Green Biocomposites: A Prospective Utilization in Automobile Industry

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Abstract Natural fiber reinforced polymer composites becomes the most promising and identified research area. As these composites not only offer the good mechanical strength but also are light in weight and cost effective. The reasons of popularity of this area reside in many important parameters such as recyclability, biodegradability and environment friendly. Now scientists have developed biopolymer derived from corn, soy etc. which is used to reinforce the natural fibers and developed a fully biodegradable composite material. The application of the natural fiber composites not only found in the building and constructions sectors but also in the automotive and aircrafts structures sectors. In this chapter we are discussing about the Green Biocomposites and their utilization in the automobile fields. The chapter also highlighted a general class of the various available natural fibers and their application in the automotive sectors. This chapter also provides an insight of the safety measures such as crashworthiness of the vehicles. Also a review of the current research in the field of automotive industry is presented and some conclusions for the future vehicle design using composites are suggested.

Keywords Natural fibres · Polymer matrix · Mechanical properties · Automotive applications · Manufacturing techniques

1 Introduction: A History of Natural Fibers in Automobile Sector

Natural fibers are easily and abundantly available in the environment. The use of natural fibers in matrix material for composite development is not a new area of research as in ancient days (in Egypt) people were using wheat straws as reinforcement in clay for increasing the strength of the material and built their houses

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and dwelling walls. Natural fibers are composed of a cellulose, hemicellulose, lignin, pectin etc. Lignin generally acts as a binder or can be treated as a matrix material. In year 1900 the natural fibers were recognized as a good application in the automotive sectors. Ultimately scientists of Ford motor company observed that soybean can be used for the extraction of the soy oil which again could be used for the production of a good-quality paint enamel and molded into a fiber based plastic. This gives around ten times more shock resistance as compared to steel. But the disadvantage of this material is that it takes too much time for curing and also it is very difficult to mold. The actual use or applications of the natural fibre were found in the later 1940s. That was the time of the World War II. During this world war there was a huge shortage of the aluminum arises. So the scientists were discovered the application of these natural fibers for the development of the various aircrafts parts such as seat belts, back rest, bearings and fuselages etc. The example of this fuselage was the Gordon–Aerolite, a unidirectional composites made by using Phenolic Resin as a matrix material reinforced with the unbleached flax yarns (Hughes 2002).

In the later years between 1950 and 1990, first car known as Trabant car was made in East Germany. They utilized the natural fibers for the development of this car. The matrix material used in this car was polyester resin and cotton fiber (natural fiber) was used as reinforcement in this matrix material.

Daimler Benz also introduced the use of natural fibers in the automotive sector in the later 1991. The subsidiary of Daimler Chrysler Mercedes-Benz headed a project namely “Beleem-Project” in South Africa’s Sao Paulo and utilized natural fibers such as coconut fibers in their commercial vehicles for a period of 9 years. Again in the late 1996 Daimler-Chrysler used Jute as natural fibers and used in making the door panels of their Mercedes E class vehicles. Also in year 2000, Daimler Chrysler started their plant and utilizes natural fibers for the production of vehicles in East London, South Africa and transfers their technology from German Plants to South Africa for the entire processing.

In European countries, from year 2005 to 2010, the use of natural fibers has increased from 70,000 to 100,000 tons in the automobile industries (Suddell and Evans 2005a, b).

In 2014 Van Eko Company utilized the natural fibers and makes an eco-friendly scooter Be.e. The various types of natural fibres such as Flax, Hemp, and even synthesized cellulose fibers are used for the development of the automotive components for scooter.

The shape of the exteriors of the scooters is hull shaped type, assuming be the stronger and also functions as the frame of the scooter.

This scooter was fitted with a 4 kW and 100 Nm motor placed in the rear wheel. The 1.9 kWh battery provides a range of 60 km at a top speed of 55 kph (van eko www.vaneko.com).

The natural fibers or cellulosic fibers can be classified into five common subgroups such as bast fibers, seed fibers, leaf fibers, fruit fibers and wood fibers. The same can be shown in Fig. 1 with some common examples of these fibers.

