxy matrix. They concluded that proper homogeneous mixing of sisal fibre, and glass fibre with epoxy resin plays a vital role in the resultant mechanical properties of the composites. Hemath Kumar et al., (2017) reinforced epoxy resin with treated sugar cane fibre and glass fibre to develop a hybrid composite, the hybrid reinforced composite was produced using the hand lay-up method. They reported that the addition of sugar cane fibre along with chopped glass fibre resulted in the improvement of the mechanical properties of the hybrid composites. Shrivastava et al., (2017) fabricated a NaOH-treated short coir fibre with glass fibre mat hybrid composite using the hand lay-up method. An experimental analysis of the mechanical properties and water absorption behaviour of the treated coir-glass fibre-reinforced epoxy composite was carried out. They concluded that though the use of glass mats reduces moisture absorption a bit, still fibre length and loading have a major effect on the mechanical properties of composites.

III. FUTURE PROSPECTS

The future prospects for lightweight composite materials in aerospace application include the primary advantages of advanced composites, which is their exceptional strength-to-weight ratio. This can reduce fuel consumption and increase payload capacity. Similarly, advanced composites offer unparalleled design flexibility, allowing design engineers to create complex and aerodynamically optimized structures that were previous unattainable. Other areas were lightweight advanced composites excel are their enhanced durability, improved safety and environmental sustainability. By enabling lighter aircraft, these composites contribute to significant fuel savings, and reduced greenhouse gas emissions.

IV. CONCLUSION

The development of lightweight composite materials has revolutionalized the aerospace industry, enabling significant weight reductions, improved fuel efficiency, and enhanced performance. From the early adoption of glass fibre reinforced polymers to the current state-of-the-art carbon fibre reinforced polymers and beyond. Composite materials have played a crucial role in shaping the modern aerospace landscape. As the aerospace industry continues to push the boundaries of innovation, lightweight composite material will remain a critical component of this journey, enabling the creation of next-generation aircraft and spacecraft that are safer, greener, and more efficient.

REFERENCES

[1]. Abdullahi, I., & Umar, A. (2011). POTENTIALS OF UNSATURATED POLYESTER -GROUNDNUT SHELL COMPOSITE AS MATERIAL IN BUILDING INDUSTRY. 5, 78–84.

[2]. Akinwande A. A., Kumar M. S., Romanovski V. (2023). Mechanical strengthening and micro-mechanical modelling of newly fabricated 7068-aluminium/lightweight-high-entropy-alloy as aero-material . Materials Chemistry and Physics 309 , https://doi.org/10.1016/j.matchemphys.2023.128344

[3]. Anandan, B., & Manikandan, M. (2023). Effect of welding speeds on the metallurgical and mechanical property characterization of friction stir welding between dissimilar aerospace grade 7050 T7651-2014A T6 aluminium alloys. Materials Today Communications, 35, 106246. https://doi.org/https://doi.org/10.1016/j.mtcomm.2023.106246

[4]. Aravinth, K., Sathish, R., Ramakrishnan, T., Balu Mahandiran, S., & Shiyam Sundhar, S. (2023). Mechanical investigation of agave fiber reinforced composites based on fiber orientation, fiber length, and fiber volume fraction. Materials Today: Proceedings. https://doi.org/https://doi.org/10.1016/j.matpr.2023.05.436

[5]. Arbo, S. M., Tomovic-Petrovic, S., Aunemo, J., Dahle, N., & Jensrud, O. (2022). On weldability of aerospace grade Al-Cu-Li alloy AA2065 by wire-feed laser metal deposition. Journal of Advanced Joining Processes, 5, 100096. https://doi.org/https://doi.org/10.1016/j.jajp.2022.100096

[6]. Awate, P. P., Barve, S. B., Pesode, P., & Shinde, S. S. (2023). Graphene/Al6061 nanocomposite for aerospace and automobile application. Materials Today: Proceedings. https://doi.org/https://doi.org/10.1016/j.matpr.2023.07.075

[7]. Barbosa, G., Carmona Hernandes, A., S, L., J, B., VA, N., & Becker, M. (2017). A Conceptual Study Towards Delivery of Consumable Materials to Aircraft Assembly Stations Performed by Mobile Robots Based on Industry 4.0 Principles.

