Biopolymers in Automotive Industry

Zahra Ranjbar, Behnaz Ranjbar, and Sahar Foroughirad

Abstract Bio-based polymers are engineered for automotive applications due to their multifunctional characteristic properties, such as biocompatibility, biodegradability, and lower disposal as well as mechanical properties in some cases. Automotive Industry can shift to use renewable materials that exhibit equal or outstanding performance compared to the other conventional counterparts. Good life span and lightweight polymeric automotive parts as a way to reduce fuel consumption and therefore limit the outflow of ozone-depleting substances will continue to prompt comprehensive research into the applicability and employment of polymers and their obtained composites in the automotive industry. In this chapter, Biocomposite's Characteristic Properties containing biomaterials as Polymeric Matrix, i.e., Natural rubber, polylactic acid or Filler, Glass, Cellulose, Wood, Flax,…, in plastic and elastic parts, tires, and foams have been reviewed. Using biopolymers improves Tensile Strength and tear strength, Young's Modulus, higher Stiffness, lightweight, reduction in fuel consumption, lower Mooney viscosity, and better rolling resistance compared to conventional polymers.

Keywords Biopolymer · Natural · Automotive · Bio-based composites · Plastic · Elastomer

---

Z. Ranjbar (✉)
Faculty of Surface Coating and Novel Technologies, Institute for Color Science and Technology, Tehran, Iran
e-mail: ranjbar@icrc.ac.ir

Center of Excellence for Color Science and Technology, Tehran, Iran

B. Ranjbar
Radsys Pooshesh Knowledge Based Co, Tehran, Iran

S. Foroughirad
Borna Chem Knowledge Based Co, Tabriz, Iran

A. K. Nadda et al. (eds.), *Biopolymers*, Springer Series on Polymer
and Composite Materials, https://doi.org/10.1007/978-3-030-98392-5_13

1 Introduction

There are many waste products in the automobiles' whole life cycle, including vehicle production, usage, disposal, and recycling. It is reported that the industry generates almost 9 million tons of waste annually during automobile parts disposal [1]. This number would be much higher by the ascending trend of motor vehicle production, represented in Fig. 1 [2], so recycling would be vital to save the environment. By using biodegradable materials in car production, it would be easier to recycle vehicle parts after the scrap.

On the other hand, during usage, there is an enormous volume of carbon dioxide emissions. By decreasing the vehicle's weight by 100 kg, the fuel consumption would reduce to almost 0.35 L per kilometer [3]. The lower the fuel consumption, the lower the carbon dioxide emission. One of the approaches to reduce the vehicle weight is to use polymers in its parts.

In the automotive industry, polymers are playing essential roles. Their functionality, resistance to corrosion, longer lifetime, the flexibility of integrating parts, being safe, economical, and low weight which lead to decreasing fuel consumption are the main reasons for using polymeric parts. Polymers are used in bumpers, seating, fuel system, dashboard, body, interior/exterior trim, panels, under-bonnet components, electrical components, lighting, upholstery, liquid reservoirs, car tires, etc.

The average weight of polymeric materials used in vehicles increased from 50 kg/car in 1970 to 157 kg/car in 2019, and it still has its growing trend until now [4].

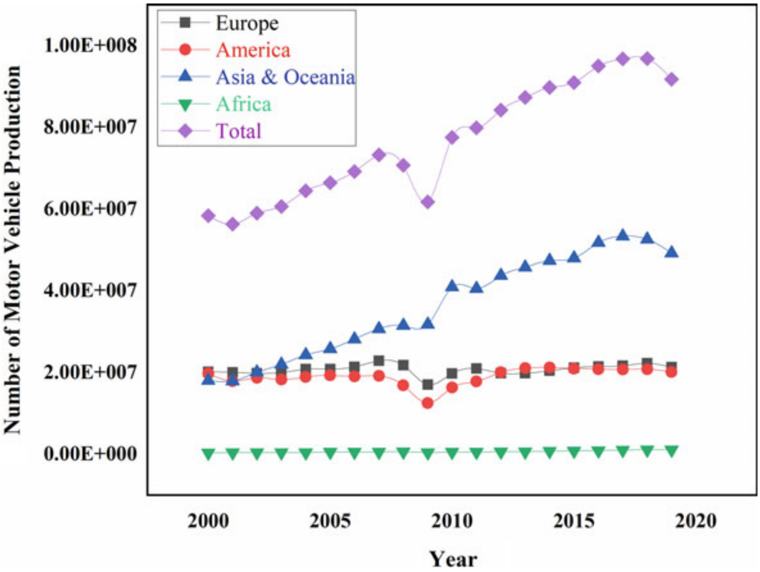

Fig. 1 The numerical trend of the production of the motor vehicle by region per year

Automotive production chains have a significant impact on the environment, production, usage, and, of course, disposal. Due to the growing trend of producing motor vehicles, as shown in Fig. 1, it is vital to use biopolymers or use bio-additives in traditional polymers. In this paper, we tried to categorize biopolymers into plastics, elastomers, and foams. In each category, we introduce biopolymers, or biodegradable additives in plastics, elastomers, and foams, and discuss the effect of using biomaterials in final product properties.

2 Plastics

Lightweight vehicles are one of the most significant markets for polymeric composites and plastics, which have been growing within the last five decades. Recently announced statistics, Fig. 2, have revealed that the North American light vehicle currently contains about 355 pounds of polymeric composites, which would be about 8.9% of the total weight. This was recently announced that plastics make up nearly half of the volume of the new lightweight vehicles but not as much as 10% of the vehicle's weight. This will ensure lower fuel consumption and so fewer greenhouse emissions [5].

