A Critical Review Of Composite Materials And Stealth Technology In Modern Aerospace Engineering

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DOI: 10.29322/IJSRP.14.03.2024.p14720
https://dx.doi.org/10.29322/IJSRP.14.03.2024.p14720

Paper Received Date: 4th February 2024
Paper Acceptance Date: 8th March 2024
Paper Publication Date: 15th March 2024

Abstract- The aerospace sector is always changing as it aims to achieve higher efficiency, safety, and performance levels. A noteworthy progression in this endeavor is the application of composite materials in aircraft construction. One of the many benefits of composites is their high strength-to-weight ratio, resistance to corrosion, and flexibility in design. They have become commonly used in contemporary airplanes, which has improved structural integrity, decreased weight, and increased fuel efficiency.

The review explores the use of composites in stealth technology, highlighting how they can be used to alter radar signatures and improve aircraft survivability.

Index Terms- Aircraft structures, Composite materials, Radar signature, Stealth technology.

I. INTRODUCTION

The aim towards improved performance, safety, and efficiency has driven continuous innovation in aerospace engineering.

This endeavor has seen two key milestones: the incorporation of composite materials and the advancement of stealth technology. Composite materials, which are formed by the synergistic interaction of two or more unique elements with significantly diverse physical or chemical properties, provide numerous advantages over typical metallic structures. These advantages include a high strength-to-weight ratio, excellent resistance to corrosion, and greater design flexibility. As a result, composites have been extensively adopted in modern aircraft, including commercial airliners, military jets, and unmanned aerial vehicles (UAVs).

Stealth technology, on the other hand, represents a novel approach to modern aircraft design, notably in military applications. This technology is intended to reduce an aircraft's detectability by radar, infrared, and other detection systems. This is accomplished through a variety of factors, including the use of advanced materials with specific electromagnetic properties, strategic sculpting of the aircraft to deflect radar waves, and the application of specialized coatings to absorb or scatter infrared radiation.

This paper provides a critical analysis of the relationship between these two advances. It delves into the distinctive features of composite materials and their specific uses in aircraft design and construction. By evaluating these improvements concurrently, the research hopes to shed light on how the evolution of materials and design has had a substantial impact on the trajectory of modern aerospace engineering.

II. ROLE OF COMPOSITES IN AEROSPACE STUCTURE

A. Understanding Composites

A composite material combines strong carry-load components with a weaker base material. The stronger substance is referred to as reinforcement, while the weaker element is called the matrix. Reinforcement provides necessary strength and rigidity to support structural loads and matrix acts as a binder which helps to maintain the position and orientation of the reinforcement.

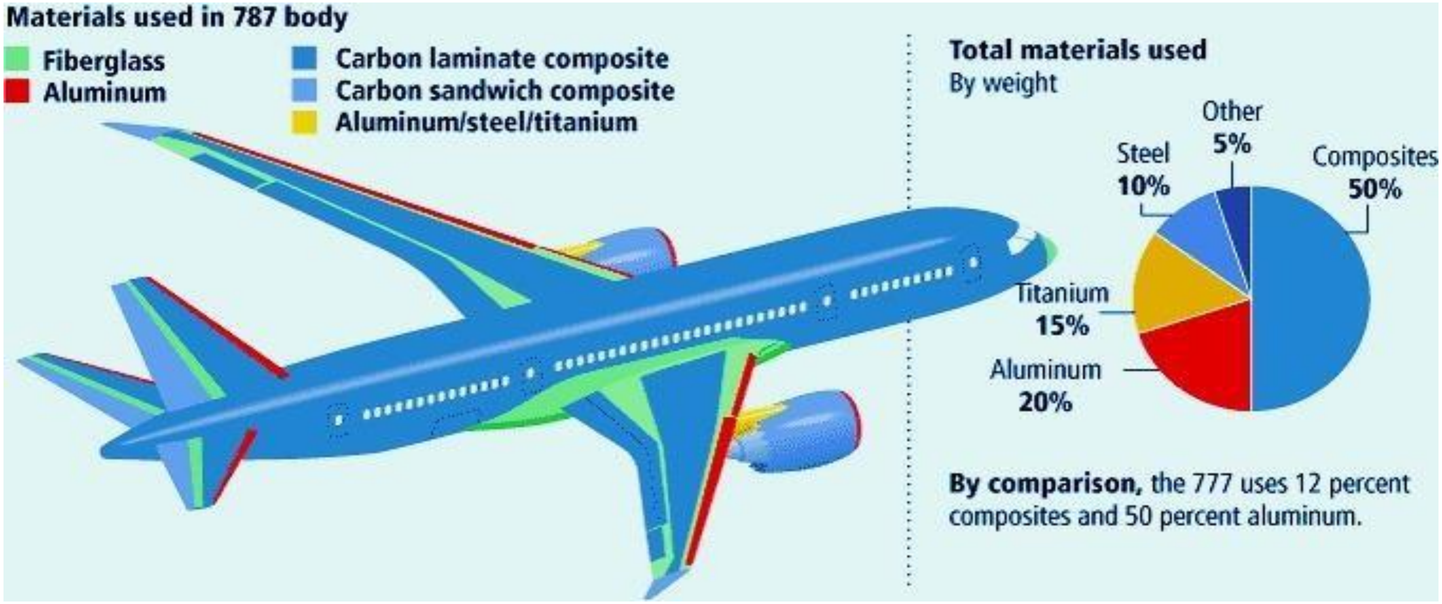
The end product is a composite material that is strong, rigid, and bend-tolerant since it combines the tensile strength of the fiber reinforcer, the compressive strength of the matrix, and the combination's bending strength [1].

