International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I4P128
Volume 72 Issue 4, 269-278, April 2024

Original Article

The Use and Recycling of Natural and Synthetic Fibre-Reinforced Polymeric Composites in the Automotive Industry: A Review

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Received: 29 September 2023 Revised: 19 December 2023 Accepted: 03 March 2024 Published: 24 April 2024

Abstract - *The number of vehicles worldwide is increasing every year, with approximately 80 million vehicles manufactured every year. Each of these vehicles contains approximately 20 kg of interior composite panels destined for landfill. The automotive industry has been increasingly using composite materials to fabricate interior panels to promote lightweight, sustainability, and fuel efficiency. The disposal process of composite interior panels made of inorganic fibre and plastics is a global environmental challenge. Normally, vehicle interior composites are disposed of in landfills through incineration. This results in air pollution, which is not environmentally friendly. This review paper discusses the application of synthetic composite and recycling processes in the automotive industry and alternative materials to be used. The disposal process, recycling methods and shortcomings of synthetic and natural fibres are discussed. The environmental concerns and impacts arising from the use of composite materials and possible solutions are discussed in this study. The use of composite materials in vehicle interior components has significant potential to lower the carbon footprint in the manufacture of automobiles.*

Keywords - *Automobile industry, Interior composites, Recycling, and Mechanical properties.*

1. Introduction

The automobile industry has manufactured composite panels using synthetic reinforcement [1]. Composite materials are more lightweight than the iron, aluminium, and steel that are currently saturating the automotive industry. However, Sustainability Development Goals (SDGs) and increased environmental awareness have compelled and encouraged researchers to develop innovative and effective renewable and green materials for use in the automotive industry [2]. There is a need for weight reduction in automobiles, which leads to improved fuel efficiency, hence reducing the carbon footprint from vehicles and conforming to environmental global legislations [3]. Composite materials are now crucial in the production of automobiles. The usage of synthetic composite materials, however, has raised significant environmental concerns. Petrochemicals, which do not biodegrade, are not renewable, are difficult to recycle, and need a lot of energy to create, are the source of the synthetic composites utilized in the automotive industry. Interior panels in automobiles give comfort and safety to the driver. Furthermore, these panels give structural integrity and enhance the aesthetics of the vehicle [4]. Synthetic composites panels in the automobile contribute approximately 20 kg of waste per vehicle which winds up in landfills and is disposed of primarily through incineration since they are not biodegradable [5]. Figure 1 shows different types of plastic composite materials used in automobiles. These vehicle composite panels are mainly disposed of through incineration, which results in air pollution [7]. Research indicates that the use of bio-composite materials can reduce the cost of automobile interior panels by 20 % and additional reduce the weight of the vehicle by as much as 30% of the automobile component [8].

Fig. 1 Composite Material components used in automobiles [6]

Natural fibres obtained from animal hair and plant bast fibre are gaining increased use and momentum in the automotive industry over synthetic material-based composites [9]. Interior panels of vehicles are the point of interaction and visual stimulus of the driver; hence, these panels must be aesthetically pleasing while being environmentally friendly [10]. With the increased environmental concerns, it has become necessary for vehicle manufacturers to incorporate recyclable materials in modern vehicles [11]. In-depth research into the recycling of automobiles is important and advantageous for environmental preservation. [12]. According to automobile manufacturers, a middle-class car typically contains 130 kg of plastic per vehicle [13].

According to these statistics, there will be 507,000 metric tons annually of plastic garbage in the landfill. If these plastics are not properly managed and disposed of, the environmental impact is significant. Vehicle plastic composite parts have evolved from conventional ornamental elements to practical and structural components.

Additionally, materials have progressed from basic plastics to composite materials that are stronger and have high-impact resistant. The most common plastic materials used in the automotive industry are shown in Figure 2. These plastics include acrylonitrile-butadiene styrene (ABS), thermoset and thermoplastic polyester, polypropylene (PP), polyurethane (PU), polyethylene (PE), polycarbonate (PC), polyvinylchloride (PVC), polyphenylene oxide (PPO), polyformaldehyde (POM), polyamide (PA), and thermoset and thermoplastic polyester [14]. The main plastic composites in a motor vehicle include the bumper, lights, grilles, instrument panel (including the sub-dashboard), the interior of the doors, the roof, the glove box, and the fuel tank [15]. Vehicle composite plastic recycling has emerged as the most crucial concern facing the globe today as the number of end-of-life span vehicles rises. Studying vehicle plastic recycling technology is important for the automobile industry's support of sustainable development and energy conservation [16].

To meet Sustainable Development Goal (SDG) 11, which focuses on sustainable cities and communities, this study reviews various composite materials that can create sustainable materials in vehicle interior components.