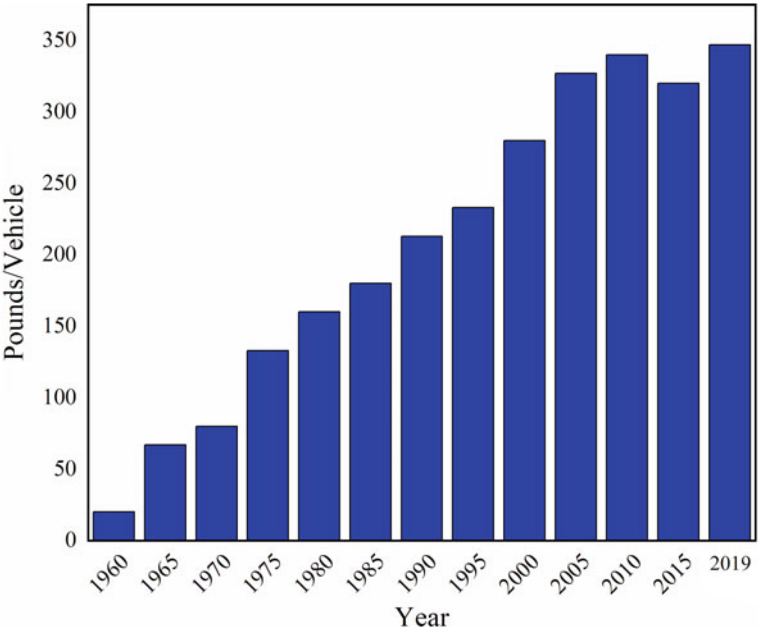

Fig. 2 Long-term trends in NAFTA (North American free trade agreement) light vehicle employment of polymeric composites (pounds/vehicle)

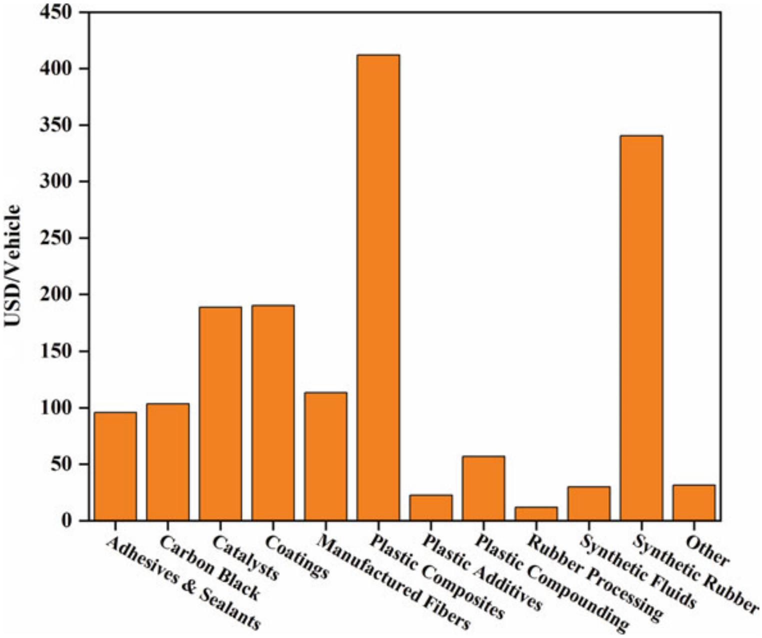

Fig. 3 The average use of polymeric composites in North American light vehicles (NAFTA) in 2019 (pounds/vehicle)

Over 15 polymeric resins are employed in the automotive industry. The most common types are polypropylene (PP), polyvinyl chloride (PVC), polyurethanes (PU), nylon, polyethylene (PE), acrylonitrile–butadiene–styrene (ABS), and polycarbonate resins. The details on pound/vehicle use are provided in Fig. 3 [5].

Many bio-based composites have been introduced to the automotive industry for obtaining low-weight vehicles. These bio-based composites can be obtained with the aid of biopolymers including Polylactic Acid (PLA) [6] by employing bio-based reinforcements into the conventional polymeric resins [7–11] or employing both bio-based resin and bio-based reinforcement simultaneously [12–16]. The following are some of the recent publications in this area.

Wei and coworkers [6] introduced a novel bio-based aromatic polyamide composite and its application in automotive biofuel supply systems. In this study, glass fiber-reinforced highly bio-based semi-aromatic polyamides (polyphthalamide, PPA) were fabricated, and the PPA matrix assessed both bio-based diesel and petroleum absorption. It was revealed that PPA had better barrier properties, confirmed by its low and slow fuel uptake.

The copolymer was produced with the aid of an 11-aminoundecanoic acid monomer. The glass fibers were first coated by a silane coupling agent and then added to the polymer matrix. About 0.5wt.% carbon black was added as UV stabilizer and coloring agent. The as-received GF30-PPA (with 30 wt.% of glass fibers) and GF23-PA12 (the glass fiber content was 23 wt.%) dumbbell specimens were aged in petroleum diesel with the aid of autoclaves. The samples were stored at about 125 °C, and the replacement of the fuels was carried out every two days to be the same as the refueling process. After 280, 560, and 700 h of aging, samples were stored in plastic bags at 4 °C until the test time.

The tensile-fractured surface was studied by SEM analysis. The fiber pull-out was obvious for both aged and unaged specimens suggesting that the significant fracture mechanism is polymer failure. A layer of polymer with 1 μm thickness was observed in the unaged sample, indicating the fibers' good adhesion into the PPA matrix. When exposed to the fuels at high temperatures, acceptable mechanical properties confirmed that the fuel could only affect the polymer matrix but not the polymer–fiber interactions.

In another research, Sadashiva and coworkers [7] synthesized a new hybrid biocomposite consisting of drumstick and glass fibers within a polyester matrix. An easy hand layup technique was employed for composite fabrication, and the fibers' orientation was studied. For this purpose, woven mats were cut and placed at the mold's surface; already prepared polyester resin and its curing agent in liquid form were added to the mold and spread carefully. The drumstick fibers were then placed on the polymer surface as the second layer and the roller was gently moved to eliminate the excess resin and any trapped air. Two specimens with different fiber orientations, longitudinal and transverse, were prepared for tensile tests. This was observed that the orientation of fiber composites can affect the properties. The authors concluded that the composite specimens fabricated by the longitudinal orientation of fibers have better properties.

Silva and Frollini [8] have recently investigated the employment of fibers obtained from sugarcane bagasse (SBU). The thermoset phenolic resin was employed as the polymeric matrix. The phenolic resin was prepared by the following weight ratios of 1.38: 1.0: 0.06 of phenol: formaldehyde: KOH. The sugarcane bunt bagasse (SBB) fibers were compared to SBU fibers. Although there are no significant differences in the structural compositions of both types of fibers, the inverse gas chromatography (IGC) revealed that the SBU surface is full of polar groups, which enhances the intermolecular interactions and improves the interaction to the matrix. Three different sizes of the fibers, 1, 3, and 5 cm, were compared. The impact strength was improved for all tested lengths; however, the longest fibers, 5 cm, showed a slightly lower improvement than the others. On the other hand, this fiber showed lower water adsorption property, making that a good candidate to be employed in situations in which water resistance is a critical factor.

