DESIGN AND DEVELOPMENT OF BASALT AND KEVLAR HYBRID COMPOSITE FOR AEROSPACE APPLICATIONS

Submitted by

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ABSTRACT

Common engineering materials, composites are created and produced for a range of uses in consumer items, sports goods, automotive components, aircraft parts, and the marine and oil industries. The global market is seeing an increase in the use of composites due to the use of lightweight components. Better-performing composite materials took the place of steel and aluminum. Due to their significant contribution to weight reduction, composite materials are utilized in both structural applications and as parts of a wide range of spacecraft and aircraft, including fighter jets, space shuttles, gliders, and hot air balloon gondolas. The creation of next-generation composite materials that are both lightweight and resistant to high temperatures will aid in the construction of efficient, high-performing airplanes. creation of composite materials based on epoxy resins that have been nanofilled in order to realize structural aeronautic components that effectively ward against lightning strikes. In order to prepare the epoxy matrix, a reactive diluent is mixed with a tetra functional epoxy precursor. This reduces the moisture content and makes the dispersion of the Nano filler easier. Reactive dilutients also help to increase the degree of cure in epoxy mixes containing nanoparticles. Compared to the epoxy precursor alone, it raises the mobility of reactive groups, resulting in a higher cure degree. My research primarily focuses on the development, study, and review of the mechanical properties, such as strain, hardness, wear and fatigue, impact strength, tensile strength, and 100% Basalt fabric epoxy composite and 100% Aramid fabric epoxy composite using various variables. It also reviews the mechanical properties by varying the blend ratio of the hybrid composite between Basalt and Aramid fabric epoxy using various variables. Once the relative mechanical properties have been developed and tested, finite element analysis will be used to evaluate the performance of 100% Basalt, 100% Aramid, and Basalt and Aramid fabric epoxy hybrid composites in aerospace applications. The results will be compared with an existing composite product that is utilized in passenger aircrafts.

Introduction

Basalt Fiber

Origin and Manufacturing:

Volcanic lava that has hardened is caked igneous rock or basalt (Jamshaid & Mishra, 2016). Igneous rock, or solidified volcanic lava, is what makes basalt, a hard, dense and inert rock that is found all over the planet (Kunal Singha, 2012). Hardened lava develops a grey and gloomy colour.

Basalt fiber is manufactured via melting, extruding, creating fibers, applying lubricants and finally winding. This procedure is known as spinning. Fiber is a substance formed into a long thread with a density of around 300 g/cm^2 and a length of 50 cm. It has no harmful reactions with water and emits no pollutants into the atmosphere. The fiber is stressed and offers rigidity, strength, heat resistance, and other structural properties in BFRP. It is alkaline and acid resistant; provides thermal, electrical, and acoustic insulation; its tensile strength may exceed that of carbon fiber and its elongation exceeds that of tiny carbon fiber (Bheel, 2021).

The raw material of basalt fiber (andesite basalt, andesite basalt, diabase and other volcanic rock) belongs to the family of inorganic non-metallic silicates and is characterized by a high content of Fe_2O_3 or FeO. A high content of Fe_2O_3 or FeO, on the other hand, results in a high melting factor, poor diathermy, and the need for a high crystallization temperature and high crystallization rate in the wire drawing process (Wu et al., 2020).

Basalt reinforced concrete

In the last few years, basalt fibers have been increasingly used to enhance concrete's stronger properties. A change in the hardened state of concrete is caused by the incorporation of these fibers into concrete (Bheel, 2021).

Properties

Mechanical:

1. **Compressive strength**
   In the last few years, basalt fibers have been increasingly used to enhance concrete's stronger properties. A change in the hardened state of concrete is

   caused by the incorporation of these fibers into concrete. In order to measure the quality of concrete, a compression force is often used. It can be defined as the ability of a material to resist the load and reducing the size of the material. Concrete typically has a high compressive strength and is capable of being highly loaded. However, the compressive strength of the mixture will be affected by an increase in the length and volume of basalt fibers (Bheel, 2021).

2. **Mechanical strength**
   The tensile strength of the Basalt fiber varies from 3000 to 4840 Mpa, which is higher than the glass fiber. Compared to E glass fibers, it has greater strength and stiffness. The specific gravity of the BF varies from 2.6gcc to 2.8gcc in comparison with ordinary fibers (Tavadi et al., 2022).

3. **Corrosion and fungi resistance**
   There is excellent corrosion and fungi resistance in the Basalt fiber. It's not reacting to air, gas or water. There is only a trace of moisture in the BF range below 1% (Tavadi et al., 2022).

