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Review Article

Application of Natural Fibre Composites in Interior Panels in the Automotive Industry: A Review

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Abstract *- The automotive industry has started using natural fibres to fabricate interior panels for vehicles to increase fuel efficiency, promote sustainability and minimise carbon footprint. Interior panel composite disposal is a global environmental challenge. The disposal methods of interior panels that are made of synthetic fibres and polymers are often not environmentally friendly. Panels are normally disposed of through incineration, which causes air pollution. This review paper discusses the effectiveness of natural fibre composites' application in the automobile sector. This paper reviews the mechanical properties, endurance, moisture absorption and insect attacks of natural fibres and possible solutions to eliminate the premature failure of the fibres. There is great potential in the use of natural fibres composites in the automotive industry because they are biodegradable, making their disposal process extremely easy and environmentally friendly. Furthermore, the cost of using natural fibre composites is significantly lower than synthetic fibres. However, the excessive moisture absorption and potential for fungus and termite attacks a challenges in natural fibres. There is still a need for further research to enhance the durability, moisture absorption and bacterial resistance of the natural fibres for them to comply with the acceptance standards.*

Keywords *- Automotive industry, Interior panel, Natural fibre composites, Polymers.*

1. Introduction

The automotive industry plays a vital role in the economy worldwide. The number of vehicles being produced worldwide is approximately 80 million per year [1]. This figure is increasing significantly with each passing year, and Europe alone produces approximately 50 million cars per year, which accounts for only 30% of the world's production [2], [3]. The disposal of vehicles at end-of-life span is a challenge for several components, such as the interior panels, which are difficult to recycle. Approximately 10 million tonnes of vehicle components are destined for the scrap yard per year around the world [2]. Vehicle's interior panels contribute approximately 20 kg per vehicle of the waste from the vehicles to be scraped [4].

A great amount of consideration goes into the looks and functionality of the vehicle interior when consumers are making purchases. It triggers emotions, provides peace of mind, security, and functionality, and radiates brand identity [5]. The interior panels are normally disposed of through incineration [6]. However, disposal of the interior panels in this manner contributes to air pollution. There is an increasing trend in the use of renewable resources in the manufacture of interior panels. These renewable resources include but are not limited to recycled materials and bio-composite materials [7]. Interior panels were historically composed of metal and wood, but due to safety, aesthetics, and cost, these materials were discontinued in favour of plastics and composites [8]. The use of polymeric composite materials for interior panels in vehicles allows design flexibility, improved durability, toughness and corrosion resistance. Furthermore, the use of composite materials gives reduced weight, leading to high performance and resiliency at a lower cost compared to traditional materials [9]. Incineration as the preferred disposal method of vehicle interior panels tends to cause air pollution by furans releasing dioxins polychlorinated biphenyls into the atmosphere, and mercury [6]. Additionally, burning polyvinyl chloride (PVC) releases dangerous halogens and contaminates the air, which has adverse effects which contribute to global warming [10]. The environment, due to the toxic substances, plants, as well as the health of people and animals, are all at risk that are released in the incineration of these plastic interior components [11]–[13]. Utilizing natural fibres as replacement materials for synthetic fibres in automobile interior composite parts has a significant impact on reducing environmental pollution and advances sustainability [14]. The automobile sector has experienced a permanent shift in the landscape due to megatrends, including automated driving, lightweight vehicles, decreased emissions, connectivity, and mobility services. The automotive supplier sector is undergoing notable changes in the materials it chooses as a result of these dynamics. [14], [15].