In another study, Al-Oqla and coworkers [9] studied the applicability of using the date palm fibers (DPF) as bio-based reinforcement in the natural fiber-reinforced polymeric composites (NFC) and their application in the automotive industry. The authors claim that by this approach, a novel reinforced biocomposite is fabricated, and at the same time, the date palm waste issue is addressed. Several comparisons, including aspect ratio (L/D), thermal conductivity, and world production content, were carried out between the DPF and other common fibers. DPF represented better properties in many studies. The date palm fibers are considered to be very cheap (about 0.02$/Kg). DPF demonstrated a specific Young modulus to price ratio of about 80 GPa/(g/cm^3) compared to Coir, Hemp, and Sisal. The authors suggest that employing DPF in the automotive industry will improve this industry as well as address the environmental waste issue.

In a recent study, Yusof and coworkers [10] introduced a conceptual design of an automotive crash box (ACB) reinforced with oil palm polymer composite. In this research, the design which got the highest score was selected as the best design. This outer part had a honeycomb structure, and the inner part had a spider web structure. A fiber foam structure supported the design to improve the energy absorption ability of the final composite. The bending collapse is known to be the primary cause of failure for ACB during the collision. The impact properties of natural fiber-reinforced ACB suggested that this new design can be substituted by conventionally used materials such as aluminum alloys and steel alloys in automotive industries.

The bio-based plant fibers, including alfa, flax, and cellulose fibers, are widely replaced by synthetic glass fibers in automotive industrial applications. These natural fibers are well known for their low density, high mechanical properties, and being environmentally friendly. In this regard, Pantaloni and coworkers [12] have recently published an article in which a completely green bio-based composite was produced consisting of three biodegradable polymers, polybutylene succinate (PBS), polyhydroxyalkanoate (PHA), and polylactic acid (PLA), and nonwoven flax fibers. The obtained composite had the same performance as the one currently used in industry, polypropylene (PP)-reinforced nonwoven flax.

For polymer film manufacturing, the granules were dried in the oven at 60 °C for 12 h, followed by extruding and calendaring to prepare the polymer films. The composite was made by film stacking, considering that the temperature plays a critical role in well-impregnating. The temperature was adjusted to 200 °C, and the time for exposure was set to be 8 min. The authors suggest that flax fibers will keep their mechanical properties by setting time and temperature in this range.

The authors suggest that all flax-reinforced biodegradable polymeric composites in this research had better mechanical stiffness and strength than PP reinforced with flax. Moreover, the flax/PLA lost about 37% of its strength only after the sixth day of being buried in garden compost. About 50% of strength loss was observed for all the biocomposites after 190 days, which is significantly higher than the flax/PP. Possessing high mechanical properties even after exposure to harsh conditions and biodegradability simultaneously have made these biocomposites a promising candidate for automotive, industrial use.

Oliver-Ortega and coworkers [13] researched the design and development of automotive parts using wood fiber-reinforced bio-based polyamide 11 composites. They carried out some novel investigations on the reinforced composite's mechanical behavior when employed as a car door handle. They suggest that using 40–60 w/w natural reinforcement can be effective in this composite to replace synthetic ones such as glass fiber reinforcement materials in the automotive industry.

The fabricated composite consisted of a stone groundwood cellulose-based reinforcement (SGW) coupled with a polyamide 11 (PA11) bio-based matrix. The results revealed that the composite possesses high mechanical properties. Changing the fiber content from 10 w/w to 50 w/w leads the tensile and flexural properties to enhance linearly, representing that the fiber is well dispersed in the mixture and an effective interface exists leading to a thriving load transfer. The optimum SGW content was reported to be 50 w/w in which the maximum flexural and tensile strengths of PA11 composites were measured to be 63.9 and 92.6 MPa, respectively.

A case study was carried out to design an interior door handle of a car. Computational analysis was used for assessing the part in the standard and limited condition. The analysis showed that by employing at least 40% w/w of the SGW, the obtained composite could be replaced by the original component. The maximum deformations and the safety factors of the obtained composite would be the same as the traditional one.

In a research carried out by Birch and coworkers [14], a cost-effective and sustainable approach was reported to develop high strength modulus and lightweight material for automotive applications. In this research, composites based on bio-based polyamide blends and cellulose fibers with different weight percentages were prepared. The mixture was extruded at 230 °C. Twice extruding was done to ensure the even distribution of cellulose in the polyamide. The mixture was then injection molded at a maximum temperature of 246 °C. Before extrusion and injection molding, materials were all dried overnight at 70 °C. They suggested that the tensile and flexural modulus increased with increasing filler content. The tensile strength stayed approximately the same level with up to 20 wt.% cellulose content, but a reduction was observed at 30% due to the filler loading interference with the matrix's stress-transfer ability. The flexural strength was the highest at 20% cellulose content. The notched Izod impact strength results showed a decrease with an increase of fiber content. However, there was no significant reduction until 30% cellulose content. Increasing the interfacial regions and, therefore, crack propagation, fibers' addition will reduce the impact strength. The thermal gravimetric analysis (TGA) demonstrated that enhancing the cellulose fiber content slightly reduces the temperature at which 10 wt.% is lost. The Polyamide blend performed well in TGA analysis by representing an intermediate property between the two different polyamides.

The interfacial adhesion is known as a critical issue, the bio-based fibers and bio-based thermoplastics interfacial adhesion is a drawback that restricts the large-scale production and application of biocomposite materials. In this regard, the fiber treatment effect was investigated on the properties of the final biocomposite by Werchefani and coworkers [15]. Polylactic acid (PLA) and Alfa short fibers were chosen as matrix and reinforcement, respectively. The authors suggest that these natural fiber-reinforced composites can be employed in industries such as automotive applications.

Three different types of Alfa fiber treatment were carried out with the aid of NaOH, xylanase, and pectinase. The untreated fibers were employed as the blank sample. The chemical compositions were assessed by biochemical analysis. The SEM analysis revealed that the chemical and enzymatic treatments had changed both the composition and the topography of the fibers. For untreated fibers, the fibers' bunches were detected, suggesting waxy materials holding the fibers together. After chemical treatment, the surface of fibers indicated that some of the constituents, including hemicellulose and lignin, are removed, and the fiber bundles have been opened.