B. Types of Composites used in Aircrafts

Ceramic Matrix Composites (CMC's): Type of composite in which both the reinforcement and the matrix material are ceramics. These types of composites are widely studied in recent years mainly because of their advanced properties such as high- temperature stability pertaining upto 1400^{0}C, high hardness upto 22.9 GPa for Al- based composites. The main examples of CMC's used in aircraft's brake disks, high- temperature engine components include silicon carbide (SiC), silicon nitride (Si_3N_4), alumina (Al_2O_3), aluminum nitride (AlN).

Metal Matrix Composites (MMC's): Type of composite in which a metal- based matrix is generally combined together with reinforcement, typically ceramics or fibers. These types of composites are used in the fuselage and doors of an aircraft mainly due to its higher yield strength, low thermal expansion and suitable wear resistance. The main examples of MMC'c used in aircrafts include Aluminium matrix composites (AMC's) such as LM25, AA6061 in aircraft wing and engines. Magnesium – based MMC's such as WE43B, ZE41A, EV31A and QE22A in landing gears and engine components. Titanium- based MMC's such as Ti6A12Sn4Zr2Mo and Ti6A14V in fuselage of the aircraft.

Polymer Matrix Composites (PMC's): Type of composite composed of a polymer matrix reinforced with fibres or particle fillers. The polymer matrix is commonly constructed of a thermosetting or thermoplastic resin, with reinforcement options including glass, carbon, aramid, or natural fibres. The distinctive features of these type of composites include low density, corrosion resistance, good thermal stability and excellent insulation properties. The main examples of PMC's used in aircraft include carbon fiber reinforced epoxy composite (CFRP) in ailerons, elevators and rudders. Polyactic fibre (PLA) reinforced glass fibre composite in window panes, acoustic liners and engine access doors.



By comparison, the 777 uses 12 percent composites and 50 percent aluminum.

Figure: Shows the distribution of various types of composites used in a Boeing 787 aircraft.[4]

C. The advantages and disadvantages of using composites in aircraft

Composite utilization is on the rise in aerospace and military industries, with projected major growth in certain categories over the next 20 years. Going forward, the overall composite material market is expected to double at a compound annual growth rate of 7.3%, reaching US $30 billion by 2026[1].

The advantages of composites include:

- Improved fuel efficiency in the range of 16% - 20%, majorly due to reduction of weight in aircraft body.
- Reduced risk of structural failure due to fatigue, thereby enhancing the overall safety of the aircraft.
- Due to less air resistance on the surface of the aircraft's body, drag reduces up to 5%.
- High impact resistance, mainly with the usage of Kevlar and Carbon fiber composites.
- As composite materials are immune to corrosion, they offer up to 100% corrosion resistance.