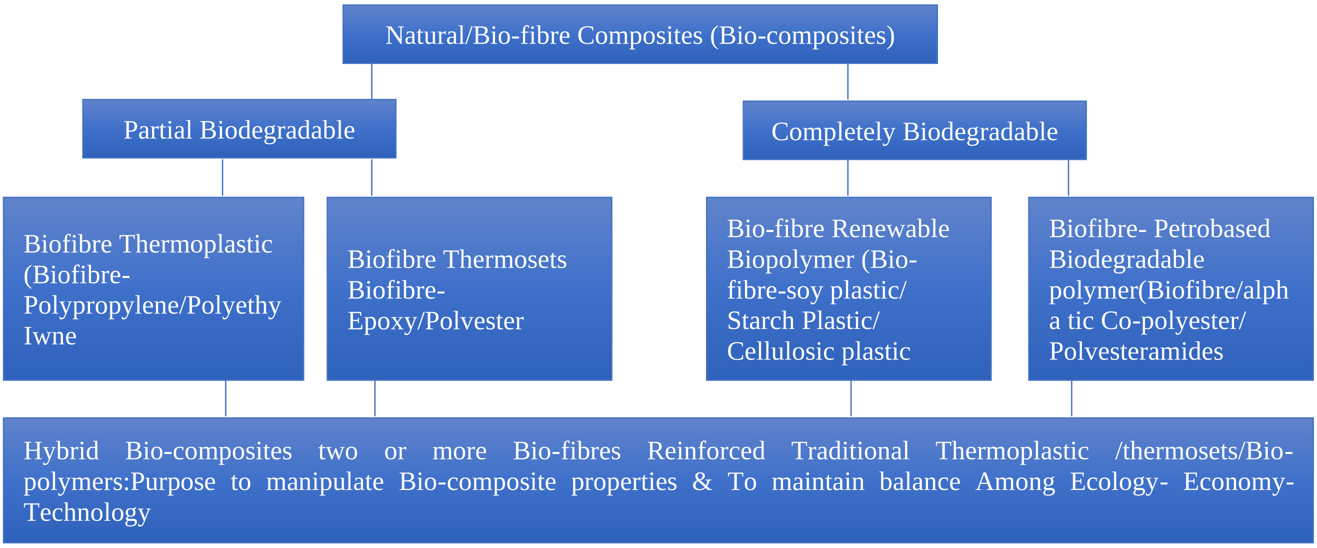

Fig. 1 Natural fibre biodegradable classification [17]

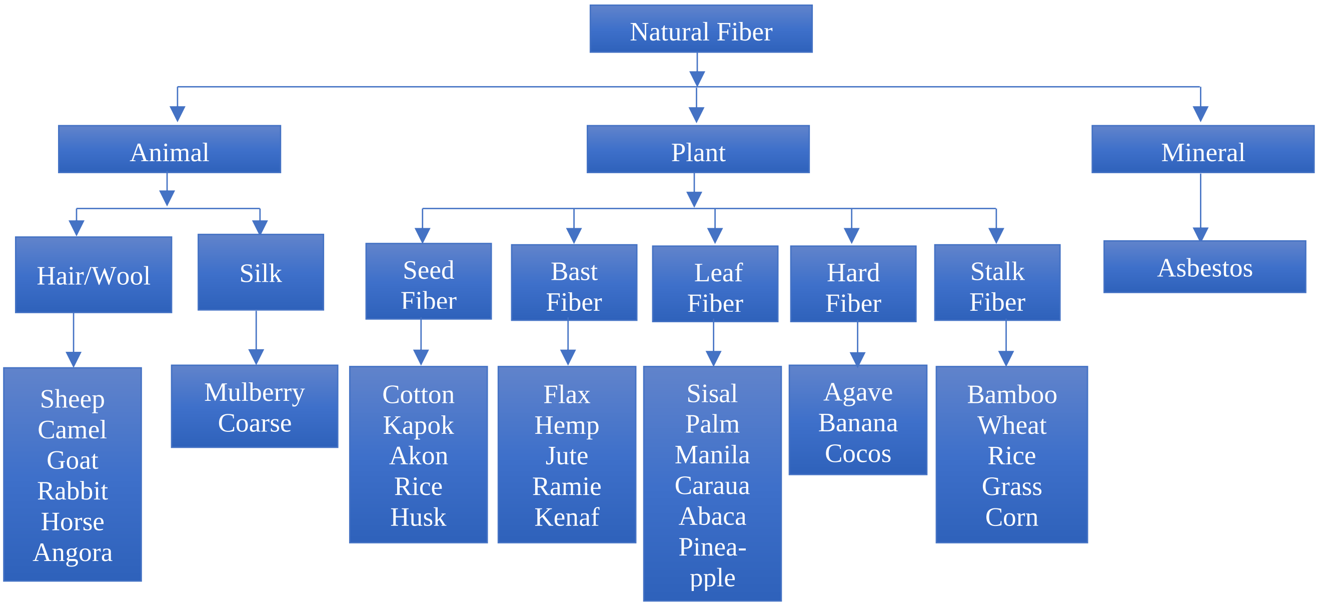

Fig. 2 Natural fibres classification [24]