The samples treated with xylanase and pectinase showed the same morphological properties. The splitting of the fibers could obviously be detected, and the fibrils had come into contact. Also, the more isolated and finer fibrils could be detected in pectinase-treated fibers.

Tensile analysis revealed that fiber modification plays a critical role in the obtained composite mechanical properties. It was observed that the enzymatic modification provides a dramatic increase in the tensile modulus and tensile strength. The Alfa fibers treated with pectinase revealed the highest tensile properties when employed as the reinforcement of the PLA matrix. This can be attributed to the pectinase treatment's morphological changes, which separates fibers into individual fibrils, as confirmed by SEM analysis.

In another research, recently published by Platnieks and coworkers [16], five compositions were prepared by nanofibrillated cellulose (NC) and microcrystalline cellulose (MC) as fillers and bio-based polybutylene succinate as the polymeric matrix. The melt blending approach performed the composite fabrication. The synergetic effect of the application of nano and micro cellulose into the polymeric matrix was investigated.

Differential scanning calorimetry revealed that nucleation and crystallization occur in both fillers. However, the MC filler can improve the crystallinity degree more than the NC filler. It is well known that the cellulose filler structure affects the crystallization process, and the agglomeration of the fillers can decrease crystallinity. Two different crystallinity values were observed for 40% NC and 40% MC composites confirming the effect of the filler structure on the degree of crystallinity. By increasing the composite's MC content, the degree of crystallization showed an increase, and the splitting in the melting peak represents the trans crystallization. This was concluded that NC forms larger agglomerations due to its higher surface area and stronger hydrogen bonding. This results in an uneven filler distribution. The MC was chosen as a more suitable candidate for industrial applications, including automotive plastic parts.

Many characteristic properties were obtained by using bio-based plastic composites in the automotive industry. The significant ones are summarized in Table 1.

3 Elastomers

Elastomers are widely used in the automotive industry due to their unique properties. They are mainly used in the interior designing of vehicles and also tires. Thermoplastic urethane (TPU) and natural rubber (NR) are the most majorly utilized elastomers in the automotive industry. Using thermoplastic polyurethane elastomers can result in better ultraviolet resistance, reduced thickness, and better mechanical properties. Additionally, the rising demand for lightweight vehicles has resulted in the remarkable growth of the elastomers market in the automotive industry.

As the elastomers do not have enough wear resistance and acceptable mechanical properties, they need to be reinforced with some fillers. On the other hand, relaxation

Table 1 Characteristic properties obtained by using bio-based plastic composites in the automotive industry

Polymeric matrix	Filler	Bio-based component	Biocomposites characteristic properties		
			Tensile strength (MPa)	Young's modulus (GPa)	References
Polyphthalamide	Glass fiber	Matrix	~140 (20 Wt.%)	~6 (20 Wt.%)	[6]
Polyamide	Cellulose fibers	Fibers	~50 (20 wt.%)	~3.6 (20 wt.%)	[14]
Phenolic thermoset	Cellulose fiber	Fibers	–	~4 (30 Wt.%)	[8]
Polyamide	Wood fiber	Fibers	–	~5 (50 Wt.%)	[13]
Polylactic acid	Flax fiber	Fibers/matrix	~100 (30 Wt.%)	~13 (30 Wt.%)	[12]
Polylactic acid	Alfa fibers	Fibers/matrix	~66 (20 Wt.%)	~3 (20 Wt.%)	[15]
Polybutylene succinate	Cellulose fiber	Fibers/matrix	~22 (40 Wt.%)	~6 (40 Wt.%)	[16]

of the elastomeric polymer chain and viscous dissipation in the elastomeric system leads to a large amount of fuel consumption. Considering the increasing trend of automobile production, this will be a remarkable issue. The more the fuel consumption, the more CO_2 emission and of course the more air pollution. As a result, using environmentally friendly components would be a solution. Some of the popular automobile producers started to use bio-based additives to the elastomers used in door panels and course tires [17].

As discussed above, the degradability of thermoplastic elastomers used in the automotive industry has attracted a lot of attention for its environmental issues. In this subject, many researchers are trying to introduce a new generation of thermoplastic vulcanisates (TPVs) with environmentally friendly specifications compared to traditional TPVs. Therefore, the researchers started to use bio-based TPVs, for example: TPVs based on poly(lactic acid)/Natural rubber, TPVs based on poly(lactic acid)/ethylene–vinyl acetate, and TPVs based on poly(butanediol–lactate–sebacate–itaconate) elastomer (PLBSI)/PLA [18]. In this regard, Audi A2 used hybrid mats based on sisal/flax-filled PU as vehicle door trim panels in 2000 [19].

The effect of using cellulose nanocrystals in improving polyurethane matrix has been investigated by Aranguren et al. [20]. It was shown that by using 0.5, 1, and 5 wt% of nanocrystal, the storage modulus was found to show an increasing trend.

The first commercial application of natural fibers in polyurethane was in S-Class Mercedes-Benz in 1999 in its door panel. In this automobile, for its 2-mm thick door panel, 65% flax/hemp/sisal fillers were added to 35% semi-rigid polyurethane

[21]. At a constant weight, the panel shows higher mechanical strength and stiffness. Some automotive producers, such as Audi, Mercedes, and BMW, have used this unique structure (lightweight honeycomb structure inside, with fiber-reinforced polyurethane shell) which has been also used in door panel and other trim parts, sun shades, spare tire covers, and load floors [17, 22].

The first time when Toyota started to use biodegradable polymers involves using Kenaf fibers in PLA matrix from sugarcane and sweet potatoes in spare tires of its RAUM 2003 [23]. Then for producing door trims in Mazda, a composite containing polypropylene reinforced with kenaf fiber was used. In 2008, in Rav-4, Toyota also used seat foams based on soybean. At the same time, for Lexus CT200h, biodegradable polypropylene/poly(lactic acid) was used in manufacturing the side trims, floor finishing plate, toolbox area, door scuff plates, and package trays [24].

Anuar et al. [25] investigated the mechanical properties of thermoplastic natural rubber and polypropylene/ethylene–propylene–diene monomer (PP/EPDM) filled with Kenaf fiber. They believed the development of PP/EPDM reinforced with Kenaf fiber has the ability to be used in automobile parts.