2. Natural Fibres

The natural fibres are low-density, compostable, non-toxic, and simple to handle. Furthermore, the use of natural fibres, which would otherwise have been considered waste, can be a source of income for the agricultural sector and rural communities [1]. Natural fibres tend to have low-cost, good insulation against heat and noise [1] [2]. It has been demonstrated that using natural fibres like hemp, flax, and sisal in place of petrochemical injection molded plastics can reduce the weight of interior panels for vehicles by 20% to 50% [3]. The majority of natural fibres are considered to be carbon neutral, which means that they absorb the same amount of carbon dioxide as they produce [4].

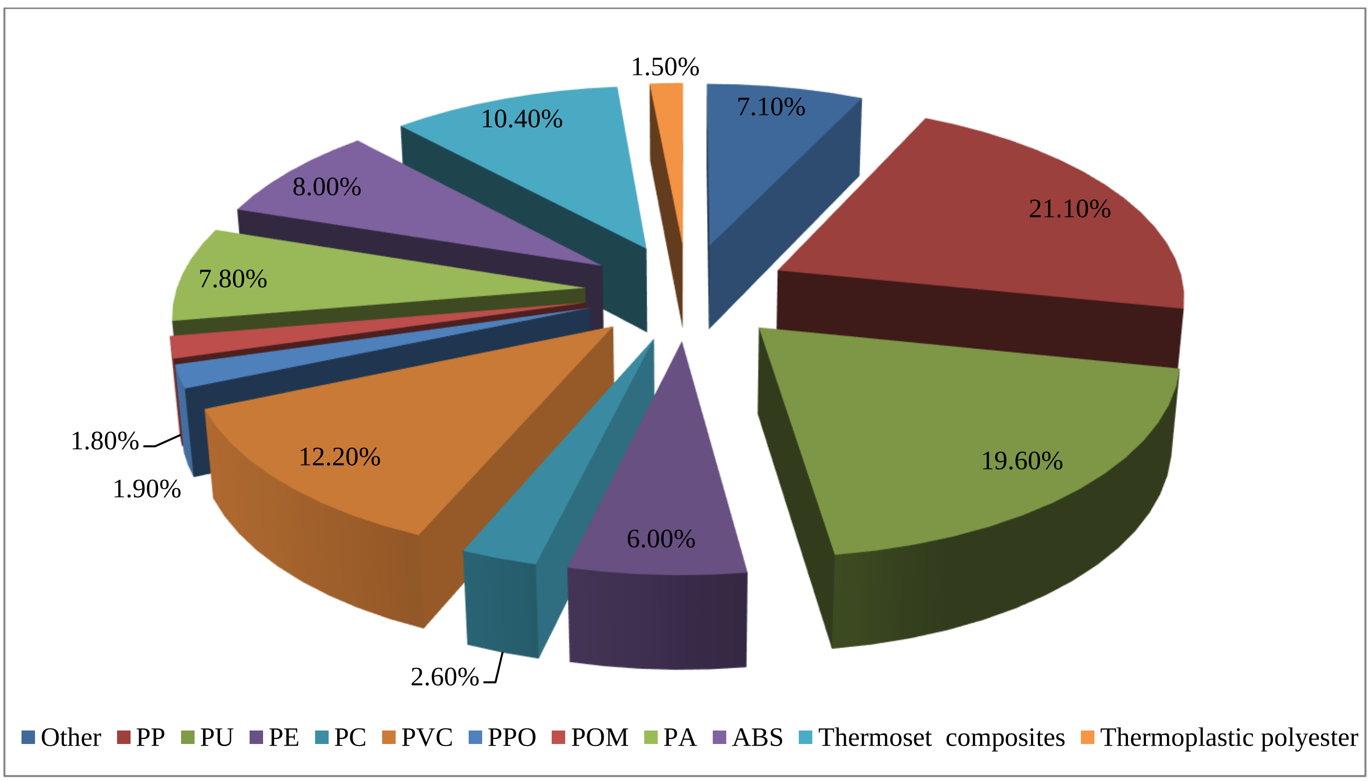

Fig. 2 Different types of plastic used in the automotive industry [12]