Some of the major disadvantages include:

- High initial cost up to 2 times when compared with the traditional materials.
- Complicated repair process of damaged composite structures.
- The materials may degrade over time, due to continuous exposure to UV radiation and temperature fluctuations.
- Difficult to detect any kind of internal damages such as dents or cracks.

III. USAGE OF COMPOSITE MATERIALS IN CURRENT AEROSPACE INDUSTRY

The A380 is the first aircraft ever that used a CFRP (Carbon Fiber Reinforced Plastic) composite central wing box, representing a weight saving of up to one and a half tones compared to the most advanced aluminum alloys [1].

Airbus was the first manufacturer to make extensive use of composites and other advanced materials for producing large commercial aircraft, beginning with the A310 jetliner – based fin box [1].

At present, the new airframes are predominantly composites, such as Boeing 787 Dreamliner and Airbus A350 XWB in which composites have 80% participation by volume (i.e., 50% participation by weight).

More than 50% of the Boeing 787 airframe and the Airbus A350 XWB consists of carbon composite, whereas aluminum compromises about only 12% of the aircraft.

On the 787’s exterior surface, the only visible metal is on the leading edges and the engine pylons. The material being used on the 787's primary structures, such as the wings and fuselage, is a redevelopment of the Toray Composites America (Tacoma, Wash). But Toray has changed the method for adding the thermoplastic toughening agent to reduce its cost, and the more recent material product form is in production use on the 777 on a substitution basis.

30% of the A400 Atlas’s structure is made up of composites. The entire tail (including horizontal and vertical stabilizers with the control surfaces), the rear cargo door and the propeller blades are made up of composite materials [2]. The extensive use of composite materials enables the A400 to be much lighter, thereby enhancing the overall performance both in terms of range and payload.

Engine fan cases on the GE’s GEnx jet engine, which are primarily used in the 787, are made from composite materials manufactured using infusion process. This first use of all- composite structure to suppress the fan blade failure represents a significant weight savings.

Airbus Atlantic, which is currently under development, aims to integrate complex composites and hybrid aerostructures showcasing a radome concept mainly made up of glass and quartz prepreg. Airbus is currently involved in design and manufacture of a wide range of thermoset and thermoplastic aircraft structures, parts and aerospace equipment [6].

IV. STEALTH TECHNOLOGY IN MODERN AVIATION INDUSTRY

Stealth is primarily a combination of numerous technologies that work together to significantly minimize the distance at which an aircraft can be detected. The key concept behind aircraft stealth technology is the use of materials that absorb radar signals and the structuring of the aircraft to divert radar signals away from the radar source. By reducing the radar's cross-section, this combination lessens the detectability of the aircraft. In order to prevent radar signals from being reflected back to the source, stealth aircraft design relies heavily on sharp edges and flat surfaces.[6]

Figure: In the F-22 Raptor, reflections were reduced when the leading edge of the wing and the tail plane were positioned at the same angle. [6]

Figure: Shows how the shape of the aircraft influences the deflection of radar signals for better stealth performance. [6]

A. Key Principles of Stealth Aircraft [11]

Aimed at reducing their susceptibility to detection by radar, infrared, and acoustic sensors, aircraft employ stealth technology. This is made possible by three fundamental ideas:

Developing the Strategy: Stealth planes are shaped differently than other aircraft, with slanted surfaces and seamless transitions. By decreasing their radar cross-section (RCS) and scattering radar waves away from enemy detection systems, these designs make it more difficult to be detectable.

Material Advantage: To further reduce the aircraft's RCS, advanced materials with particular electromagnetic properties, such as low-observable coatings and radar-absorbing composites (RAM), are essential. By scattering or absorbing radar waves, these materials interfere with the enemy's radar signature.

Heat Management: In order to avoid heat-seeking missiles, stealth technology also takes into account infrared (heat) signature. Stealth aircrafts utilize coatings which absorb infrared red radiation allowing them to be less detected by enemy radar.