4. **Abrasion property**
   Basalt filaments have hard filaments and hardness varies between 5 to 9 Mohr's scales. The abrasion properties are better and more powerful in a Basalt filament (Tavadi et al., 2022).

5. **Ecological friendliness**
   The raw materials used to make BF are usually basalts extracted from the rocks. It's not harmful to the health of humans. There is no biological risk and it does not pose a waste disposal problem. Therefore, the ecosystem considers this material to be a friend (Tavadi et al., 2022).

Chemical composition

Depending on the geographical location and the conditions of the formation of the source rock, the chemical composition of basalt varies. Basalt consists primarily of silicon, aluminum, calcium and iron oxides, similar to glass fibers. Basalt is classified according its SiO_2 content, where alkali basalts contain up to 42% SiO_2, mildly acidic basalts contain 43 – 46% SiO_2 and acidic basalts contain > 46% SiO_2 (Ralph et al., 2019) .

SiO_2, Al_2O_3, CaO, MgO, Fe_2O_3 and FeO are the most important components of basalt fibers. A large cross-linked molecule composed of primary bonds is formed by the different oxides. Pyroxene, clinopyroxene, olivine, and plagioclase minerals are the chemical components of the Basalt fibers. The SiO_2 content of the Basalt material shall determine their classification. If there is a shortage of silica in the basalt, it shall be classified as alkaline basalt. In addition, it's known as acidic basalt when its mineral content is high in silica (Afroz et al., 2017).

Table 1.1 Chemical composition of Basalt rocks % (Kunal Singha, 2012)

Element	Percentage
SiO_2	52.8
Al_2O_3	17.5
Fe_2O_3	10.3
MgO	4.63
CaO	8.59
Na_2O	3.34
K_2O	1.46
TiO_2	1.38
P2O5	0.28
MnO	0.16
Cr_2O_3	0.06

Applications of Basalt Fiber

Basalt fiber is a Possible polymer reinforcement material which may be used in the application Instead of glass fibers, polymer matrix composites are used. In thermoset polyester matrix composites, it is possible to reinforce the Basalt fiber (Kunal Singha, 2012).

Nuclear Power Plant

Basalt strands are utilized for eradicative materials in thermal energy stations since they don't retain radiations. The defensive cap utilizing geo-composites in the garbage removal locales, consolidating the basalt materials, can offer best security against atomic risk climate (Tavadi et al., 2022).

Concrete reinforcement

Because of their excellent resistance to fire, basalt fibers are utilized in the construction industry, particularly in civil structures. These filaments are likewise utilized in extensions, passages and railroads sleepers. The epoxy binder and 80 percent of the basalt fibers that go into making basalt rebar give reinforced concrete, which is less expensive, mechanical strength (Tavadi et al., 2022).

Building Material

Building interiors, doors, and sound insulation are all possible applications for BF. It has phenomenal sound resistance characteristics. It can proceed as closing in the recurrence range up to 1800HZ. These filaments used as well material sections for development of house like roof. The BF has phenomenal warm protecting properties which are multiple times than asbestos. These textures are utilized in obstructing material out in the open vehicle framework (Tavadi et al., 2022).

Road construction

The advantages of basalt fibers over glass fibers and metal mesh pavement reinforcement are numerous. They are eco-accommodating and offer protection from exceptionally high temperatures of liquid black-top.

Additionally, they are safe materials for tunnel lining work. As a stabilization and climate- and environment-friendly safety measure, the basalt fiber material is suitable for soil and stone constructed to carry roads (Tavadi et al., 2022).

Abrasion Resistance

Using fabrics and prepregs to saturate with a binder, the filament winding technique can be used to make pipes. These pipes can be used to move gases and liquids. The 60- to 80-year service life of basalt-made pipes is two to three times longer than that of conventional metallic pipes. Additionally, these are used in the cement, oil, and chemical industries (Tavadi et al., 2022).

Agriculture

BF can be used for drainage pipes, irrigation pies, and hosing, among other things. It is also used to build agricultural machines (Tavadi et al., 2022).

Aramid

Aramid strands are fragrant polyamide filaments in which no less than 85% of the amide linkages are joined straightforwardly to two sweet-smelling rings (Lee, 1989).