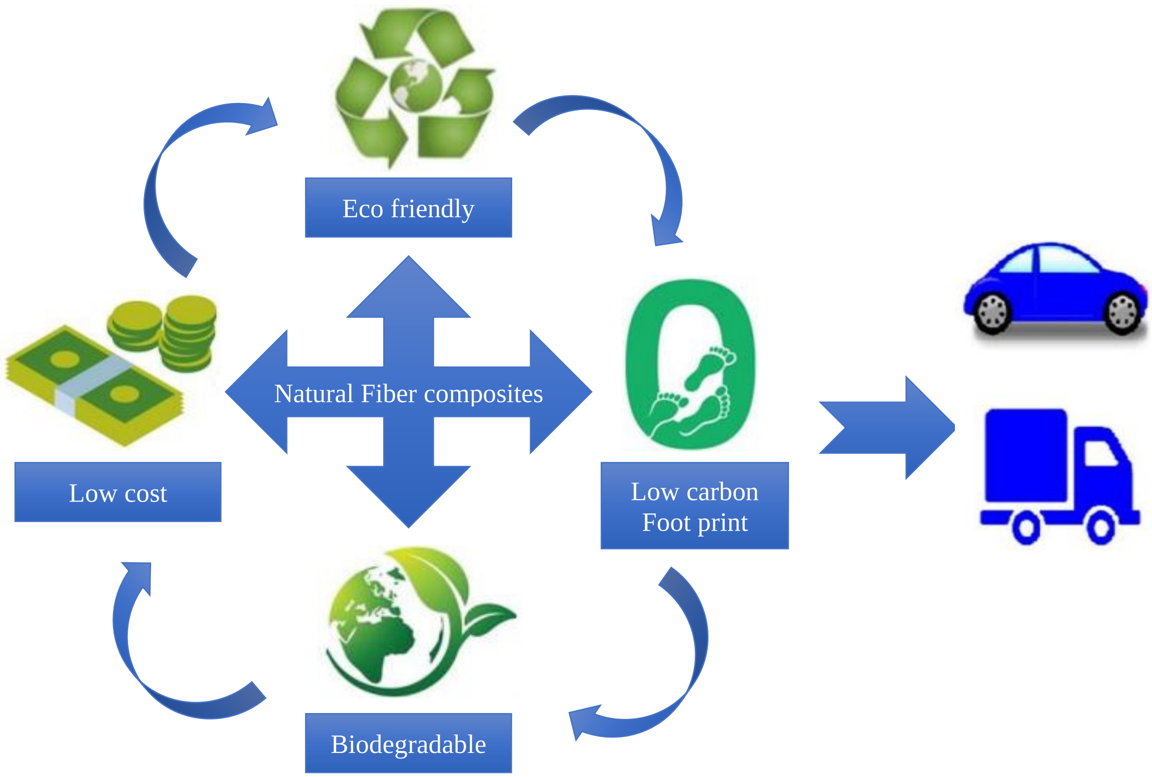

Fig. 3 Natural fibre composites' sustainable attributes and possible applications in the automobile industry