Car manufacturers are carrying out research and development in bio-composite interior panels as they can be lightweight yet have high mechanical strength [4]. Manufacturing technology has advanced thanks to hybrid bio-composites consisting of materials derived from both petrochemicals and biological sources. More environmentally friendly bio-composites made of fibres from plants and polymers from crops are the subject of extensive research due to their low carbon footprint[16]. Biodegradable composites have demonstrated promise for significant applications in interior components of automobiles. Bio-composites are generally classified as shown in Figure 1. Recycled plastic materials intended for disposal can be diverted and used again for mixing in composite applications, reducing the need for virgin petroleum-based resources [16]. Research on the compatibility of waste and recycled materials with other components in composite structures for improved mechanical performance and interface presents significant scientific problems. Due to the difficulties in recycling petroleum-based materials, research has shifted to the application of bio-composites made of natural fibres.[16]

2. Natural Fibres

Natural fibres are used as composite reinforcement material and have the advantage of being cheap, sustainable and environmentally friendly, making them excellent for reinforcement in different polymeric matrices. Numerous industries, such as the building and automotive sectors, as well as soil conservation, use natural fibres. Additionally, the main source of cellulose is natural fibers. [18]. It has been proven that natural fibre composites have good mechanical properties and electrical resistance [19]. Furthermore, natural fibres have good thermal and acoustic insulation properties and higher cracking resistance [19].

Table 1. Mechanical properties of natural fibres

Fibres	Tensile strength (MPa)	Young's Modulus (GPa)	Elongation at break (%)	Density (g/cm^3)
Abaca	400	12.00	3.00-10.00	1.50
Bagasse	350	22.00	5.80	0.89
Bamboo	290	17.00	-	1.25
Banana	529-914	27.00-32.00	5.90	1.35
Coir	220	6.00	15-25	1.25
Cotton	400	12.00	3.00-10.00	1.51
Curaua	500-1150	11.80	3.70-4.30	1.40
Flax	800-1500	60.00-80.00	1.20-1.60	1.40
Hemp	550-900	70.00	1.60	1.48
Jute	410-780	26.50	1.90	1.48
Kenaf	930	53.00	1.60	-
Pineapple	413-1627	60.00-82.00	14.50	1.44
Ramie	500	44.00	2.00	1.50
Sisal	610-720	9.00-24.00	2.00-3.00	1.34
E-glass	2400	73.00	3.00	2.55
S glass	4580	85.00	4.60	2.50
Aramid	300	124.00	2.50	1.40
Hs Carbon	2550	200.00	1.30	1.82
Carbon (std PAN-based)	4000	230.00-240.00	1.40-1.80	1.40

Natural fibres need 17% less energy during production than synthetic fibers, such as glass fibers. [20]–[22]. There are three types of natural fibers: plant, animal, and mineral fibres. Vegetable fibres are seed, bast, leaf, stalk, cane, grass, and reed. Animal fibres are classified into two categories: wool and silk. Lastly, mineral fibres include asbestos and fibrous brucite. Natural fibres provide numerous advantages over synthetic fibres in strengthening composites due to their biodegradability and eco-friendly behaviour and can be thus efficiently employed for different applications. Furthermore, natural fibres possess less explored characteristics, such as the electric resistance, thermal conductivity and acoustic insulation properties of plant-based composites[23]. Natural fibres are obtained from animals, minerals and plants and classified as shown in Figure 2. The manufacture of natural fibres uses minimal energy because they are renewable resources. Oxygen is returned to the atmosphere while CO_2 is consumed. It is an intriguing product because it can be made at a low cost and with little commitment. Natural fibers are biodegradable so that they can be eliminated from the environment after the life cycle. They can also be incinerated with energy recovery [25]. The Comparison of tensile of natural and synthetic fibres [23].

3. Benefits of Natural Fibres in Automotive Industry

The use of natural fibres in interior panel composites has an effect of weight reduction of approximately 10% compared to traditional materials [26]. This weight reduction can translate to an increase in fuel efficiency of up to 7%. Furthermore, 1 kg weight reduction in a vehicle can save the environment of approximately 20 kg of carbon dioxide [26].