Journal of Aeronautics & Aerospace Engineering, 06. https://doi.org/10.4172/2168-9792.1000187

[8]. Bhavya, S., Velmurugan, R., & Arunachalam, K. (2021). Evaluation of E glass epoxy composite laminate as an electromagnetically transparent aerospace material. Materials Today: Proceedings, 46, 4825–4834. https://doi.org/https://doi.org/10.1016/j.matpr.2020.10.320

[9]. Bhoopathi, R., Ramesh, M., & Deepa, C. (2014). Fabrication and Property Evaluation of Banana-Hemp-Glass Fiber Reinforced Composites. Procedia Engineering, 97, 2032–2041. https://doi.org/https://doi.org/10.1016/j.proeng.2014.12.446

[10]. Cavaleiro, D., Figueiredo, D., Moura, C. W., Cavaleiro, A., Carvalho, S., & Fernandes, F. (2021). Machining performance of TiSiN(Ag) coated tools during dry turning of TiAl6V4 aerospace alloy. Ceramics International, 47(8), 11799–11806. https://doi.org/https://doi.org/10.1016/j.ceramint.2021.01.021

[11]. Dimple, Singh, G. P., & Mangal, R. (2023). A comprehensive review of natural fiber reinforced composite and their modern application. Materials Today: Proceedings. https://doi.org/https://doi.org/10.1016/j.matpr.2023.03.745

[12]. Edwin Raja Dhas, J., & Arun, M. (2022). A review on development of hybrid composites for aerospace applications. Materials Today: Proceedings, 64, 267–273. https://doi.org/https://doi.org/10.1016/j.matpr.2022.04.511

[13]. Elfaleh, I., Abbassi, F., Habibi, M., Ahmad, F., Guedri, M., Nasri, M., & Garnier, C. (2023). A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials. Results in Engineering, 19, 101271. https://doi.org/https://doi.org/10.1016/j.rineng.2023.101271

[14]. Faruk, O., Bledzki, A. K., Fink, H.-P., & Sain, M. (2012). Biocomposites reinforced with natural fibers: 2000–2010. Progress in Polymer Science, 37(11), 1552–1596. https://doi.org/https://doi.org/10.1016/j.progpolymsci.2012.04.003

[15]. Gad, S. M., Jin, Z., Emad, S., Vergara, J. E., Yawas, D. S., Dagwa, I. M., & Momoh-Bello Omiogbemi, I. (2023). Potential of rare-earth compounds as anticorrosion pigment for protection of aerospace AA2198-T851 alloy. Heliyon, 9(3), e14693. https://doi.org/https://doi.org/10.1016/j.heliyon.2023.e14693

[16]. Gholampour, A., & Ozbakkaloglu, T. (2020). A review of natural fiber composites: properties, modification and processing techniques, characterization, applications. Journal of Materials Science, 55(3), 829–892. https://doi.org/10.1007/s10853-019-03990-y

[17]. Guo, K., Liu, X., Ren, Y., & Jiang, H. (2023). Experimental study on crashworthiness and failure mechanisms of aeronautical multi-fibers hybrid composite corrugated structures with Carbon, Glass, Kevlar. Aerospace Science and Technology, 142, 108599. https://doi.org/10.1016/j.ast.2023.108599

[18]. Habibi, M., Selmi, S., Laperrière, L., Mahi, H., & Kelouwani, S. (2020). Post-Impact Compression Behavior of Natural Flax Fiber Composites. Journal of Natural Fibers, 17(11), 1683–1691. https://doi.org/10.1080/15440478.2019.1588829

[19]. Helal Miah, M., Singh Chand, D., & Singh Malhi, G. (2023). Research on formation analysis of Al-Mg-Si alloy FSLW process in aerospace technology. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.02.305

[20]. Hemath Kumar, G., Babuvishwanath, H., Purohit, R., Sahu, P., & Rana, R. S. (2017). Investigations On Mechanical Properties Of Glass And Sugarcane Fiber Polymer Matrix Composites. Materials Today: Proceedings, 4(4, Part D), 5408–5420. https://doi.org/https://doi.org/10.1016/j.matpr.2017.05.052