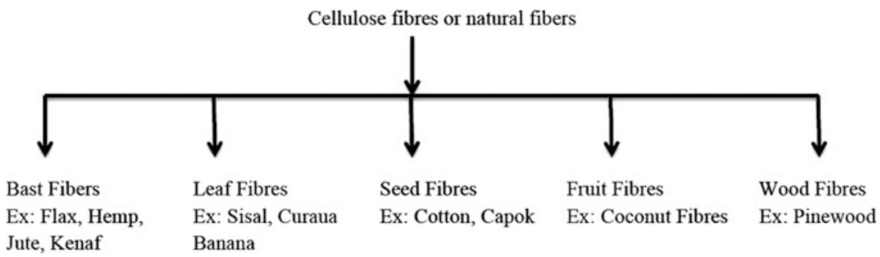

Fig. 1 Examples of natural fibres. Reproduced with permission from Elseveir Ltd. (Faruk et al. 2012)

(a) ***Flax Fibres***:
Flax fibers also known as Linum usitatissimum, generally comes under the category of bast fibres. This is termed as the oldest crop in the world and grows in temperate regions. The flax is most frequently used in the textile markets. At present the wide application of these fibers can be found in the areas of composite materials.

(b) ***Hemp Fibres***:
Hemp is the next significant fiber which comes under the category of bast fibers and cannabis family. This plant grows annually in temperate regions. At present Hemp is generally considered as an important subject of European Union Subsidy only for the non-food agriculture in Europe.

(c) ***Jute Fibres***:
Jute can be extracted from the plants of genus Corchorus, includes around 100 species. The jute fiber is considers to be one of the less expensive natural fiber available at present with the maximized production volume. The good growing conditions of the jute fiber can be seen in Bangladesh, India and China.

(d) ***Kenaf Fibres***:
Kenaf generally goes to the family of genus Hibiscus. Kenaf is generally observed as a potential raw material for its applications in composite materials products.

(e) ***Sisal Fibre***:
Sisal belongs to the family of agave (Agave sisalana) and commercially grew in Brazil and East Africa. But on the other side, between 1998–2000 and 2010 the demand for sisal fibers and its products decreased by an expected annual rate of 2.3%.

(f) ***Banana Fibres***:
The abaca/banana fiber, which can be extracted from the banana plant, is strong and resistant to seawater. Abaca, the strongest of the commercially available cellulose fibers, is locally available in the Philippines and in Ecuador. Banana fibers have good applications in marine.

Table 1 Chemical composition of some common natural fibers (Faruk et al. 2012)

Fibre	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)	Waxes (wt%)
Bagasse	55.2	16.8	25.3	–
Bamboo	26–43	30	21–31	–
Flax	71	18.6–20.6	2.2	1.5
Kenaf	72	20.3	9	–
Jute	61–71	14–20	12–13	0.5
Hemp	68	15	10	0.8
Ramie	68.6–76.2	13–16	0.6–0.7	0.3
Abaca	56–63	20–25	7–9	3
Sisal	65	12	9.9	2
Coir	32–43	0.15–0.25	40–45	–
Oil palm	65	–	29	–
Pineapple	81	–	12.7	–
Curaua	73.6	9.9	7.5	–
Wheat straw	38–45	15–31	12–20	–
Rice husk	35–45	19–25	20	14–17
Rice straw	41–57	33	8–19	8–38

(g) ***Cotton Fibre***:

Cotton is nearly pure cellulose, having properties such as softness and breathability which ultimately tuned it the world's most accepted natural fibre. The length and diameters of the fibres are varied from 10 to 65 mm, and 11 to 22 μ respectively. The other properties of the cotton fibres is the good moisture absorption which ultimately utilized in the production of cotton clothes (recommended to wear in hot weather), having high tensile strength and easily washable.

(h) ***Coconut Coir Fibre***:

Coir fibers are positioned between the husk and the outer shell of the coconut. Plentiful quantities of coconut husk suggested that the availability of labor and other inputs can adjust rapidly to market conditions and prices. It is calculated that around 10% of all husks are used for fiber extraction, fulfilling the increased demand for fiber and products made by coir fibers.