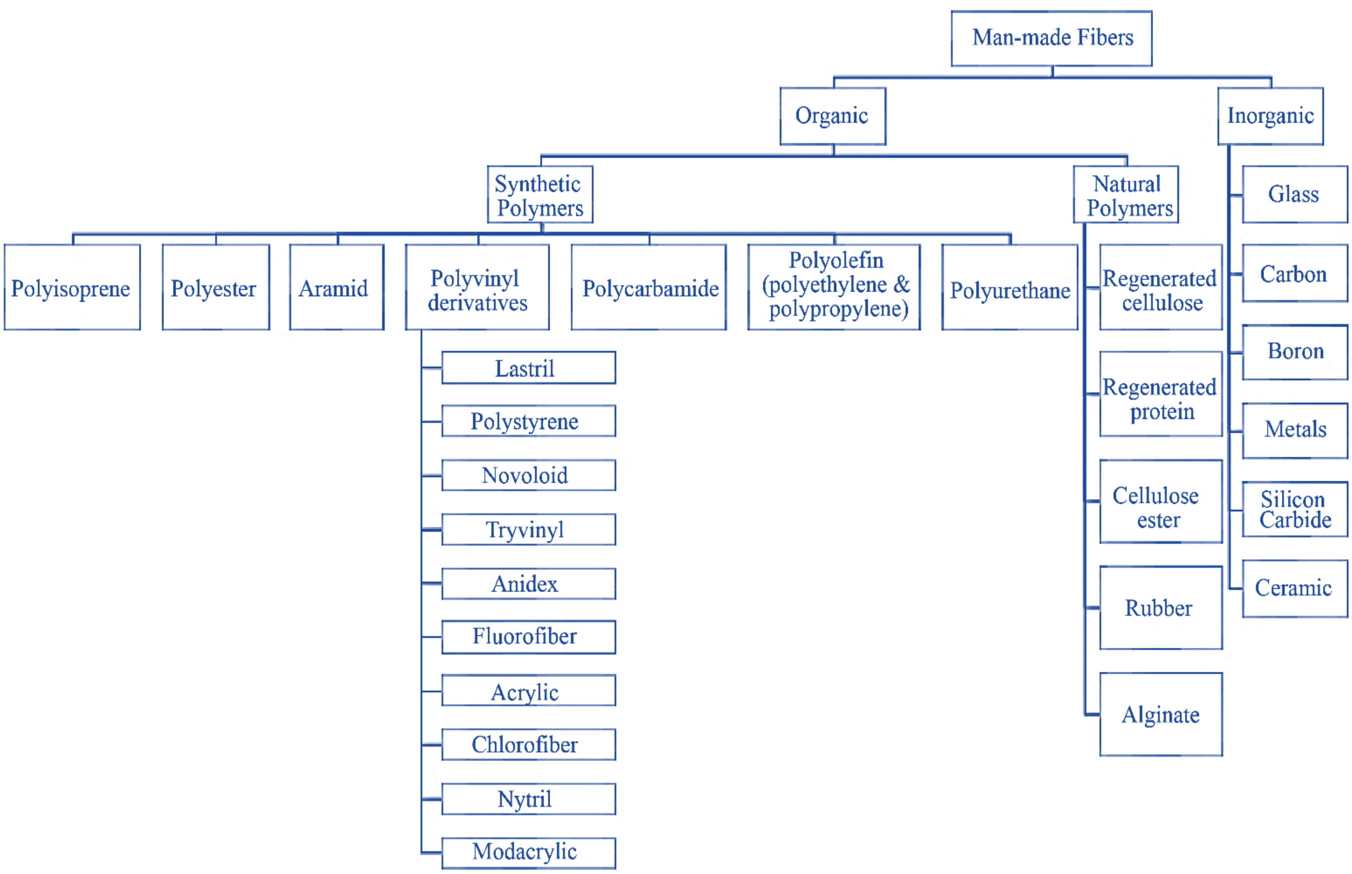

Fig. 4 Classification of synthetic fibre and polymers [7]

Table 1. The Comparison of tensile of natural and synthetic fibres [10]

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

Literature shows that composites made from natural fibres have the potential to replace those made from synthetic fibres in the automotive industry. Natural fibres used in the automotive sector and their potential to replace petroleum-based fibres are the subjects of current research [5]. Fig provides a schematic representation of the sustainable qualities and the potential of natural fibre composites in the automotive industry.

3. Synthetic Fibres

Composite interior panels have been made using synthetic fibre composites. Figure 4 shows the broad classification of synthetic fibre reinforcements. Synthetic composites are artificial, and the majority of them are made from petrochemicals, which are fundamental components derived from petroleum. A microscopic unit or monomer, which is a repeating unit, is the foundation of synthetic fibres and polymers. In the automotive sector, materials including polypropylene, nylon, acrylics, and polyurethane, are frequently used as examples. Millions of tons of this fibre are produced annually over the world [22].

3.1. Organic Fibres

Composite materials can be reinforced using organic synthetic polymers. [8]**.** Organic fibres are natural fibres such as wool, cotton, sisal, banana and hemp fibres.

3.2. Inorganic Fibres

Additionally, inorganic fibres are used to strengthen composite materials. Glass, carbon, boron, metals, and silicon carbide are a few examples of these inorganic fibres. Some of the most often utilized inorganic fibres in concrete include glass, carbon, and steel [25]. E-glass-reinforced composites had better mechanical characteristics than composites made with natural fibres. This occurs as a result of the superior mechanical characteristics of glass as a material. Because of the size of the fibre, E glass is a continuous that improves the transmission of stresses [9]. Synthetic fibres make it simpler to reach the desired length than natural fibres.

Table 1 shows a comparison of the tensile strength of natural and synthetic fibres used in automotive composites.

4. Environmental Interests

Due to its carbon footprint, the disposal of composite panels in the automotive industry has recently drawn attention [28]. Environmental awareness has forced policymakers to update their laws and regulations to harmonize matters like resource conservation, carbon dioxide (CO2) emission reduction, and recycling [28]. These legislations have had an impact on the materials used in automobiles and motivated the development of bio-composite materials. This has propelled the automotive industry to move from petrochemical composites to natural fibre-based composites since they are environmentally friendly [29]. The rising costs of synthetic and petrochemical composites and unstable sources of fossil fuels have led to significant strides in the use of natural fibres in the automotive industry [30]. Special consideration must be used while selecting an alternate material to promote light weight composite. Natural fibres from animals and plants may seem the logical choice as a means of preserving the environment. However, It must be remembered that cotton is grown using significant amounts of water and insecticide [20].