Kevlar

Kevlar was developed at E by Paul Wintrop Morgan (1911–1992) and Stephanie Louise Kwolek (1923–2014) in Du Pont de Nemours and Company, which received US Patent 3287323A in 1966 for its "Process for the production of a highly orientable, crystallizable, filament forming polyamide". It is created by the buildup response between 1,4-phenylene-diamine and terephthaloyl chloride: the condensate, that is the compound left over from the response, is hydrochloric corrosive. Mechanical drawing of the item delivers Kevlar filaments (Baker, 2018).

Mechanical Properties

Tensile strength decreases as the percentage of glass fabric increases in combinations with a higher percentage of Kevlar fabric, as opposed to combinations with a lower percentage of Kevlar fabric. Flexural strength decreases as the percentage of Kevlar fabric increases in combinations with a higher glass fabric percentage. From drop weight test, found from visual examination harmed region is expanded with an expansion in the glass texture rate (Nabeel et al., 2020).

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

Figure 1.1 Material Properties (Matweb, 2015)

Chemical Composition

Poly para-phenyleneterephthalamide is the chemical that makes up the kevlar aramid fiber. Liquid crystalline polymers are the group of materials that include para-aramid fibers (Chang, 2001). The internal structure of Kevlar, as well as the way its molecules are naturally arranged in regular and parallel lines, and the way it is made in fibers through knitting, contribute to the material's remarkable properties. Poly (p-pheylene terephthalamide) molecular Weight (274.276g/mol) is the chemical formula for Kevlar (Karthik et al., 2022).

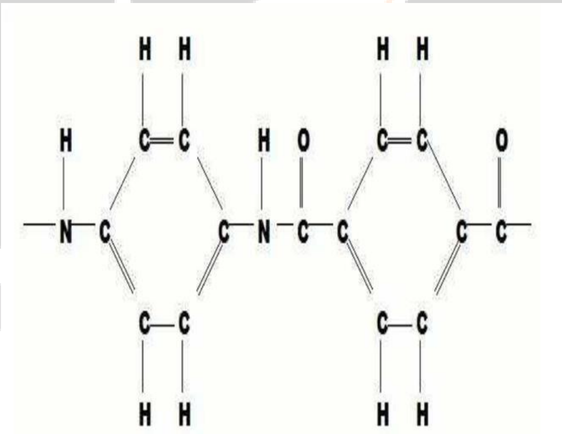

Figure 1.2 Chemical structure of Kevlar

Future Challenges

- Extremely less examination have been acted in hybridization of Kevlar and regular strands. Kevlar composites can be made for less money by combining them with cheaper and stronger natural fibers like jute, sisal, coir, and so on using the right design methods.
- For its application in exceptionally high temperature climate, the warm soundness of the Kevlar composites should be additionally gotten to the next level. This can be accomplished by hybridizing the Kevlar composites with additional thermally steady strands like basalt.
- To further develop the delamination properties during the machining system, the machining boundaries should be enhanced utilizing various methods and math of the machining apparatus (Singh & Samanta, 2015).

Applications

The effect strength of Kevlar 149 is similarly higher than Kevlar 49 and 29, carrying out it to be applied in various applications like resistive long-range rockets, big haulers, and impenetrable gatekeepers. Kevlar 149 has sturdiness and thickness contrasted and different sorts of textures. According to Manigandan (2015), the tensile strength and modulus of Kevlar were determined to be 3.4 GPa and 186 GPa, respectively. Elongation at break was examined to be 2% (Kumar, 2022).

Use of KEVLAR 49 in Aircraft Components includes wing – to- body fairings, landing gear doors, leading and trailing edges of wings and control panels, access panels, radomes, engine nacelles, cowlings and pylons, helicopter blades, propellers, aircraft interiors, window reveals, overhead and side panels, cargo liner panels, floors, partitions, lavatories, gallies and bulk heads, pressure bottles for escape slides, air ducting, passenger seat pedestals, missiles and space, filament wound rocket engine cases and pressure bottles (Khusiafan, 2018).

Composites

A composite is a material structure that consists of at least two or more macroscopically identifiable materials that work together to achieve a better result. (Nijssen, 2015) Composite materials consist of two or more different materials that form regions large enough to be regarded as continua and which are usually firmly bonded together at the interface. Many natural and artificial materials are of this nature, such as: reinforced rubber, filled polymers, mortar and concrete, alloys, porous and cracked media, aligned and chopped fiber composites, polycrystalline aggregates (metals), etc. (Hashin, 1983)