Table 1 represents the mechanical properties of the some common and important natural fibres (Faruk et al. 2012).

So based on the previous studies of natural fiber utilizations it is found that because of the easy availability, low cost and less weight, natural fibres are the good alternative to synthetic or man-made fibres. In this chapter the utilization of natural fibers in the automotive sectors has been elaborated. The various manufacturing techniques of composite development are also discussed in the present chapter. The mechanical properties of the developed automotive components have been included in the present chapter.

2 Basic Needs of the Materials Used in Automotive

The materials selection in the automotive industries is very important task as those materials have to satisfied some standard before approbation. Those standards are generally related to the environmental and safety issues and some of them are the need of the customers. However following are the different factors which can be considered for the basic requirement for the selection of the materials in automotive industries:

2.1 Less Weight

In present days increasing environmental issues such as greenhouse emissions and related air pollutions, it is very difficult for the automotive industries to achieve high fuel efficiencies with conventional or heavy weight automotive parts. Many research and development departments of the automotive industries, parts or component manufacturers, suppliers and assemblers are remarkably working together to make lightweight materials components. The objective behind the manufacturing of light weight material/component is to achieve high fuel efficiency in the transportation sector. Most of the companies or industries are focusing on the utilization of the lightweight materials and to get more market insight by manufacturing parts and different vehicle structures manufactured from lightweight materials. The only disadvantage of using lightweight materials is their high cost; this can be overcome by the development of the new manufacturing technologies and processes. In transportation sector, the reduction in fuel consumption and greenhouse gases can only be achieved by the reduction in weight of the materials. It has been noticed that the fuel economy (about 7%) can only be achieved by the reduction/elimination of weight (about 10%) from the vehicle's total weight. Now a days various research have been carried out by the automotive industries for the replacement of steel by aluminium, magnesium, composites and foams (Lotus Engg Company Report).

2.2 Cost

Cost is one of the most significant factor in automobile industries. The cost of a new material is comparable to the currently utilized material in a product. It is one of the most significant variables that decide the selection of new material for the vehicle parts or components. Cost basically involves three main components, these are: Existing cost of raw materials, manufacturing cost, and the design and testing cost of the product. It has been observed that the cost of Aluminum and magnesium alloys is greater than that of the existing materials such as steel and cast irons that they might substitute. As the improved performance or functionality of the material ultimately justified the selection of light metals by avoiding their higher.

2.3 Crashworthiness

Crashworthiness of the structure in the vehicle can be defined as the capacity to absorb impact energy resulting the safety of the passengers. The two significant safety factors that can be consider in the automotive industries are Penetration Resistance and the crashworthiness. Scientifically the crashworthiness can be further defined as the absorption of impact energy by different modes and mechanisms that give moderate deterioration during absorption. On the other hand the penetration resistance. On the other hand the penetration resistance dealt with total absorption without projectile or fragment penetration (Jacob et al. 2002). It has been observed that the present law for design of automobiles required that if an impact arises at speed up to 15.5 m/s with immovable object then the passenger in the compartment undergo a resulting force that ultimately produces a total deceleration more than 20 g (Jacob et al. 2002; Ghassemieh 2011).

Now days the automobile industries are focusing more and more towards the reduction of the weights of the automobiles which ultimately increases the fuel efficiency of the vehicles. This is only achieved by replacing the metal parts by polymer composites. It is also noticed that the behavior of failure in compression of the metal part is just opposite to the composites failure. From study it has been found that mostly composites are characterized by a brittle and not by ductile under the action of load. If we are talking about the failure mechanisms of the metal structures and composites it is found that they both are quite different with each other. As metal structures generally fails under crush or impact by buckling having substantial plastic deformation. On the other hand the composites failure takes a sequence of fracture mechanisms like fibre fracture, de-bonding of fibre–matrix, delamination and interplay separation. This is also observed that the failure mechanisms are mostly dependent on the structure, lamina orientation, crush speed and high energy absorbing mechanisms (Ghassemieh 2011).