B. Types Of Stealth Materials [9]

Radar Absorbent Surfaces (RAS) are the parts of the aircraft with surfaces that have the ability to deflect incoming radar waves and shorten the detection range. The angles at which the aircraft's fuselage or its individual parts are positioned allow RAS to function.

Radar Absorbent Materials (RAM) are composite materials consisting of a matrix, or insulating binder, and reinforcements, or conductive and magnetic fillers. Through its significant absorption of incident electromagnetic energy, it works to lower the reflected electromagnetic radiations. It functions by absorbing a large percentage of the incident electromagnetic energy, hence reducing the reflected electromagnetic radiation.

Nano-Composite Coating are typically employed to shield the aircraft's surfaces and structures from abrasive conditions. The need for more dependable high-performance coatings has increased due to the strict criteria, which include resistance to extreme temperatures, extreme climates, corrosion, abrasion, and wear of engine parts. Future engine performance could be enhanced by greater operating temperatures made possible by certain nanomaterial coatings with enhanced high temperature characteristics.

C. Basic Requirements of Stealth Materials [7]

The material should be lightweight & should have good resistance to extreme temperatures (from -60 to +60 degrees C)

The material should have high reliability and should be durable. The material should not intervene with the aerodynamic performance of the aircraft (Certain material orientations may cause a loss in aerodynamic performance)

The material cannot corrode, e.g. should be able to deal with extreme weather conditions

The material should have high friction resistance (Due to the high speeds the air causes friction with the outside layer of coating)

The material should be radiation resistant (Up in the atmosphere radiation values are substantially higher)

V. CHARATERISTICS OF STEALTH MATERIALS

FeCo-MOG/CP, a metal-organic gel containing collagen peptide (CP), Fe^{3+}, and Co^{2+} ions complexed with 1,3,5-benzenetricarboxylic acid (H3BTC), was the material employed in the study [18]. With the help of this precursor, nitrogen-doped carbon aerogels with an even dispersion of magnetic particles can be made for improved radar stealth. Models are coated with the FeCo/Fe_3O_4/NC-600 aerogel and exposed to electromagnetic wave (EMW) radiation as part of the radar stealth demonstration. The radar cross-section (RCS) values of the coated and uncoated models are compared using computer simulations of real-world far-field circumstances. Findings indicate that the FeCo/Fe_3O_4/NC-600 aerogel effectively attenuates radar waves by dramatically reducing RCS values, particularly on the J-20 fighter model. Radar stealth is improved through improved impedance matching, which is facilitated by uniform magnetic particle distribution.

FeCo/Fe3O4/NC and FeCo/NC aerogels perform exceptionally well in terms of electromagnetic wave absorption and radar stealth by:

1. Magnetic Coupling: Through heterometallic magnetic coupling systems, dual soft-magnetic particles improve microwave absorption.

2. Uniform Dispersion: This improves radar stealth by preventing the aggregation of magnetic particles and ensuring effective absorption.

3. Tailored Framework: FeCo/Fe3O4/NC aerogel's virus-shaped particles serve as antennas, enhancing the absorption and transmission of electromagnetic waves.

4. Impedance Matching: By lowering reflection losses and increasing wave absorption, magnetic particles enhance impedance matching.

Radar stealth and electromagnetic wave absorption are generally quite good in FeCo/Fe3O4/NC and FeCo/NC aerogels due to magnetic coupling, uniform dispersion, customized structure, and impedance matching.

According to another study [14], Carbon-based materials, such as carbon blacks, carbon fibers, carbon nanotubes, graphite, graphene, and MXene, are utilized in radar absorbent materials (RAMs) for stealth technology. The materials were selected because of their special qualities that make them perfect for radar absorption.

Due to their high specific surface area, materials based on carbon can interact with electromagnetic waves more. Because of their low weight, these materials are appropriate for uses where weight is a crucial consideration. By virtue of their superior dielectric qualities, materials made of carbon can efficiently absorb and disperse electromagnetic energy. Electromagnetic waves can be more easily absorbed and dispersed when materials based on carbon have a high electrical conductivity. Since carbon-based materials are proven to remain stable in extreme environments, military applications can benefit from their use.