Bio-composites are generally not as stable as synthetic fibre-based or metal composites, and thus, researchers are searching for possible solutions to increase the durability of bio-composites. A lot of research is being done to fully understand the mechanism of bio composite degradation and modification to improve their mechanical strength.The effects of chemical and physical treatment on the morphological, chemical resistance, and mechanical properties of natural fibres have been the subject of extensive research to improve the interfacial bonding between the fibre and the matrix [31]. A common treatment method is the use of alkali to enhance the surface properties of the fibre [32]. Natural fibre composites, in general, have advanced significantly over the past ten years, and they are now finding more industrial uses. Furthermore, natural fibres have the advantage of being able to be used as thermal energy at the end of their useful lifespan, consequently not adding to the environmental and landfill disaster.

5. Application of Polymeric Composite Materials in the Automotive Industry and Recycling Methods in the Automotive Industry

Different types of polymers are used in a vehicle; Table 2 shows the different types of plastics used in the automobile and their applications [11], [12]. One of the main obstacles to the use of engineering plastics and composites in automobiles is the cost increase, pollution, and recycling challenges. Furthermore, large amounts of plastic waste have been produced because of engineering plastics' extensive use and quick pace of uptake in automotive applications. Fortunately, Due to their higher attributes and high-performance features, engineering plastics can be effectively utilized after recycling as opposed to recycled commodity plastics [40]. Separation is a crucial step that needs to be completed before recycling since the passenger vehicle plastic mixture frequently contains numerous types of waste plastics. Due to the nature of plastics, separation of mixed plastics, is one of the most challenging procedures in the management system for plastic waste and presents numerous challenges[13].

Table 2. Components and types of plastics used in the automotive industry [17]

Components	Types of plastics used
Bumpers	ABS, PC, PS, PP
Seating	PVC, PUR
Dashboard	ABS, PC/ABS, PP, SMA
Fuel systems	PBT, HDPE, PA, PP, POM
Body including panels	PU, PPE, PP
Under-bonnet components	PP, PA, PBT
Interior trim	ABS, PP, PET, PVC, POM
Exterior trim	PA, ABS, PBT, POM, PP
Lighting	ABS, PP, PC, PMMA
Liquid reservoirs	PA, PE, PP
Electrical components	PA, PE, PP, PVC
Upholstery	PUR, PP, PVC, PE

The classic plastic separation techniques can be categorized into two groups: wet separation and dry separation, depending on whether water or another liquid medium must be added during the separate process. An air classifier, melting separation, mechanical separation, electronic sorting, and artificial separation are some of the dry separation procedures. Gravity separation, heavy medium separation, and the froth flotation process are examples of wet separation methods. [11]. In addition to conventional techniques, plastic electrostatic separation technology has quickly developed due to its straightforward equipment design, simple operation, lack of pollution, and high separation efficiency. Recent years have seen the development of some combinatorial separation technologies, which combine several conventional sorting techniques with electrostatic separation techniques. Examples of combined sorting techniques include the electrostatic separation of mixes of shredded plastic using a tribo-cyclone [12] and ozone-treated flotation and separating a plastic mixture by triboelectric separation and air tabling [15], [16].

6. Recycling of Plastic Composite Interior Panels

Utilizing recycled engineering plastics reduces the cost of fabrication [18]. Recycling is the most effective method for managing polymers beyond their useful life. [19]. The cost of recovering the resources, the efficiency of plastic waste separation, and the availability of a suitable facility for dismantling, sorting, and storing waste are all factors that must be considered when using recovered engineering plastics [20]. Recycling and proper disposal of biodegradable plastics and engineering plastics should be a part of any good program for the disposal of used cars. The separation, extraction, and processing of recyclable plastics may be handled by one branch, while the composting and disposal of bioplastics may be handled by another. The recycling department may use the materials it processes to make new automobile components. The engineering plastics ABS, polybutylene terephthalate (PBT), PC, polyamides (PA) and are the most often used ones in automobiles [21]. These materials can typically be recycled and continue to exhibit good qualities after their useful lives. Additionally, by melting the plastics and blending them with maleic anhydride-grafted ABS (ABS-g-MA), the hardness of recovered plastic composites can be greatly enhanced [22]. Aluminum (Al)-low-density polyethylene (LDPE)-aluminum panels are one type of metal hybrid sandwich that is becoming increasingly popular in automobile applications because of its lightweight and sound-dampening properties.

Metal and thermoplastic components included in hybrid materials can be recycled much more effectively [23]. Additionally, reinforcing recycled plastics could result in new automobile components with enhanced mechanical qualities [24],[25]. Recycling bio-based materials is helpful for extending the life of the material more than composting. Recycled composite materials can create identical or new goods from the elements recovered after sorting.