3 Crashworthiness: A Safety Perspective

The main objective of the crashworthiness is to have an optimized or defect free vehicle structure which ultimately can absorb impact energy generated by controlled vehicle deformation and provides sufficient space so that the remaining crash or impact energy can be govern by restrain systems to lessen the loads transfer to the vehicle passengers. In actual form the collisions of vehicles are distinct dynamic occurrence where the vehicle may collide with the other vehicle of similar or dissimilar shape and mass and stiffness. There may be the case that vehicle may collide with the stationary objects like tree, pole etc. the safety experts describes and categorized the vehicle collisions as frontal, rear, side crashes etc. the reasons of vehicle crashes is due to the extensive range of speeds, impact with stationary objects such as when a vehicle hits a tree, or for few seconds as in rollover events.

3.1 Requirement of Crashworthiness

The following requirements for a range of occupant sizes, ages, and crash speeds for both genders:

- Should be deformable but stiff, front structure should have crumple zones that can absorb the kinetic energy resulting from frontal collisions and develop plastic deformations and block intrusions into the passenger's compartment specifically in the case of collisions with narrow objects such as trees etc.
- Should have deformable rear structure so that the robustness of the rear occupants compartment can be maintained and also the protection of the fuel tank.
- There should be perfectly designed side structures so that the intrusions from the side impact can be minimized which ultimately block the doors from opening caused by the crash loads.
- There should be well built roof structure for rollover protection.
- There should be some arrangements which can accommodate different chassis designs for various power train locations and drive configurations (Khalil 2014).

4 Reinforcements Used for Making Automobile Components

4.1 Glass Fibres and Glass Mats

Glass fibres are made by feeding molten glass bushings of platinum alloy. Generally the diameter of the filament is varied from 5 to 25 µ. The filaments are coated with a silane chemical "coupling agent". This is because coupling agent gives a strong bond between the glass and the polymer matrix and increased the reinforcing effect. There are various types of fibres are available as per the requirement such as E-glass fibres and R-glass for high mechanical performance, D-glass where high dielectric strength is required and AR-glass which is alkali and corrosion resistant. For the thermoplastics, the glass fibres can be distinguished as short fibres of less than 1 mm length and long fibres of 1–5 mm length for injection molding applications. Similarly for the compression molding, long fibres should be of 5–25 mm length and glass mat, 10 mm to infinite. On the other hand thermosets are reinforced with chopped strands, glass mat. Also for car applications (automotive), sheet moulding compound (SMC) or bulk moulding compound (BMC) are used. All of these products are known as composites.

4.2 Natural Fibres

Natural fibres are frequently used by a number of car producers such as Ford and Mercedes-Benz. These automakers have particularly flax, sisal or hemp as a replacement for glass fibre. Natural fibres ultimately lower the weights of the automobiles as the density is lower than conventional metals. Further, the most important factor to be considered is the environmental and ecological point of view. The famous automaker such as Ford Cologne lab has performed substantial experiments with flax-PP (Polypropylene) and found that this is approximately equivalent to GF-PP. To avoid discoloration the injection moulding temperature should be kept low. Audi Avant A4 utilizes flax-PP for the development of the hatch door cover. It has been observed that at low temperatures the product is not brittle at all. The same product has upgraded noise reduction and also 30% lower in weight than the GF-PP equivalent. On the other hand Johnston Controls supplies door trim panels to Mercedes Benz made by “Fibropur” natural fibre mat-PE composite. In this the fibres are a blend of 50% sisal and 50% flax. Similarly, SAI Automotive AG, Europe’s leading system supplier of cockpits and doors, has made “Lignoprop”, a blend or mixture of wood fibre and PP.

4.3 Aramid Fibres

These fibres are made from aromatic polyamides with a high amount of 1.4 chemical bonds right between the aromatic rings, provided additional linear molecules. The main manufacturers of fibres are DuPont with Kevlar and Akzo Nobel with Twaron. These expensive fibres have a very high strength and heat resistance and are generally used in bullet proof vests, ropes, performance tyres, e.g. trucks and reinforcement in car drive and timing belts. A good application of aramid fibres reinforced thermosets are found in aero plane construction. As aramid fibres are so expensive and no significant use is foreseen in car applications.