4 Green Tires

The green tire technology was introduced in 1992 by Michelin company using silica plus a bi-functional silane, bis-(triethoxysilylpropyl)tetrasulfide in tire treads instead of carbon black in Europe due to consumer appreciation for better handling, energy cost, and environmental issues. The demand for green tires now has an increasing trend in the world [26].

In the Goodyear company, it was shown that using silica along with carbon black in the tire formulation would result in a 50% reduction in rolling noise, about 10% in wet traction, and 5% reduction in the consumption of fuel and of course air pollution. [27].

For this remarkable innovation, they were awarded at the Geneva Motor show [17]. In spite of the fact that polyisoprene derived from natural rubber has optimum properties, there is some problem using them and the tire producers should shift to replace it totally or partially. One is the shortage of resources in some areas and the next is the environmental issues. So, in tire manufacturing, it has been considered to utilize a type of isoprene which is bio-based.

Woody biomass, switchgrass, and molasses of sugarcane have been shown to be utilized as an acceptable alternative for natural rubber-derived polyisoprene. Mevalonic acid and also 1-deoxy-D-xylulose-5-phosphate pathways by using fermentable sugars as feedstock were utilized to generate the precursors for the synthetic bio-based polyisoprene [28].

In filled polymeric systems, many factors can affect the tire rolling resistance. These parameters include dispersion state, aggregate structure, macromolecular structure, and, of course, interfacial properties. The rolling resistance coefficients of tires and the amount of the elastomers loss modulus at 60 °C are laboratories and industrial benchmarks for automobile fuel consumption. For decreasing fuel consumption, wear resistance, and also wet traction, the most important part to be considered is the tire tread, as this part is the main elastomeric part of the product.

An important safety parameter for a tire is wet traction. Because with a sufficient tire wet traction, dissipation of energy in the using of the braking system would be good enough. For an optimum wet traction, the loss tangent should be high at 0 °C. But at the same time, at 60 °C, the loss tangent should decrease. A good commercialized option for use in tire tread manufacturing to make green tires is anionic solution styrene–butadiene rubber which is reinforced with silica particles [29]. This material has the specifications described above.

Dominic et al. [30] have studied the effect of reinforcing natural rubber with Rice Husk-Derived Nano-cellulose (RHNC) instead of carbon black in tires. They showed that the scorch time and curing rate were improved when they used 5% RHNC and 25% carbon black instead of 30wt% carbon black. The tensile strength and tear resistance of both samples were shown to be almost the same. The technological properties and also swelling index show comparable results in both composites. The stress transfer was shown to be effective in both composites. The presented method in this research can be extensively applied in automotive tires, rubber reinforcement, and other green elastomeric materials.

One of the challenges of using silica in tire tread composition is its dispersion. In another research, Lolage et al. [31] have utilized highly dispersible bio-based silica (HDS) instead of carbon black in the composition of tire tread. They believed that the HDS which is obtained from rice husk ash would cause better dispersion, 15% decreased sample viscosity, higher tensile strength and elongation at break rather than normal silica, and better dispersion. Finally, they conclude that their method leads to an environmentally friendly process that produces a valuable product from the agricultural waste.

The annual value rate of the green tire market is predicted to be 20.63%, and the annual volume rate is predicted to be 22.57% during the forecast period. It has been predicted that the green tire market will be worth USD 152.40 billion by 2023. The key manufacturers of the green tire are Michelin, The Goodyear, Pirelli & C. S.p.A., Kumho Tire, Continental AG, Bridgestone Corporation, Hankook Tire, Cheng Shin Rubber Ind. Co. Lt., Zhongce Rubber Group Co., Ltd (ZC-Rubber), and Nokian Tyres plc [32].

Due to the growing demand for silica in green tires and low interfacial compatibility between silica and NR compared with carbon black and NR, renewable and non-toxic processing aids are required. Some researchers tried to solve this problem. Song [33] used multi-alcohol parts of hydrophilic and hydrophobic groups as a processing aid to increase compatibility between NR and silica. They showed using this processing aid would finally lead to enhanced dry and wet braking performance and durability at high speeds. In another research, Das et al. [34] used a new SBR grafted-(novel 3-Octanoylthio-1-propyltriethoxysilane) in nano silica/3-Octanoylthio-1-propyltriethoxysilane grafted on SBR composite. Their results showed that tensile strength, tear strength, and also rolling resistance of the composites were shown to be better using this grafting agent. In another research, Hassan et al. [35] used soybean oil-derived silanized plasticization for compatibilizing SBR and silica particles.

According to the increasing use of silica-based green tires, some researchers focused on chemical functionalization and devulcanization of waste SBR [36], and also by pyrolysis of waste green tires [26]. Jiang et al. [37] have recently used Silica–graphene hybrid (HGKS), with different hybrid grafting ratios, in natural rubber to be used in the tire tread. They believe in this composition. There is an excellent interfacial interaction between polymer and matrix, which is the essential factor in determining the rubber composite performance used in green tires.

Saleem et al. [38] have fully described using natural fibers as a hybrid with carbon, glass, and basalt fibers in polymers used in the automotive industry.

Another strategy for solving economic issues of using elastomers in the automotive industry is using bio-compatible resources to make elastomeric materials. Some of them which have been commercialized are polyhydroxyalkanoates [39], polylactide [40], and poly(butylene succinate) [41]. Elastomers based on Soybean [42, 43], poly(diisoamyl itaconate-co-isoprene) rubber [44], and polyester elastomers have already been previously investigated. However, for tire applications, no bio-based elastomer has been formulated until now. But research is still being continued in this area.

Li et al. [45] have recently used trans-1, 4-poly (butadiene-co-isoprene) (TBIR) in tire tread formula. They showed a composite containing carbon black-filled TBIR/NR/ESBR showing a reduced rolling resistance and a significant fatigue and abrasion resistance. They introduced this composition as a good candidate for tire tread of automobiles. The effect of using bio-derived elastomeric composites has been summarized in Table 2.

5 Foams

One of the essential topics has become CO_2 emissions due to high fuel consumption in the automotive industry in recent decades. One of the promising solutions would be the production of lightweight vehicles in which metals replace polymers. Foams are widely used as acoustic materials in this regard. However, most commercial materials contain harmful chemical compounds or time-consuming fabrication processes [46]. Employing bio-based materials in foam formulations has introduced more comfortable and safer fabrication conditions. Moreover, biomass is sustainable and renewable compared to fossil resources, and this alteration would be noticeable and crucial for human life [47].