Radar Absorbing Mechanism [16]

RAMs operate on two main mechanisms to reduce or eliminate reflected waves:

1. Absorption Mechanism: This mechanism involves absorbing electromagnetic waves by the material, leading to dielectric, resistive, and/or magnetic losses. The absorbed energy is converted into heat energy.

2. Multiple Internal Reflections: RAMs utilize multiple internal reflections of the incident wave from the back and front interior faces of the material to reduce wave intensity.

3. Optimization of RAMs: The composition, microstructure, and surface geometry of RAMs can be optimized to enhance their radar absorbing capabilities. By adjusting these factors, the effectiveness of RAMs in reducing radar signals can be improved.

The unique properties of carbon-based materials, such as their large specific surface area, lightweight nature, excellent dielectric properties, high electrical conductivity, and stability under harsh conditions, make them ideal for radar absorbing materials in stealth technology applications. These materials, combined with optimized composition and structure, play a crucial role in reducing radar detection and enhancing the stealth capabilities of military equipment.

The review article [10] explores the use of composites, specifically carbonaceous-based polymer composites, as radar absorbing materials (RAMs) for stealth aircraft. The materials explored include carbon black particles, carbon fibers, carbon nanotubes (CNTs), and graphene. The article suggests that composites containing carbon fiber as a filler have shown optimized absorption properties, making them a preferred choice for stealth applications. Additionally, CNTs are favored due to their smaller loading (0.35%) to achieve conductivity equal to a higher concentration of carbon black (20%), thus improving the stealth technology. Furthermore, the article discusses the enhanced electromagnetic absorption properties achieved from graphene-based RAMs, especially when incorporating magnetic particles of different microstructures, particle size, and electromagnetic characteristics. These materials contribute to the stealth capability of the aircraft by minimizing the reflection of electromagnetic waves back to a radar system. The composites, especially those containing carbon fiber, CNT’s and graphene are designed to tailor the wave's absorption properties, thus reducing the radar cross-section and making the aircraft less detectable by opponent's detection systems.

In another study [12], Microwave absorbing materials that says about how carbon materials, metal oxides, and High-entropy alloys (HEAs) are used in stealth application. Carbon materials are effective microwave absorbers due to their low density and good electrical conductivity. Examples include carbon nanotubes, graphene, and carbon black. Metal oxides are materials that can effectively absorb microwave radiation by varying their composition and morphology. Some examples include ferrites, perovskites and spinels.
High entropy Alloys (HEA) are a new class of materials with unique properties including excellent microwave absorption. HEAs are composed of five or more elements in equal or near equal proportions, which gives them a complex microstructure and superior properties compared to traditional alloys. Furthermore, research indicates that some HEAs have considerably better strength-to-weight ratios, with a higher degree of fracture resistance, tensile strength and corrosion and oxidation resistance than conventional alloys.

In another study [17], fiber mats are considered better than coatings due to their huge reflection loss phenomena and also providing low maintenance of the coating in some cases. Some of the key properties emphasized by the author when manufacturing radar absorbing materials would be permeability, thickness, complex permittivity and intrinsic impedance of the material influences the performance of stealth coatings. The exact composition of RAM is classified, but according to one of the articles he reviewed in which the composition $BaFe_{12}O_{19}$, a combination of barium, iron and oxygen had high reflection loss and loss in bandwidth. Further studies also inclined towards how adding certain metallic elements improved more on the stealth capabilities. The author suggests that combining these materials with strategic aircraft shaping significantly reduces radar cross-section (RCS) thereby giving more survivability to the aircraft.

Pyramidal shaped RAMs in another study [19], found to be more effective in diverting radar power and reduce electromagnetic issues in the airframe. Another study [18] explored the use of various nano materials for airframe and propulsion materials as they were best considered for stealth technology due to their low observability, light weight, high strength, high toughness and corrosion resistance. The author also says about various methods like echo cancellation and radar absorbent materials used in stealth technology.