Advantages	Disadvantages
Weight saving	High material costs
High degree of freedom in form, material and process	Sophisticated computational methods sometimes required
Easy to colour	Colour and gloss preservation
High degree of integration of functions possible	Finishing not yet well developed
Strength, stiffness, thermal and electrical resistance can be designed	Stiffness and failure behaviour can be undesirable; sensitive to temperature, fire and lightning strike
Low total maintenance costs	High costs of raw materials
Water- and chemically resistant	Sensitive to UV light
Use of durable materials possible	Recycling not yet well developed
Automated manufacturing possible	Sometimes capital intensive production methods (e.g. automated methods)

Table 1

Figure 1.3 Advantages and Disadvantages of composites

Hybrid composites

Greek and Latin roots can be found in the word "hybrid," which is used in many scientific disciplines. When co mpared to traditional monolithic composites, hybrid composites offer better combined characteristics. Various h ybrid combinations, include one reinforcing phase embedded with two or more matrices, two or more reinforce ment incorporated in numerous matrices, or two or more reinforcing phases embedded in a single continuous ph ase (matrix). (Jawaid and Siengchin, 2019)

Because of its many uses in engineering, hybrid composite materials are valued for their high strength, low weight, easy structure construction, low cost, and strength to weight ratio. Composites and hybrid composites are used in various external and interior applications in the automotive industry. (Ravishankar et al., 2019)

Properties

A hybrid composite's orientation, length, and content of fibers, as well as the two fibers' layering patterns, intermingling abilities, fiber-to-matrix contact, and failure strain of individual fibers, can all affect the composite's characteristics. (Hao et al., 2018)

Applications

For principal structures in commercial, industrial, aeronautical, marine, and recreational structures, a hybrid composite can be employed.

Its many advantages in the aerospace sector include outstanding fatigue and corrosion resistance as well as good impact resistance.

Reducing weight is the biggest benefit, since it can result in savings between 20% and 50%. (Hao et al., 2018)

The most significant applications for hybrid composites are in commercial aircraft.Compared to other forms of transportation, aircraft require a higher priority on weight and safety. By employing materials with highly specialized qualities, they are accomplished.
Modern civil aircraft must be built to fulfill a number of safety and power requirements. (Gururaja and Rao, 2012)

Fiber epoxy composites have been employed to improve the system's performance in aviation engines. Hybrid resin composites have also been used to make aircraft doors for the pilot's cabin, and these materials are also utilized in various transportation systems. (Gururaja and Rao, 2012)

Advantages

A hybrid composite has several advantages over a regular fiber composite, including better mechanical qualities including greater strength, stiffness, and toughness. This is accomplished by fusing the ductility and toughness of one type of fiber or reinforcement material with the strength and stiffness of another. Consequently, hybrid composites are more resilient to stresses and deformations than regular fiber composites

1) Merits

- The higher performance to a given weight leads to fuel savings. Excellent strength-to weight and stiffness-to-weight ratios can be achieved by composite materials. This is usually expressed as the strength divided to density and stiffness (modulus) divided by density. These were so-called "specific" strength and "specific" modulus characteristics.
- It is easier for achieve smooth aerodynamic profiles to drag reduction. Complex double-curvature parts with a smooth surface finish can be made as one manufacturing operation.
- Laminate patterns and ply build-up in the part can be also tailored to give the required mechanical properties in various directions.
- Production cost are reduced. Composites may be made by the wide range of processes.

2) Demerits

- Composites are more brittle than wrought metals and thus were more easily damaged. Cast metals also tend to be brittle.

- Repair introduces with a new problems: Materials require refrigerated transport and storage and have limited shelf lives.
- Composites must be done thoroughly cleaned all contamination before repair.
- Composites must be dried before repair because all resin matrices and some fibers absorb moisture.

Use of hybrid composites in aerospace applications

- Light-weight due to high specific strength and stiffness
- Fatigue-resistance and corrosion resistance
- Capability of high degree of optimization: tailoring the directional strength and stiffness
- Capability to mould large complex shapes in small cycle time reducing part count and assembly times:
- Good for thin-walled or generously curved construction
- Capability to maintain dimensional and alignment stability in space environment
- Possibility of low dielectric loss in radar transparency
- Possibility of achieving low radar cross-section
- These composites also have some inherent weaknesses:
- Laminated structure with weak interfaces: poor resistance to out-of-plane tensile loads
- Susceptibility to impact-damage and strong possibility of internal damage going unnoticed
- Moisture absorption and consequent degradation of high temperature performance
- Multiplicity of possible manufacturing defects and variability in material properties. (Antil, R. et al,2015)

References

Afroz, M., Patnaikuni, I., & Venkatesan, S. (2017). Chemical durability and performance of modified basalt fiber in concrete medium. *Construction and Building Materials*, *154*, 191–203. https://doi.org/10.1016/j.conbuildmat.2017.07.153

Antil, R. et al. (2015) 'APPLICATIONS OF COMPOSITE MATERIALS IN AEROSPACE', International Journal Of Science Technology & Management, No.04(No. 11).