Mazzon and coworkers [46] introduced a novel highly reactive epoxy foams in 2015. This project aimed to investigate the efficacy of this new foam in reducing the vehicle weight and, therefore, fuel consumption. Exothermicity regulators were employed in foam making, due to their endothermic dehydration reaction. Different foams with various compositions were prepared and characterized. The authors claim

Table 2 Characteristic properties obtained by using bio-based elastomeric composites in the automotive industry

Polymeric matrix	Filler	Bio-based component	Biocomposite's characteristic properties	References
Polyurethane	Cellulose nanocrystal	Filler	Increasing Young's modulus from 50 to 110 MPa	[20]
Polyurethane	65% flax/hemp/sisal	Filler	Higher Stiffness, light weight	[17]
Natural rubber	Silica + carbon black	A part of filler	5% reduction in fuel consumption	[27]
Natural rubber	Bio-based highly dispersible silica	A part of filler	15% lower Mooney viscosity compared to conventional silica, better dispersion, better reinforcement factor (from 4.2 to 4.5), higher tensile strength(from 130 to 180 kg/cm2), and elongation at break(from 293 to 426%)	[31]
3-Octanoylthio-1-propyltriethoxysilane grafted SBR	Silica	Filler	Higher tensile and tear strength, better rolling resistance	[34]
Biomass-derived isoprene	Carbon black	Matrix	Comparable with traditional Helping environmental issues	[28]
PLA derived from sugarcane and sweet potatoes	Kenaf fiber	Both matrix and filler	Increasing mechanical strength up to 70 MP and storage modulus up to 6 GPa	[23]

that highly effective foams can be easily obtained in a few minutes by the suggested components and approach.

Recently, in 2020, Mazzon and coworkers [47] published new bio-based epoxy foams by mixing two epoxidized plant oil-derivatives with a non-toxic foaming agent and anhydride hardener. Highly reactive epoxy foams were prepared in less than 3 min. The effect of thermal domains and the blowing agent's decomposition was studied on the final foam production. They revealed that the best characteristics could be obtained by choosing a blowing agent who starts acting when the crosslinking has almost finished. In other words, the trap of gas in the polymeric matrix can be carried out with no effect on the crosslinking degree.

Sound isolation is one of the critical issues in automotive parts, including dashboards and door panels. In this regard, many researchers focus on developing new bio-based foams for application in automotive industries. Rus and coworkers [48] have published a recent article related to this issue. In this paper, a novel biopolymer foam was fabricated by employing biofillers. Wood dust and tire rubber waste were used as fillers, and the cooking oil waste was converted to the monomer. The hybrid fillers percentage was set as 2.5%, 5.0%, 7.5%, and 10% weight to weight ratio with bio-monomer. The foam with 10.0% fillers revealed the highest sound absorption coefficient ($\alpha = 0.963$). This filler loading, 10.0%, resulted in the smallest pore sizes, but the pores were interconnected, leading the air molecules within the pores to vibrate. This vibration would reduce the original energy of the air molecules. This was concluded that the biocomposite fabricated from wastes could be effectively used in the automotive industries' acoustic application.

Polyurethane foams are highly considered in the automotive industry regarding their acoustic properties. In this regard, Ji and coworkers [49] have recently introduced a novel polyurethane foam based on tung oil (TOPUF) by employing miscanthus lutarioriparius (ML) to improve acoustic performance. A one-step synthesis procedure was used for composite fabrication. For this purpose, polyols and methylene diphenyl diisocyanate were used for polyurethane foam synthesis. Silicone and Deionized water were added as foam stabilizers and blowing agents, respectively. The filler, ML, was added to the polyurethane foam, including NaOH solution (5 wt.%) as a treatment solution for filler. All the reagents except methylene diphenyl diisocyanate were mixed for 20 s. followed by adding the ML and methylene diphenyl diisocyanate to the mixture and stirring for more 10 s. The foam was fabricated by molding for 60 min at 50 °C. The common behavior was observed in all samples, by adding various amounts of ML. This was suggested that the cavity size will be decreased by increasing the content of ML powder. The optimum acoustic properties were obtained at 0.3 wt% of ML. The transmission loss and the average sound absorption coefficient were measured to be19.05 and 0.518 dB, respectively. The authors claimed that the suggested method and the fabricated foam can fabricate acoustic materials, specifically in the automotive industry.

The addition of Lignin as a non-toxic, inexpensive, and abundant component into the polyurethane (PU) foam was another strategy for developing reinforced biocomposites in automotive industries. In this research, Faruk and coworkers [50] carried out a green PU foam with the aid of soy polyol. The isocyanate content, with potential health hazards, was reduced by introducing lignin to PU foam. It was reported that the foaming procedure was delayed due to the addition of fiber. The presence of fiber also hindered the expansion of the polymer matrix. The SEM analysis of the foam revealed that the addition of lignin had reduced cell size in PU foam. However, no meaningful change was detected in the cell shape and roundness.

Yu and coworkers [51] have introduced novel non-isocyanate polyurethanes by employing bio-based poly(cyclic carbonates) and amines. The effect of catalysts was investigated, and the properties of the final coating were studied in this research. Carbonated Soybean Oil (CSO) was synthesized with the aid of CO_2 and ESO. Tetrabutylammonium bromide (TBAB) was used as a catalyst. Once finished all solvents were removed with the aid of a rotary evaporator. The Carbonated Sucrose Soyate (CSS) was prepared by the same method with some modifications. It was suggested that the higher functionality of the CSS could effectively improve the coating properties.

6 Conclusion

The contribution of polymer composites has significantly grown up in the automotive industry, regarding their unique properties. Light vehicles have represented an essential market for plastics and polymer composites during the last five decades. Polymeric composites, including plastics, elastomers, and foams, are widely employed in lightweight automobiles and have paved the way for becoming a vital part of the automotive industry. In recent decades, green synthesis and bio-based materials have gotten worldwide attention, and the automotive industry is a pioneer in this field. Due to their improved environmental applications and recyclability, automobile manufacturers are eager to employ bio-based materials. It is approved that the recycling of bio-based fillers requires lower energy than commercial reinforcements such as glass fibers.