Another article [10] discussed how stealth technology plays its role in airpower. The article explores the evolution of airpower and the increasing importance of stealth technology in shaping warfare. It reviews the role of stealth aircraft and the significance of stealth technology in recent conflicts, the paper delves into the fundamental aspects of stealth technology including radar, infrared and visual signatures, their sources, modeling techniques and methods of signature reduction. It highlights the growing importance of infrared signatures relative to radar signatures and compares the lock-on and surveillance ranges of infrared detectors. Future projections in stealth technology, especially concerning anti-stealth technologies, are also discussed. It emphasizes the impact of stealth technology on air superiority and the survivability of aircraft in hostile environment. It touches upon the advantages of IR detection systems over radar systems and the effectiveness of Electronic Warfare techniques with stealth aircraft. The paper also addresses the sources of IR radiation, methods for reducing IR signatures, and the threat posed by IR-seeking missiles. It compares radar and IR signatures, discussing the advantages and limitations of each in modern warfare scenarios and concludes by highlighting the significance of reducing radar and IR signatures for enhancing aircraft survivability and achieving air superiority in combat situations.

VI. FUTURE SCOPE

Self- reliant materials such as self- cleaning polymerics and self- repairing materials have great potential for use in modern aircrafts.
The self- healing materials can be generally polymer, ceramic or metal matrix composites. According to [1], carbon nanotube technology is been looked forward as these can be applied for EMI shielding of large-scale aircrafts. Shape memory metals (SSM's) are being widely looked upon as they revert back to their pre-deformed shape when heated, thereby reducing the repair costs.
Green composites which are derived from renewable resources is bringing up a promising potential for its use in aircrafts aiming for sustainable development. These green composites are generally fabricated using plant fibers and resins which are currently used in automobile body parts aiming to provide better mechanical performance when combined with synthetic ones [3].

The future of stealth technology is very fascinating as it advances through the aerospace industry. Advancing technologies in aircraft design also further comes to a challenge for how these materials may be placed on aircraft such that performance and stability does not decrease. As the technology further advances so is the challenge of making better stealth materials comprehending towards improved radar signature machines and various radar guided missiles for better survivability of the aircraft. With Artificial Intelligence (AI) blooming in recent technological fields, unmanned aerial vehicles (UAV) are more employed towards autonomous operations to minimize human risks in highly risky mission. Stealth materials can help in less detection which enables the equipment to come back in one piece thereby reducing the repair costs. AI can easily identify and acquire accurate information for successful operations in these situations, wherein the inclusion of stealth materials is also vital so that their better survivability of the aircraft.

VII. CONCLUSION

In conclusion, this paper serves as a comprehensive examination of composite materials within the contemporary aviation industry. The review provides insight into composites utilized and their respective applications, which are aimed at enhancing aircraft performance. Deliberate attention is given to elucidating the advantages and disadvantages inherent in these materials, alongside an overview of their integration into prominent aircraft models such as the Boeing and Airbus aircrafts. Furthermore, the advancements in composite materials is looked up on thereby providing insights into sustainable and more reliable composites.

The review investigates into the growing utilization of composites, indicating them as the paradigm shift in the quest for more efficient and economically viable aircraft manufacturing. Notably, the exploration extends to the realm of stealth technology, particularly its evolution in military applications, which showcases pioneering advancements leveraging novel materials. This technology, with its primary objective of evading radar detection in high-risk missions, emerges as a pivotal asset in modern warfare strategies.
This technology in brief, is very useful towards avoiding radar detection of enemies in high-risk missions. Many UAV's also use this technology so that there is a decrease in cost of production and low risk towards human life. Overall, composite plays a vital role in helping grow the aviation industry towards more sustainable methods towards reduced disposable and wastage of materials.

In essence, composite materials symbolize a pivotal enabler in propelling the aviation industry towards greater efficiency and ecological responsibility. As such, their continued innovation and integration promise to reshape the landscape of aviation, paving the way for a more sustainable and technologically advanced future.