According to life cycle assessment studies, composting has a greater environmental impact than recycling [26], [27]. Due to their limited volume, compostable plastics are currently not recycled in traditional mechanical recycling facilities, and mechanical recycling adaptations are still needed [28]. There are several recycled polymeric materials used in the auto industry. For instance, recycled polyethylene terephthalate (PET) fibre is used to make velour molded automotive carpets. Overall, while recycling plastics in the automobile industry, the expected costs, efficiency, and environmental impact are important considerations. Some of the common plastics used in the industry are generally inexpensive to recycle, yet they have a significant carbon footprint that negatively affects the environment. The efficiency of recycled plastic in the supply chain is greatly influenced by the type of material. For instance, ABS is widely applicable, easily recycled, and recycled very well [29]. Figure 5 shows the solution of the composite's life cycle.

The car dashboard is a crucial functional and decorative component, as seen, and because of its intricate composition and design, it is challenging to recycle [12]. Dashboards and gasoline tanks are recycled using the same thermal degradation and energy recovery techniques [17].

Crushed and blended PP-type dashboards are combined with an additive made up of a mixture of 70–92% wax polymer and 8–30% inorganic filler. The resulting synthetic resin, which contains 45– 65% PP, 10 – 20% ethylene rubber, and 20 – 40% inorganic filler, is melted and milled. A new dashboard matrix is created using the obtained resin ingredients [17].

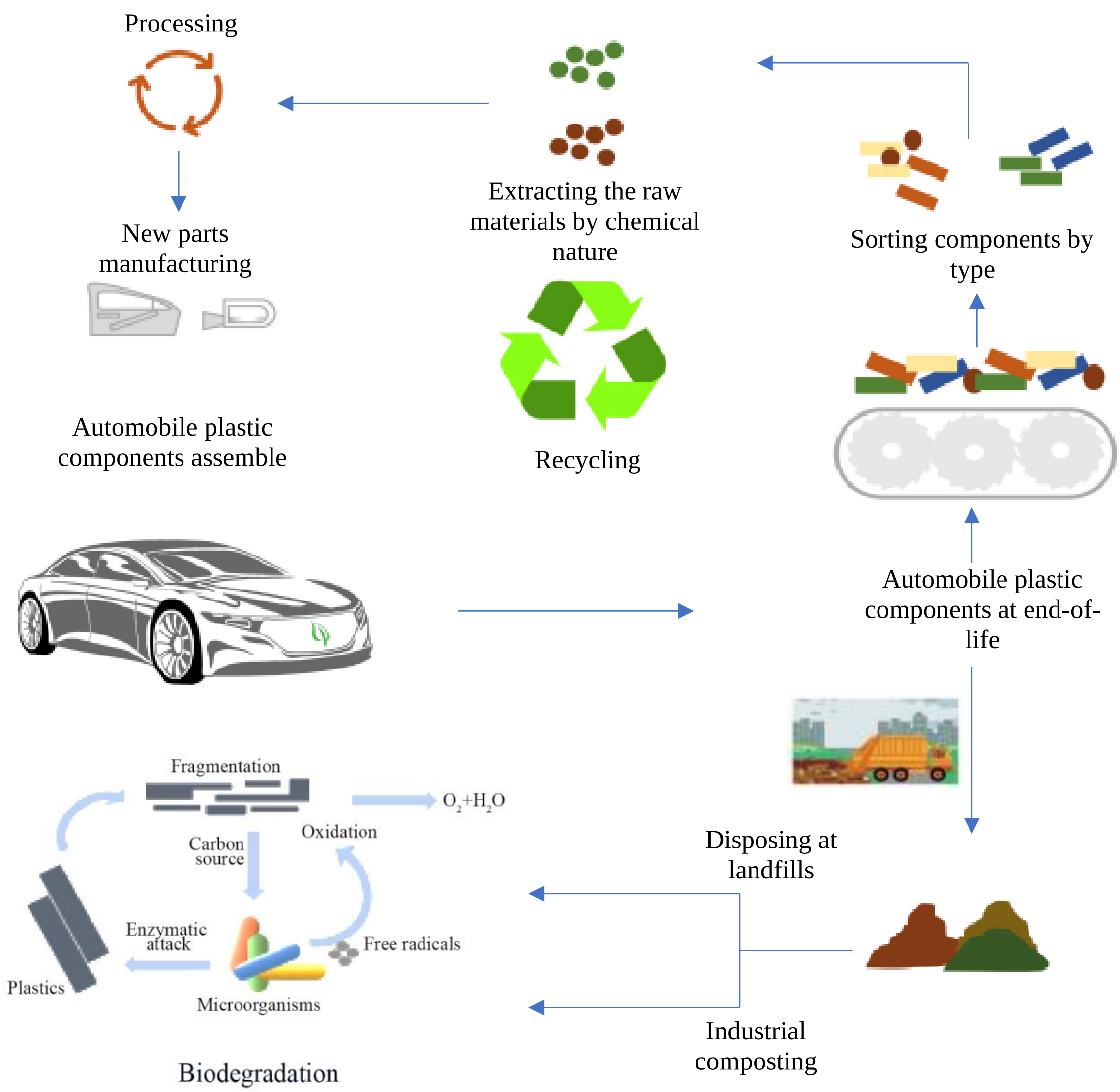

Fig. 5 Composites plastic life cycle [20]