[21]. Irina, M. M. W., Azmi, A. I., Tan, C. L., Lee, C. C., & Khalil, A. N. M. (2015). Evaluation of Mechanical Properties of Hybrid Fiber Reinforced Polymer Composites and their Architecture. Procedia Manufacturing, 2, 236–240.

https://doi.org/https://doi.org/10.1016/j.promfg.2015.07.041

[22]. Jensin Joshua, J., Singh Lohchab, D., Nikhil Aanandhan, A. R. S., Ashwin, M., Keerthana, S., Sateesh, R., & Seralathan, S. (2023). Evaluation of quasi static strength of Kevlar/Basalt-Epoxy and Kevlar/Glass-Epoxy Intra-woven composite laminate. Materials Today: Proceedings. https://doi.org/https://doi.org/10.1016/j.matpr.2023.04.249

[23]. K., V. C., M.N., P., Lee, D. W., & Song, J. (2023). Development of carbon prepreg/epoxy self-healing composites by inserting bio lumen carriers: A novel approach. Journal of the Mechanical Behavior of Biomedical Materials, 143, 105883. https://doi.org/https://doi.org/10.1016/j.jmbbm.2023.105883

[24]. Kamal, A., Shukla, A. K., Shinde, V. M., & Rajasekhar, B. V. (2023). Microstructure and mechanical properties of C/SiC-niobium alloy (C103) joint brazed with TiCuAg alloy for aerospace applications. Ceramics International, 49(17, Part B), 29265–29273. https://doi.org/https://doi.org/10.1016/j.ceramint.2023.06.218

[25]. Kanok, Md. M. H., Shifa, S. S., Haque, M. S., & Akter, A. (2023). Comparative study on mechanical properties of banana-glass fiber reinforced epoxy hybrid composites. Materials Today: Proceedings. https://doi.org/https://doi.org/10.1016/j.matpr.2023.08.356

[26]. Karaboga F., Golec F., Yunus D. E., Toros S., Oz Y. (2024). Mechanical response of carbon fiber reinforced epoxy composite parts joined with varying bonding techniques for aerospace applications. Composite Structures 331 , https://doi.org/10.1016/j.compstruct.2024.117920

[27]. Kazemi M. E., Medeau V., Chen Y., Xu Z., Petrinic N., Greenhalgh E., Robinson P., Finlayson J., Pinho S. T. (2024). Ballistic performance of bio-inspired hybrid interleaved composite structures suitable for aerospace applications. Composites Part A 179 , https://doi.org/10.1016/j.compositesa.2023.107992

[28]. Khalid, M. Y., Al Rashid, A., Arif, Z. U., Ahmed, W., Arshad, H., & Zaidi, A. A. (2021). Natural fiber reinforced composites: Sustainable materials for emerging applications. Results in Engineering, 11, 100263. https://doi.org/https://doi.org/10.1016/j.rineng.2021.100263

[29]. Kudva, A., Kotian, A., Mahesha, G. T., & Pai, D. (2023). Experimental investigation of mechanical properties of bamboo/carbon fiber reinforced hybrid polymer matrix composites. Materials Today: Proceedings. https://doi.org/https://doi.org/10.1016/j.matpr.2023.04.398

[30]. Lahbari A., Bouchaala K., Essoussi H., Faqir M., Ettaqi S., Essadiqi E. H. (2024). Homogenization heat treatment influence on microstructure evolution and mechanical properties of as-cast Al–Li–Cu–Mg–Zr alloy for lightweight aerospace application. Heliyon 10 , 24426

[31]. Lakshmi Kala, K., & Prahlada Rao, K. (2022). Synthesis and characterization of fabricated fiber metal laminates for aerospace applications. Materials Today: Proceedings, 64, 37–43. https://doi.org/https://doi.org/10.1016/j.matpr.2022.03.488

[32]. Li S., Yue X., Li Q., Peng H., Dong B., Liu T., Yang H., Fan J., Shu S., Qiu F. Jiang Q. (2023). Development and applications of aluminum alloys for aerospace industry. Journal of Materials Research and Technology , 944-983.