Using natural fibers for reinforcing polymers used in the automotive industry has some drawbacks despite having the benefits mentioned before. They are more flammable than traditional fillers. Their mechanical properties are not as high as traditional ones. They need lower processing temperature, and because of their nature, they are not compatible with hydrophobic matrices, so there are some mixing issues. Another challenge is the non-uniformity and non-reproducibility of the natural fibers due to their different ways of extraction. One way to overcome these drawbacks is to use hybrid composites. However, it is still a challenge to use biodegradable fibers.

References

1. Konz RJ (2009) Note the end-of-life vehicle (ELV) directive: the road to responsible disposal. Regulation 431:431–457
2. https://www.oica.net/category/production-statistics/2019-statistics

3. Goede M, Stehlin M, Rafflenbeul L, Kopp G, Beeh E (2009) Super Light Car-lightweight construction thanks to a multi-material design and function integration. Eur Transp Res Rev 1(1):5–10. https://doi.org/10.1007/s12544-008-0001-2
4. Patil A, Patel A, Purohit R (2017) Science direct an overview of polymeric materials for automotive applications. Mater Today Proc 4(2):3807–3815. https://doi.org/10.1016/j.matpr.2017.02.278
5. https://www.automotiveplastics.com/2019-light-vehicle-materials-report/
6. Wei XF, Kallio KJ, Bruder S, Bellander M, Olsson RT, Hedenqvist MS (2020) High-performance glass-fibre reinforced biobased aromatic polyamide in automotive biofuel supply systems. J Clean Prod 263:121453. https://doi.org/10.1016/j.jclepro.2020.121453
7. Sadashiva M, Abhishek JV (2020) Characteristic evaluation of tensile properties of hybrid bio composites with different orientation of fibers. AIP Conf Proc 2274. https://doi.org/10.1063/5.0027006
8. da Silva CG, Frollini E (2020) Unburned sugarcane bagasse: bio-based phenolic thermoset composites as an alternative for the management of this agrowaste. J Polym Environ 28(12):3201–3210. https://doi.org/10.1007/s10924-020-01848-y
9. Al- FM, Sapuan SM (2014) Natural fiber reinforced polymer composites in industrial applications: Feasibility of date palm fibers for sustainable automotive industry. J Clean Prod 66:347–354. https://doi.org/10.1016/j.jclepro.2013.10.050
10. Yusof NSB, Sapuan SM, Sultan MTH, Jawaid M (2020) Conceptual design of oil palm fibre reinforced polymer hybrid composite automotive crash box using integrated approach. J Cent South Univ 27(1):64–75. https://doi.org/10.1007/s11771-020-4278-1
11. Sadeghi- M, Safapour S (2018) Salt-free dyeing of cotton fabric modified with prepared chitosan-poly (propylene) imine dendrimer using direct dyes. Prog Color Color Coatings 11(1):21–32
12. Pantaloni D, Shah D, Baley C, Bourmaud A (2020) Monitoring of mechanical performances of flax non-woven biocomposites during a home compost degradation. Polym Degrad Stab 177:109166.https://doi.org/10.1016/j.polymdegradstab.2020.109166
13. Oliver-Ortega H, Julian F, Espinach FX, Tarrés Q, Ardanuy M, Mutjé P (2019) Research on the use of lignocellulosic fibers reinforced bio-polyamide 11 with composites for automotive parts: car door handle case study. J Clean Prod 226:64–73. https://doi.org/10.1016/j.jclepro.2019.04.047
14. Birch A, Dal Castel C, Kiziltas A, Mielewski D, Simon L (2015) Development of cost effective and sustainable polyamide blends for automotive applications. SPE Automot Compos Conf Exhib Troy, MI, USA, no. November, pp. 1–10, 2015. https://www.researchgate.net/publication/283504893
15. Werchefani M, Lacoste C, Belguith H, Gargouri A, Bradai C (2020) Effect of chemical and enzymatic treatments of alfa fibers on polylactic acid bio-composites properties. J Compos Mater 54(30):4959–4967. https://doi.org/10.1177/0021998320941579
16. Platnieks O, Gaidukovs S, Barkane A, Sereda A, Gaidukova G, Grase L, Thakur VK, Filipova I, Fridrihsone V, Skute M, Laka M (2020) Bio-based poly(butylene succinate)/microcrystalline cellulose/nanofibrillated cellulose-based sustainable polymer composites: thermo-mechanical and biodegradation studies. Polymers (Basel) 12(7):1–20. https://doi.org/10.3390/polym12071472
17. Holbery J, Houston D (2006) Natural-fiber-reinforced polymer composites in automotive applications. JOM 58(11):80–86. https://doi.org/10.1007/s11837-006-0234-2
18. Baran A, Tuhin B (2020) Automotive applications of thermoplastic vulcanizates, 1–19. https://doi.org/10.1002/app.49181
19. Mohanty AK, Misra M, Drzal LT (2005) No title. Nat fibers, Biopolym. Biocomposites
20. Aranguren MI, Marcovich NE, Salgueiro W, Somoza A (2013) Effect of the nano-cellulose content on the properties of reinforced polyurethanes. A study using mechanical tests and positron anihilation spectroscopy. Polym Test 32(1):115–122. https://doi.org/10.1016/j.polymertesting.2012.08.014
21. https://www.ptonline.com/articles/natural-fibers-the-new-fashion-in-automotive-plastics