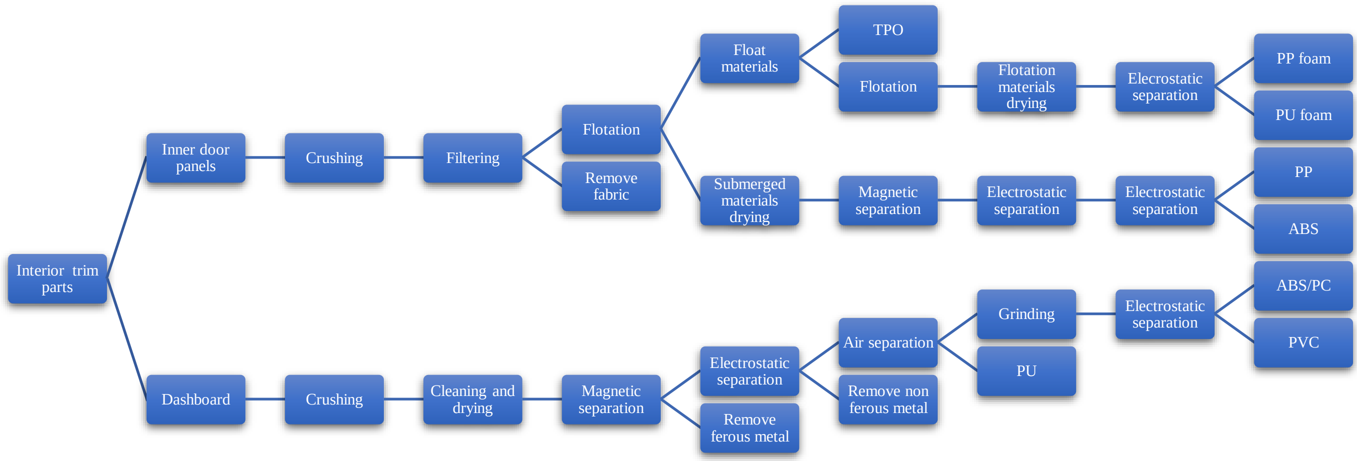

Fig. 6 Recycling of interior panels process [17]

Additionally, a multilayer hydrocarbon polyvinyl dashboard recycling method was created. In this technology, the recycling materials are improved during the remanufacturing process by adding ethylene-propylene copolymer and PP. A new dashboard or other plastic components can be made using recycled plastics [30]. The instrument panel parts and all-polyurethane instrument panels can be recycled using the glycolysis technique (a metabolic process that breaks down carbs and sugars through a series of chemical reactions) [30], [31].

Using a life cycle assessment method (an important tool for evaluating the environmental impact of products and services from the cradle to the grave), it was found that conventional instrument panels made of steel, plastic, and bioplastic emit greenhouse gases 15, 29, and 37% less than magnesium [32].

The incineration of scrap plastic parts, however, would result in several environmental issues, most notably the release of certain air pollutants like CO_2, nitrogen oxide, and Sulphur dioxide. Volatile organic compounds, smoke (particle matter), particulate-bound heavy metals, polycyclic aromatic hydrocarbons, polychlorinated dibenzofurans, and dioxins are additionally recognized by-products of the combustion of plastic. Additionally, carcinogens (PAHs, nitro-PAHs, dioxins, etc.) from the burning or cremation of synthetic polymers like PVC, PET, PS, and PE have been found in airborne particles. [33] used in passenger vehicles.

These panels typically consist of three layers: the skeleton, the middle layer, and the epidermis. The center layer is constructed of either PP or PU foam, the skeleton is made of ABS or reinforced PP, and the epidermis is largely formed of thermoplastic olefin (TPO) and PVC materials.