REFERENCES

1. Mrazova, M. (2013). Advanced composite materials of the future in aerospace industry. *INCAS Buletin*, *5*(3), 139–150.
2. Zhang, X., Chen, Y., & Hu, J. (2018). Recent advances in the development of aerospace materials. *Progress in Aerospace Sciences*, *97*, 22–34.
3. Balakrishnan, P., John, M. J., Pothen, L. A., Sreekala, M. S., & Thomas, S. (2016). Natural fiber and polymer matrix composites and their applications in aerospace engineering. In *Elsevier eBooks* (pp. 365–383).
4. Williams, J. C., & Starke, E. (2003). Progress in structural materials for aerospace systems11The Golden Jubilee Issue—Selected topics in Materials Science and Engineering: Past, Present and Future, edited by S. Suresh. *Acta Materialia*, *51*(19), 5775–5799.
5. Basheer, A. A. (2020). Advances in the smart materials applications in the aerospace industries. *Aircraft Engineering and Aerospace Technology*, *92*(7), 1027–1035.
6. Rana, S., & Fangueiro, R. (2016). *Advanced composite materials for aerospace engineering: Processing, Properties and Applications*. Woodhead Publishing
7. McIlhagger, A., Archer, E., & McIlhagger, R. (2020). Manufacturing processes for composite materials and components for aerospace applications. In *Elsevier eBooks* (pp. 59–81).
8. Kastratović, G., Grbović, A., Sedmak, A., Božić, Ž., & Sedmak, S. (2021). Composite material selection for aircraft structures based on experimental and numerical evaluation of mechanical properties. *Procedia Structural Integrity*, *31*, 127–133.
9. Ahmad, H., Tariq, A., Shehzad, A., Faheem, M., Shafiq, M., Rashid, I. A., Afzal, A., Munir, A., Riaz, M. T., Haider, H. T., Afzal, A., Qadir, M. B., & Khaliq, Z. (2019). Stealth technology: Methods and composite materials—A review. *Polymer Composites*, *40*(12), 4457–4472.
10. Rao, G. A., & Mahulikar, S. P. (2002). Integrated review of stealth technology and its role in airpower. *The Aeronautical Journal*, *106*(1066), 629–642
11. Navdeep Banga, 2017. "Research on stealth aircraft and its effect on radar system in modern warfare, International Journal of Current Research, 9, (08), 55654-55658.
12. Sahoo, P., Saini, L., & Dixit, A. (2022). Microwave-absorbing materials for stealth application: a holistic overview. *Oxford Open Materials Science*, *3*(1)
13. Pattanaik, B., & Chauhan, A. (2023). A study of stealth technology. *Materials Today: Proceedings*, *81*, 543–546
14. Parveez, B., Kittur, M., Badruddin, I. A., Kamangar, S., Hussien, M., & Umarfarooq, M. A. (2022). Scientific Advancements in Composite Materials for aircraft Applications: a review. *Polymers*, *14*(22), 5007.
15. Li, X., Hu, R., Xiong, Z., Wang, Q., Zhang, Z., Liu, C., Zeng, X., Chen, D., Che, R., & Nie, X. (2023). Metal–Organic gel leading to customized Magnetic-Coupling engineering in carbon aerogels for excellent radar stealth and thermal insulation performances. *Nano-Micro Letters*, *16*(1).
16. Filippatos, A., Markatos, D. N., Tzortzinis, G., Abhyankar, K., Malefaki, S., Gude, M., & Pantelakis, S. (2024). Sustainability-Driven design of aircraft composite components. *Aerospace*, *11*(1), 86.
17. Zhang-Hao Qu . Large-Scale, Mechanically Robust, Solvent-Resistant, and Antioxidant MXene-Based Composites for Reliable Long-Term Infrared Stealth. *Advanced Science, Wiley(2024).*
18. Li, X., Hu, R., Xiong, Z., Wang, Q., Zhang, Z., Liu, C., Zeng, X., Chen, D., Che, R., & Nie, X. (2023, December 4). Metal–Organic Gel Leading to Customized Magnetic-Coupling Engineering in Carbon Aerogels for Excellent Radar Stealth and Thermal Insulation Performances. Nano-Micro Letters.
19. Xin Li1, Ruizhe Hu1, Zhiqiang Xiong, Dan Wang1, Zhixia Zhang1, Chongbo Liu1, Xiaojun Zeng, Dezhi Chen, Renchao Che, Xuliang Nie. Metal–Organic Gel Leading to Customized Magnetic-Coupling Engineering in Carbon Aerogels for Excellent Radar Stealth and Thermal Insulation Performances. *Springer 2023.*

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