3.1. Short-coming of Natural Fibres in the Automobile Industry

The automotive industry faces several challenges when using natural fibre composites, including moisture absorption, durability, low mechanical strength, and weak interfacial adhesion between the fibre and matrix [27]. Furthermore, bio-composites tend to be susceptible to environmental degradation. The environmental degradation modes are shown in Table 2. These include mechanical, water, weather, biological and fire degradations. Bio-composites degrade biologically because of organismal attack. Hemicelluloses are the first materials that organisms assault and hydrolyze into digestible units. [30]. The fibre-matrix interface deteriorates as a result, which lowers the strength of the bio-composites. Enzyme reduction and oxidation processes also contribute to biodegradation. Chemical treatment of the fibres can eradicate it. [31]. The degradation of water is another issue with bio-composites. Natural fibres tend to absorb moisture from the environment because they are hydrophilic. The void and non-crystalline content of a natural fibre determines how much water it absorbs. [30].

Table 2. Degradation of mechanical properties [28], [29]

Environmental Attack	Means of degradation
Biological degradation	Hydrolysis, reduction, and oxidation
Mechanical degradation	Stress, fracture, abrasion, stress
Water degradation	Swelling, freezing, shrinking, and cracking
UV degradation	Impact resistance, Mechanical integrity, Ductility, Tensile strength
Thermal degradation	Hydrolysis, oxidation, and dehydration

Bio-composites which are exposed to water and moisture frequently have wetter and drier areas within the composite leading to differential swelling and ultimately cracking [30]. The water that is absorbed by bio-composites weakens the interfacial bond and lowers the mechanical strength of the bio-composites [32].

3.2. Moisture Regain of Natural Fibres

Natural fibres that are hydrophilic and lignocellulosic have a propensity to absorb moisture. There are multiple potential hydrogen bonds (hydroxyl groups solitary bond-OH) between the macromolecules in the fibre cell wall. When moisture encounters natural fibres, hydroxyl groups form new hydrogen bonds with the molecules of water. Table 3 displays several natural fibres' moisture recovery rates.

Moisture moves along the length of the fibre through the wicking process. The fibres' propensity to swell upon absorption of moisture interferes with and reduces the bonding strength at the matrix interface. Dimensional instability, matrix cracking, and poor mechanical properties of the composites are all caused by this phenomenon [21]. Therefore, treating the fibres is a crucial step in preventing moisture absorption in natural fibre. By removing the hydrophilic hydroxyl groups from the surface of natural fibres by various chemical processes, it is possible to decrease the amount of moisture that natural fibres absorb. [22]. Several treatment techniques can be used to lower the moisture regain, such as the use of coupling agents and various chemical treatments [37].

4. Chemical Treatment of Natural Fibres

It is common practice to change the cellulose molecular structure of natural fibres by treating them with sodium hydroxide (NaOH**) [**38]**.** The use of NaOH in treatment creates an amorphous area on the fibres and flips the direction of the highly packed crystalline cellulose arrangement [38]**.** This makes it easier for chemicals to penetrate.

Water molecules occupy the holes created by the separation of the cellulose macromolecules in the amorphous zone. The molecules' alkali-sensitive hydroxyl (OH) groups are dismantled, which causes the water molecules to react and leave the fibre structure. Between the chains of molecules making up cellulose, the remaining reactive molecules form fibre-cell-O-Na [38]**.** As a result, hydrophilic hydroxyl groups are reduced, increasing the fibres' ability to resist moisture. A portion of the hemicelluloses, lignin, pectin, wax, and oil-covering substances are also eliminated [39]**.** The outcome is a clean surface on the fibre. In other words, by eliminating microvoids, the fibre surface becomes more uniform, which enhances the stress transfer capability between the final cells. Furthermore, this treatment lowers the diameter of the fibres and raises the aspect ratio (length to diameter). This enhances the effective fibre surface area for an excellent matrix adhesion matrix [40]**.** By using this procedure, the composite's mechanical and thermal characteristics are greatly enhanced. If the alkali concentration is higher than the ideal level, there may be excessive delignification of the fibre, which weakens or harms the fibres [41]**.** The lignin concentration of treated fibres is decreased, the wax and oil cover components have been partially removed, and the crystalline cellulose order has been disrupted. The most recent findings on how alkali treatments affect mechanical and thermal properties are compiled in Table 4.