Fig. 7 Scrapped seats for vehicles

Fig. 8 Scraped bumper after life span

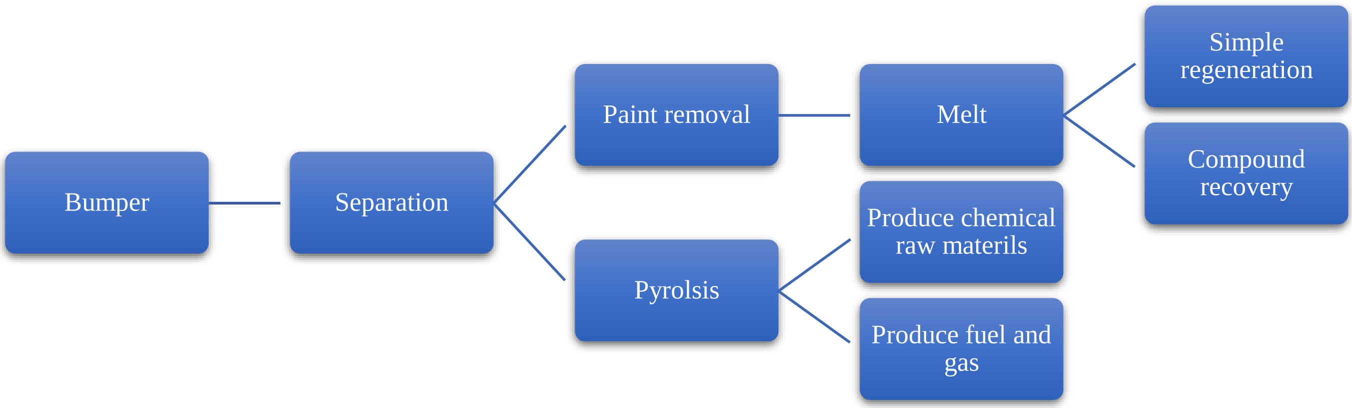

Fig. 9 Process used for recycling bumper

The interior door panel of automobiles is composed of a variety of fabric-reinforced composites. Using the flotation method and electrostatic separation, which is repeated numerous times, one component of the PP, PVC, ABS, and TPO plastic can be recovered after the crushed reinforcing fabric has been filtered away. Figure 4 shows various ways in which composite door panels and dashboard materials can be recycled. In vehicle seats, the skeleton, skin and cushioning pad of seats are made of polymeric materials, which also include composites. The main component of the seat skeleton is a thermoplastic-reinforced PP material. Cushioning pads are often constructed of PU materials that are soft and flexible. Materials from recycled seat cushioning pads can be used in energy-absorbing projects like vibration and sound reduction, sports field surfacing, and carpet underlay. When granulating foam/fabric laminates and polyester PU foam, diphenylmethane diisocyanate (MDI) is added to create fresh foam [34]. Fig shows a scrap bumper that has been removed and destinated for the scrap yard. Fig then shows the melting method that can be used to recycle the bumper. The bumper is soaked in chemicals to remove the coating on the surface.The polycarbonates (PC) or polypropylene (PP) that are obtained afterwards undergo a complex renewal process and are used to fabricate and produce composite parts that do not require superior performance or aesthetics. This process has a poor ability for coating removal, and the waste liquid that is remaining is very unsafe to the environment. The companies that are recycling bumpers use the pyrolysis process to produce fuel and gases that result can produce secondary pollution [17]. The automotive industry that is recycling bumpers isolates the different plastic composite materials used in the vehicle based on translucency or density. The use of a modifier permits the paint coat to be removed from the bumper exterior [35]. Hyundai Motor Company employs water jets to provide a significant impact on the bumper surface in order to remove the coatings [11]. After the paint has been removed, using a twin-screw extruder to process recycled bumper materials results in new plastic granules that are used to manufacture new recycled bumpers.

Pyrolysis can also be utilized in the process of recycling bumpers. Pyrolysis is a process that uses heat to chemically degrade organic molecules to produce fuel gas, oil or chemical raw materials [41-54].

7. Conclusion

The Conclusion section should clearly explain the main findings and implications of the work, highlighting its importance and relevance. The utilization of synthetic and natural fibres composites in the automobile industry will continue to increase as the number of automobiles increases globally. Synthetic composites have good mechanical strength, are durable, and have low moisture regains compared to natural fibre composites.

The advantages of using natural fibre-based composites are their ease of work, lower cost, accessibility, and biodegradability, unlike synthetic fibre composites.However, the high moisture regain of natural fibre can be a source of premature composite failure as it can cause mechanical degradation. Furthermore, this mechanical degradation opens pores and channels for termite attack and fungus attack. However, despite some of the shortcomings of natural fibres, there is a growing popularity in their use due to them being environmentally friendly. The automotive field will continue to use more natural fibre-reinforced composites, increasing sustainability fuel efficiency and reducing carbon dioxide footprint.

Funding Statement

This study is funded by the Vaal University of Technology.

Acknowledgments

This research work was supported by the Vaal University of Technology. The authors wish to thank the Department of Industrial Engineering, Operation Management and Mechanical Engineering at Vaal University of Technology for facilitating this work.

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