[33]. Lomo F. M., Patel M. J., Vargas-Uscategui A., King P. C., Cole I. S. (2023). A design and optimisation framework for cold spray additive manufacturing of lightweight aerospace structural components☆. Additive Manufacturing 78 , 1-23

[34]. Naik, A. K., Nazeer, M., Prasad, D. K. V. D., Laha, T., & Roy, S. (2022). Development of functionally graded ZrB2–B4C composites for lightweight ultrahigh-temperature aerospace applications. Ceramics International, 48(22), 33332–33339. https://doi.org/https://doi.org/10.1016/j.ceramint.2022.07.276

[35]. Nuryanta, M. I., Sentanuhady, J., & Muflikhun, M. A. (2022). Moisture absorption behavior of hybrid composite laminates consist of natural and glass fiber. Materials Today: Proceedings, 66, 2924–

2928.https://doi.org/https://doi.org/10.1016/j.matpr.2022.06.559

[36]. Oyewo A. T., Oluwole O. O., Ajide O. O., Omoniyi T. E., Hussain M. (2024). A Summary of Current Advancements in Hybrid Composites Based on Aluminium Matrix in Aerospace Applications. Hybrid Advances , 1-14

[37]. Paladugu, S. R. M., Divya Aparna, N., & Rama Sreekanth, P. S. (2022). Experimental investigations and mechanical analysis of hybrid natural fibre reinforced composites. Materials Today: Proceedings, 56, 1115–1119. https://doi.org/https://doi.org/10.1016/j.matpr.2021.10.272

[38]. Pathania, A., Anand Kumar, S., Nagesha, B. K., Barad, S., & Suresh, T. N. (2021). Reclamation of titanium alloy based aerospace parts using laser based metal deposition methodology. Materials Today: Proceedings, 45, 4886–4892. https://doi.org/https://doi.org/10.1016/j.matpr.2021.01.354

[39]. Pazhani A., Venkatraman M., Xavior M. A., Moganraj A., Batako A., Paulsay J., Jayaseelan J., Anbalagan A., Bavan J. S. (2023). Synthesis and characterisation of graphene-reinforced AA 2014 MMC using squeeze casting method for lightweight aerospace structural applications. Materials and Design 230 , 1-14

[40]. Rana, R. S., kumre, A., Rana, S., & Purohit, R. (2017). Characterization of Properties of epoxy sisal / Glass Fiber Reinforced hybrid composite. Materials Today: Proceedings, 4(4, Part D), 5445–5451. https://doi.org/https://doi.org/10.1016/j.matpr.2017.05.056

[41]. Sahu, M., Patnaik, A., Kishor Sharma, Y., & Dalai, A. (2023). Physico-mechanical and tribological behaviour of natural fiber reinforced polymer composites: A short review. Materials Today: Proceedings. https://doi.org/https://doi.org/10.1016/j.matpr.2023.03.822

[42]. Saxena, M., Pappu, A., Sharma, A., Haque, R., & Wankhede, S. (2011). Composite Materials from Natural Resources: Recent Trends and Future Potentials. In P. Těšinova (Ed.), Advances in Composite Materials (p. Ch. 6). IntechOpen. https://doi.org/10.5772/18264

[43]. Sehgal, A. K., Juneja, C., Singh, J., & Kalsi, S. (2022). Comparative analysis and review of materials properties used in aerospace Industries: An overview. Materials Today: Proceedings, 48, 1609–1613. https://doi.org/https://doi.org/10.1016/j.matpr.2021.09.498

[44]. Siengchin S. (2023). A review on lightweight materials for defence applications: Present and future developments. Defence Technology , 1-17

[45]. Shao, M., Cai, D., Yu, Q., Xing, D., Hu, F., Kuang, N., & Zhou, G. (2023). On mechanical properties of double-sided-loop 2D woven laminated composites. Composite Structures, 312, 116874. https://doi.org/https://doi.org/10.1016/j.compstruct.2023.116874

[46]. Sharma, V. K., Kumar, V., & Joshi, R. S. (2019). Investigation of rare earth particulate on tribological and mechanical properties of Al-6061 alloy composites for aerospace application. Journal of Materials Research and Technology, 8(4), 3504–3516. https://doi.org/https://doi.org/10.1016/j.jmrt.2019.06.025