22. Seagrave TD (2003) Automotive polyurethane composite parts made with natural fiber mats and honeycomb cores. Bayer and Hennecke GmbH Report. https://www.yumpu.com/en/document/read/3284814/automotive-polyurethane-composite-parts-made-with-natural-fiber
23. Cunha AM, Campos AR, Cristovão C, Vila C, Santos V, Parajó JC (2006) Sustainable materials in automotive applications. Plast Rubber Compos 35(6–7):233–241. https://doi.org/10.1179/174328906X146487
24. Toyota green innovations, pp 7–12, 2014. https://www.toyota.com
25. Anuar H, Surip SN, Adilah A (2010) Development of reinforced thermoplastic elastomer with kenaf bast fibre for automotive component, pp 1–5
26. Al-Hartom OA, Al-ghamdi AA, Farha SA, Said A, Dishovsky N, Ward MB, Mihaylov M, Ivanov M (2015) Characterization of carbon silica hybrid fillers obtained by pyrolysis of waste green tires by the STEM-EDX method. Mater Charact 101, 90–96. https://doi.org/10.1016/j.matchar.2014.09.003
27. Bledzki AK, Sperber VE, Faruk O (2002) Natural and wood Fibre reinforcement in polymers. Rapra Technol
28. Bouvier F, Rahier A, Camara B (2005) Progress in lipid research biogenesis, molecular regulation and function of plant isoprenoids 44:357–429. https://doi.org/10.1016/j.plipres.2005.09.003
29. Lei W, Zhou X, Russell TP, Hua K, Yang X, Qiao H, Wang W, Li F, Wang R, Zhang L (2016) High performance bio-based elastomers: energy efficient and sustainable materials for tires. J Mater Chem A 4(34):13058–13062. https://doi.org/10.1039/C6TA05001H
30. Dominic M, Joseph R, Sabura Begum PM, Kanoth BP, Chandra J, Thomas S (2020) Green tire technology: Effect of rice husk derived nanocellulose (RHNC) in replacing carbon black (CB) in natural rubber (NR) compounding. Carbohydr Polym 230:115620. https://doi.org/10.1016/j.carbpol.2019.115620
31. Lolage M, Parida P, Chaskar M, Gupta A, Rautaray D (2020) “Jo ur of,” sustain. Mater Technol, e00232. https://doi.org/10.1016/j.susmat.2020.e00232
32. G. G. T. M. R. Report, p. https://www.marketresearchfuture.com
33. Song SH (2020) Characterization of eco-friendly processing aids for styrene butadiene rubber composites with silica. https://doi.org/10.1177/0021998320916230
34. Das S, Chattopadhyay S, Dhanania S, Bhowmick AK (2020) “Improved dispersion and physico-mechanical properties of rubber/silica composites through new silane grafting. Polym Eng Sci 60(12):3115–3134. https://doi.org/10.1002/pen.25541
35. Hassan AA, Formela K, Wang S (2020) Enhanced interfacial and mechanical performance of styrene-butadiene rubber/silica composites compatibilized by soybean oil derived silanized plasticization. Compos Sci Technol 197:108271.https://doi.org/10.1016/j.compscitech.2020.108271
36. Ghosh J, Hait S, Ghorai S, Mondal D, Wießner S, Das A, De D (2019) Resources, conservation & recycling cradle-to-cradle approach to waste tyres and development of silica based green tyre composites. Resour Conserv Recycl 154:104629. https://doi.org/10.1016/j.resconrec.2019.104629
37. Jiang L, Huang K, Wang Y, Wang J (2020) Effective reinforcement of hydrogen-bonding assembly silica-graphene hybrid in natural rubber, pp 1–10. https://doi.org/10.1002/vnl.21797
38. Saleem A, Medina L, Skrifvars M, Berglin L (2020) Hybrid polymer composites of bio-based bast fibers with glass, carbon and basalt fibers for automotive applications-a review. Molecules 25(21). https://doi.org/10.3390/molecules25214933
39. Li Z, Loh XJ (2015) Water soluble polyhydroxyalkanoates: future materials for therapeutic applications. Chem Soc Rev 44(10):2865–2879. https://doi.org/10.1039/C5CS00089K
40. Dusselier M, Van Wouwe P, Dewaele A, Jacobs PA, Sels BF (2015) GREEN CHEMISTRY. Shape-selective zeolite catalysis for bioplastics production. Science 349(6243):78–80. https://doi.org/10.1126/science.aaa7169
41. Ullah MH, Mahadi WNL, Latef TA (2015) Aerogel Poly (butylene succinate) biomaterial substrate for rf and microwave applications. Nat Publ Gr, 1–8. https://doi.org/10.1038/srep12868

42. van Lith R, Gregory EK, Yang J, Kibbe MR, Ameer GA (2014) Engineering biodegradable polyester elastomers with antioxidant properties to attenuate oxidative stress in tissues. Biomaterials 35(28):8113–8122. https://doi.org/10.1016/j.biomaterials.2014.06.004
43. Wang Z, Zhang X, Wang R, Kang H, Qiao B, Ma J, Zhang L, Wang H (2012) Synthesis and characterization of novel soybean-oil-based elastomers with favorable processability and tunable properties. Macromolecules 45(22):9010–9019. https://doi.org/10.1021/ma301938a
44. Wang R, Ma J, Zhou X, Wang Z, Kang H, Zhang L, Design and preparation of a Novel Crosslinkable, high molecular weight and bio-based elastomer by emulsion polymerization, pp 1–4
45. Li H, Zong X, Li N, Zhang X, He A (2021) Influences of crosslinkable crystalline copolymer on the polymer network and filler dispersion of NR/ESBR/CB nanocomposites. Compos Part A Appl Sci Manuf 140:106194. https://doi.org/10.1016/j.compositesa.2020.106194
46. Mazzon E, Habas A, Habas JP (2015) Lightweight rigid foams from highly reactive epoxy resins derived from vegetable oil for automotive applications. Eur Polym J 68:546–557. https://doi.org/10.1016/j.eurpolymj.2015.03.064
47. Mazzon E, Guigues P, Habas JP (2020) Biobased structural epoxy foams derived from plant-oil: formulation, manufacturing and characterization. Ind Crops Prod 144:111994. https://doi.org/10.1016/j.indcrop.2019.111994
48. Rus AZM, Azahari MSM, Kormin S, Soon LB, Zaliran MT, Sadrina A (2017) Hybrid waste filler filled bio-polymer foam composites for sound absorbent materials. AIP Conf Proc 1877. https://doi.org/10.1063/1.4999883
49. Ji Y, Chen S, Cheng Y (2019) Synthesis and acoustic study of a new tung oil-based polyurethane composite foam with the addition of miscanthus lutarioriparius. Polymers (Basel) 11(7). https://doi.org/10.3390/polym11071144
50. Faruk O, Sain M, Farnood R, Pan Y, Xiao H (2014) Development of lignin and Nanocellulose enhanced bio PU foams for automotive parts. J Polym Environ 22(3):279–288. https://doi.org/10.1007/s10924-013-0631-x
51. Yu AZ, Setien RA, Sahouani JM, Docken J, Webster DC (2019) Catalyzed non-isocyanate polyurethane (NIPU) coatings from bio-based poly(cyclic carbonates). J. Coatings Technol Res 16(1):41–57. https://doi.org/10.1007/s11998-018-0135-7