Baker, I. (2018). Kevlar and Other Aramid Fibers. In I. Baker, *Fifty Materials That Make the World* (pp. 101–104). Springer International Publishing. https://doi.org/10.1007/978-3-319-78766-4_19

Bheel, N. (2021). Basalt fiber-reinforced concrete: Review of fresh and mechanical properties. *Journal of Building Pathology and Rehabilitation*, *6*(1), 12. https://doi.org/10.1007/s41024-021-00107-4

Chang, K. K. (2001). Aramid Fibers. In D. B. Miracle & S. L. Donaldson (Eds.), *Composites* (pp. 41–45). ASM International. https://doi.org/10.31399/asm.hb.v21.a0009242

Gururaja, M., Rao, A.H., 2012. A review on recent applications and future prospectus of hybrid composites. International Journal of Soft Computing and Engineering 1, 352–355.

Hao, L., Sapuan, S., Hassan, M., Sheltami, R., 2018. Natural fiber reinforced vinyl polymer composites, in: Natural Fiber Reinforced Vinyl Ester and Vinyl Polymer Composites. Elsevier, pp. 27–70.

Hashin, Z., 1983. Analysis of composite materials—a survey.

Jawaid, M., Siengchin, S., 2019. Hybrid composites: A versatile materials for future. Applied Science and Engineering Progress 12, 223–223.

Jamshaid, H., & Mishra, R. (2016). A green material from rock: Basalt fiber – a review. *The Journal of The Textile Institute*, *107*(7), 923–937. https://doi.org/10.1080/00405000.2015.1071940

Khusiafan, F. J. (2018). Use of KEVLAR ® 49 in Aircraft Components. *Engineering Management Research*, *7*(2), 14. https://doi.org/10.5539/emr.v7n2p14

Karthik, K., Rajamani, D., Raja, T., & Subramani, K. (2022). Experimental investigation on the mechanical properties of Carbon/Kevlar fiber reinforced epoxy LY556 composites. *Materials Today: Proceedings*, *52*, 668–674. https://doi.org/10.1016/j.matpr.2021.10.077

Kumar, M. H. (Ed.). (2022). Natural/inorganic fillers reinforced kevlar fabric based polymer composites. Nova Science Publishers, Inc.

Kunal Singha. (2012). A Short Review on Basalt Fiber. *International Journal of Textile Science*. https://doi.org/10.5923/j.textile.20120104.02

Nabeel, M., Nasir, M. A., Sattar, M., Malik, R. A., Alzaid, M., Butt, M. S., Saleem, M., & Alrobei, H. (2020). Numerical and experimental evaluation of the mechanical behavior of Kevlar/glass fiber reinforced epoxy hybrid composites. *Journal of Mechanical Science and Technology*, *34*(11), 4613–4619. https://doi.org/10.1007/s12206-020-1019-1

Nijssen, R., 2015. Composite materials: an introduction. Inholland University of Applied Sciences Delft, The Netherlands.

Ralph, C., Lemoine, P., Summerscales, J., Archer, E., & McIlhagger, A. (2019). Relationships among the chemical, mechanical and geometrical properties of basalt fibers. *Textile Research Journal*, *89*(15), 3056–3066. https://doi.org/10.1177/0040517518805376

Ravishankar, B., Nayak, S.K., Kader, M.A., 2019. Hybrid composites for automotive applications–A review. Journal of Reinforced Plastics and Composites 38, 835–845.

Singh, T. J., & Samanta, S. (2015). Characterization of Kevlar Fiber and Its Composites: A Review. *Materials Today: Proceedings*, *2*(4–5), 1381–1387. https://doi.org/10.1016/j.matpr.2015.07.057

Tavadi, A. R., Naik, Y., Kumaresan, K., Jamadar, N. I., & Rajaravi, C. (2022). Basalt fiber and its composite manufacturing and applications: An overview. *International Journal of Engineering, Science and Technology*, *13*(4), 50–56. https://doi.org/10.4314/ijest.v13i4.6

Wu, Z., Wang, X., Liu, J., & Chen, X. (2020). Mineral fibers. In *Handbook of Natural Fibers* (pp. 433–502). Elsevier. https://doi.org/10.1016/B978-0-12-818398- 4.00015-3