[47]. Shrivastava, R., Telang, A., Rana, R. S., & Purohit, R. (2017). Mechanical Properties of Coir/ G Lass Fiber Epoxy Resin Hybrid Composite. Materials Today: Proceedings, 4(2, Part A), 3477–3483. https://doi.org/https://doi.org/10.1016/j.matpr.2017.02.237

[48]. Soutis, C. (2005). Fibre reinforced composites in aircraft construction. Progress in Aerospace Sciences, 41(2), 143–151. https://doi.org/https://doi.org/10.1016/j.paerosci.2005.02.004

[49]. Sunith Babu, L., Ashok Kumar, K., Jaya Christiyan, K. G., Byary, M. A., Manu Puranic, V., Mohammed Jawad, A. A., & Poojary, N. (2023). Effect of laminate thickness on low-velocity impact of GFRP/epoxy composites. Materials Today: Proceedings. https://doi.org/https://doi.org/10.1016/j.matpr.2023.08.229

[50]. Tahir, N., Umar, A., & Abdullahi, I. (2022a). Optimization of Mechanical Properties of Hybrid Biocomposite from Sterculiasetigeradelile Fibre and Pterocarpuserinaceus Wood Dust Epoxy.

[51]. Tahir, N., Umar, A., & Abdullahi, I. (2022b). Optimization of the mechanical properties of SterculiaSetigeraDelile fibre

epoxy composite using Taguchi methodology. 5, 33–42.

[52]. Tsai, W.-H., Chang, Y.-C., Lin, S.-J., Chen, H.-C., & Chu, P.-Y. (2014). A green approach to the weight reduction of aircraft cabins. Journal of Air Transport Management, 40, 65–77. https://doi.org/https://doi.org/10.1016/j.jairtraman.2014.06.004

[53]. Vasanthakumar, P., Sekar, K., & Venkatesh, K. (2019). Recent developments in powder metallurgy based aluminium alloy composite for aerospace applications. Materials Today: Proceedings, 18, 5400–5409. https://doi.org/https://doi.org/10.1016/j.matpr.2019.07.568

[54]. Veera ajay, C., Elangovan, S., & Justus Panicker, C. T. (2020). Studies on single point incremental forming of Ti-6Al-4V alloy for aerospace applications. Materials Today: Proceedings, 22, 1967–1976. https://doi.org/https://doi.org/10.1016/j.matpr.2020.03.162

[55]. Vigneshwaran, S., Sundarakannan, R., John, K. M., Joel Johnson, R. D., Prasath, K. A., Ajith, S., Arumugaprabu, V., & Uthayakumar, M. (2020). Recent advancement in the natural fiber polymer composites: A comprehensive review. Journal of Cleaner Production, 277, 124109. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.124109

[60].

[56]. Wu, G., Ren, Y., Du, J., Wang, H., & Zhang, X. (2023). Mechanical properties and failure mechanism analysis of basalt-glass fibers hybrid FRP composite bars. Case Studies in Construction Materials, 19. https://doi.org/10.1016/j.cscm.2023.e02391

[57]. Zhao, Q., Sun, Q., Xin, S., Chen, Y., Wu, C., Wang, H., Xu, J., Wan, M., Zeng, W., & Zhao, Y. (2022). High-strength titanium alloys for aerospace engineering applications: A review on melting-forging process. Materials Science and Engineering: A, 845, 143260. https://doi.org/https://doi.org/10.1016/j.msea.2022.143260

[58]. Zhu, L., Li, N., & Childs, P. R. N. (2018). Light-weighting in aerospace component and system design. Propulsion and Power Research, 7(2), 103–119. https://doi.org/https://doi.org/10.1016/j.jppr.2018.04.001

[59]. Xia Q., Wang X., Huang Z., Chen L., Li C., Wang X., Lv G., Huang X., Chen Q., Chen M., Li J. (2024). Lightweight titanium dioxide/carbon nanotube composites prepared by atomic layer deposition for broad-band microwave absorption. Ceramics International , 1-8 https://doi.org/10.1016/j.ceramint.2024.05.203