Table 3. Moisture regain of natural fibres [33]–[35][36]

Natural fibres	Moisture absorption (%)
Abaca	5.0 - 10.0
Bamboo	11.7
Banana	2.0 - 3.0
Coir	0.2 - 10.0
Cotton	7.5 - 20.0
Flax	7.0 - 12.0
Hemp	6.0 - 12.0
Jute	10.0 - 13.0
Ramie	7.5 - 17.0
Sisal	10.0 - 22.0

Table 4. Chemical treatment of natural fibres

Fibres matrix composites	Applied treatment methods	Results mechanical and thermal properties	Reference
Flax-epoxy	Alkali treatment	Pectin removal results in a 30% improvement in tensile strength and modulus.	[39]
Sisal-polyester	0,5,1,2,4,10% NaOH treatment a room temperature	Maximum tensile strength properties were reported after 4% alkali treatment.	[39]
Hemp non-woven mat with euphorbia resin	0,16% NaOH for 48 h.	Tensile strength was increased by 30% and doubled the shear strength properties.	[42]
Jute-vinyl ester	5 % NaOH for 4,6 and 8h	4h alkaline treated composite accounted 20% and 19% increase in flexural strength and interlaminar shear strength properties.	[43]
Sisal-polycaprolactone composite	10% NaOH for 1,3,24 and 48h	Increased elastic modulus with the increased reaction time.	[43]
Hemp fibre	8% NaOH treatment	There was a 4% increase in thermal stability.	[38]
Coir-polyester	5% NaOH treatment for 72 h	Flexural and impact strength was increased by 40%.	[44]

Table 5. Application of natural fibres in the automotive industry [49], [50]

Company	Model	Natural fibre	Matrix /Resin	Application
Audi	A2, A3, A4, A6, A8, Roadster, Couple, Q7	Wood Fiber, Flax, Sisal	PP, Epoxy, PUR	Seat backs, side and back door panels, boot lining, hat rack, spare tire lining.
BMW	3,5 and 7 series	Kenaf, flax, hemp, wood fibre	PP	Door trim panels, Headliner panel, boot lining, seat backs, noise insulation panels, dashboard.
Citroen	C5	Wood Fiber, flax	Epoxy	Interior door panelling
Fiat	Punto, Brawa, Marca, alfa ROMEO,146,156	Flax, sisal, hemp, cotton, coconut fibres	PP	Door cladding, seatback linings and floor panels, seat bottoms, back cushions and head restraints.
Diamler Chrysler	Sebring	Flax, sisal, Abaca	PP	Door panel, seat cushion, head restraint.
Ford motors	Ford Flex, Ford Focus BEV	Wood fibre, wheat straw, coconut fibre	PP, PUR	Interior panel bin, load floor, Foam seating, headrests, headliners.
General Motors	Cadillac Deville, Chevrolet Impala, GMC Envoy, Trailblazer, Terrian, Opel Vetra	Wood, kenaf, Flax, Cotton	PP Polyester	Seatbacks, trim, rear shelf, Cargo floor, Door panels, Package trays, Acoustic insulator, Ceiling linear.
Honda	Pilot	Wood fibre	N/a	Floor area parts
Land rover		2000, others	Kenaf	Insulation, Rear storage shelf/door panel, seat backs.
Lotus	Eco elise	Hemp	Polyester	Body panels, Spoiler seats, interior carpets.
Mazda	5 hydrogens RE hybrid	Corn	PLA	Console, Seat fabric
Mercedes Benz	A class, C class, E class, M class, R class, S class	Abaca/banana, Hemp, Flax, sisal, Jute	PUR, PP, Epoxy	Door panels, seat cushions, head restraints, underbody panels, seat backs, spare tire covers, Engine and transmission cover.
Mitsubishi	Concept car	Bamboo	PBS	Interior components
Peugeot	406	Hemp, Flax	PP, PUR	Seat backs, parcel shelf
Renault	Clio, Twingo	Jute, Coir	PP, PUR	Rear parcel shelf
SAAB	9 s	Flax	PP	Spare wheel, Door panels
Toyota	Lexus CT 200h, Prius, Raum	Kenaf, Bamboo, Corn, Starch	PET, Sarona, EP	Luggage compartment, speaker, floor mats, instrument panel, air conditioning vent, spare tire cover, shelves.
Volkswagen	Golf, Passat, Bora flux, Touareg	Flax	PP	Door panel, seat back, boot lid finish panel, boot liner.
Volvo	C70, V70	Flax	Polyester	Seat padding, Natural form

PP - Polypropylene, PUR - Polyurethane, PLA - Polylactic acid, PBS- Polybutylene succinate, PET-Polyethylene terephthalate, Sorana EP- poly trimethylene terephthalate

5. Application of Natural Fibres in the Automotive Industry

Research on the use of natural fibres in composite materials in the automotive industry is gaining increasing traction [45], [46]. The low energy required for the production of natural fibres makes them more attractive than synthetic fibres [47]. Other advantages of natural fibres include higher impact absorption, lower health risks and ease of work. Since 2005, natural fibres have been adopted in the automotive industry to replace synthetic fibres in more than 1.5 million vehicles in the United States. Furthermore, in Germany, 160,000 tons of natural fibres were used to fabricate composites for vehicles [48].

Natural fibres have been used in the automotive industry by various manufacturers, as shown in Table 5, in different applications, such as interior panels. There are also some new applications outside interior panels, including battery trays, brake shoes, spare wheel covers, cowl screens, tank shields, air cleaning housing, trim parts and splash shields. The use of biocomposites in vehicles could result in approximately 25% weight reduction, saving more than 250 million barrels of crude oil annually. Additionally, this reduction in weight could lead to a reduction in carbon dioxide emissions. Japanese Toyota automaker has announced its intention to replace plastic interior composites with natural fibre composites [51], [52].

This initiative has seen the use of kenaf and polypropylene to fabricate door trim [53]. The volume fraction ratio used to fabricate seat backs was 65% kenaf and 35% polypropylene. The mechanical strength realised was lower than the conventional synthetic fibre composites. However, the strength was acceptable for use as door trims in the automotive industry. Furthermore, the production cost was much lower [54]. Cotton and kenaf are currently used to fabricate acoustic insulation and ceiling liners at General Motors. Flax is used as a reinforcement with polypropylene in Chevrolet Impala to fabricate rear shelf composite components. Kenaf and flax were used to fabricate door panels and tray packages in the Saturn L300. Wood fibres were used to fabricate seat backs in the Cadillac DTS's and in the cargo floor of the Chevrolet Trailblazer and GMC Envoy [21]. Ford is using a significant amount of recyclable material to fabricate seat cushions and seat backs from soy and bio-based resins. Ford Electric has floors made of polypropylene and coconut fibres (Bajwa & Bhattacharjee, 2016). Furthermore, the Ford F-250 pick-up truck also has structural guides made of a coconut shell composite. By using natural fibres, the automotive industry has saved approximately $4.5 million in North America. Rice husks have been used to enhance sustainability as a substitute for talc in electric stiffness in F-150 trucks from year 2014 [55]. In addition, some new features include recycled cotton fibre for insulation in the carpet, and soybean oil-based for seat cushions and recycled tires to make underbody covers and shields.Volvo has also stepped up its use of natural fibre composites in its vehicles. Volvo is used to fabricate load trays using moulded polyester. However, Volvo has progressively shifted and is now using flax to fabricate its load floor mat composites [56]. Volvo has been using soy-based foam with natural fibres to fabricate seats. At this stage 85% of interior components in Volvo are made from recyclable material [49]**.** Mazda is also using Polylactic acid and kenaf fibres to fabricate seat covers and interior panels.

6. Conclusion

The use of natural fibres in automobiles will continue to rise as it is a sustainable and environmentally friendly means of production. Synthetic fibres, which have been traditionally used, have superior mechanical properties. However, the disposal and manufacture of synthetic fibres for use in the automotive industry are not environmentally friendly. Natural fibres are cheaper and biodegradable, unlike most of the synthetic fibres. However, excessive moisture absorption, endurance, termite attacks, and fungus attacks are a source of failure. Furthermore, degradation of mechanical properties is evident due to ultraviolet (UV) radiation from the sun. There are several mitigation methods for these shortcomings—impregnation of natural fibres with an alkaline shield from fungal attacks and termites' attacks. Bio-composite materials can be utilized to fabricate and develop interior panels with improved excessive moisture absorption that could result in degradation while sustaining good mechanical properties and integrity. Bio- composites will continue to rise in popularity due to the numerous advantages associated with their use. Researchers in the area of biocomposites in automobile use should focus on identifying mechanical, chemical and biological treatments that could be used to prolong the durability and increase fibre–matrix bond strength. The use of natural fibres could save the automotive industry a significant amount of money and possibly create employment as a branch of industry. In an African context, the use of natural fibres could have a significant impact on improving the economy due to the abundance of fibres.

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