4.4 Carbon Fibres

The two main processes used for the manufacturing of these fibres are carbonization under exclusion of air and from pitch. It has been found that the carbon fibre have high strength fibre just like aramid fibre and are necessarily used as a plastic reinforcement in sport applications and in aerospace industry. The wide applications of these carbon fibres (CF) epoxy resins composites can be found in aeroplanes wing flaps and tail parts also the body parts of Formula 1 racing cars are made by CF-thermosets by using hand lay up techniques. The main manufacturers of these composites are Akzo Nobel in USA, Mitsubishi and Toho Rayon in Japan and Carbon in Germany.

4.5 Particulate Reinforcements

The reinforcement generally means to improve or enhance the properties such as mechanical properties of the material or plastics. The main mechanical properties that can be improved by the reinforcements are tensile strength, impact strength, stiffness, compression and many more. But these properties can only be improved if we reinforce the fibrous material into the matrix material. However the particulate reinforcement like talc, surface treated calcium carbonate (which improves the bond strength) presents a marked reinforcing results with polymer matrix (if it is a matrix material) which again improves the mechanical properties (Mann et al. 1999a, b).

5 Types of Polymer Matrix Used for Composite Development

5.1 Thermoplastic Matrix

Thermoplastic comes under the category of polymers and can be softened or melted by the application of heat. It can be processed either in the softened state or in the liquid state. As compared to the thermosets, another classification or category of polymers cannot be melted by the application of heat. However the thermoplastic polymers can be repeatedly processed by the application of heat and can be recycled for making new products. But it should be noted that repeated processing may cause degradation or failure in some of their properties. The various fabrication techniques used for the development of the thermoplastic parts are such as injection molding, blow molding, and thermoforming are detailed further in the next headings of this chapter. The main advantage of using thermoplastics is its recyclability. But additionally it has several other advantages over thermosets also. These are good ductility, good impact resistance etc. Thermoplastics can also be joined by using various types of welding processes such as resistance welding, vibration welding and ultrasonic welding. Also in regard to the processing time for thermoplastic parts is notably lesser than that for thermoset parts. The reason for this is that thermoset parts involves a cross linking chemical reaction in the mold, which, depending on the various parameters such as mold temperature and part thickness, may take several minutes to several hours for final processing. On the other hand processing of thermoplastics composites does not require any chemical reaction in the mold.

5.2 Thermosets Matrix

The main function of thermoplastic matrix is to transfer load from one fiber to the next. It affects the compressive strength and shear strengths of the composite material and contributes to the fracture resistance and energy absorption properties of the composite. Moreover, it shields the fibers from environment and controls the following properties of a polymer based composite.

- Chemical resistance
- Maximum temperature
- Moisture absorption
- Tolerance to fluids

The selection of matrix material also plays an important role and controls the processing aspects of polymer–matrix composite. The important processing attributes applicable for thermoset matrix resins are:

- Should have low initial viscosity which results good resin flow through the fibre bundles and provide good impregnation. This also removes the air and solvents from the bundles before the completion of the curing reaction.
- Should have fast curing for high productivity.
- Should have good fiber surface wettability, which can be enhanced by using fiber surface treatment.
- Low curing shrinkage.

It has been noticed that thermoset polymers generally used in the automotive industries are either polyester or vinyl ester resins. The epoxy resins certainly have better mechanical properties as compared to polyesters and vinyl esters, and are frequently used thermoset matrix in aerospace composites. Although, epoxy resins are more expensive and also the curing time for epoxies is too high (several hours). Because of this reason, epoxies are not generally considered as the main matrix material for automotive composites. The properties of polyester, vinyl ester and epoxy resins are given in Table 2.

Table 2 Properties of different resins

Polymer	Density (g/cm^3)	Tensile modulus (GPa)	Tensile strength (MPa)	Elongation at failure (%)	Coeff. of thermal expansion ($10^{-6}/^\circ C$)	Shrinkage (%)
Polyesters	1.1–1.43	2.1–3.45	34.5–103.5	1–5	–	5–12
Vinyl Esters	1.12–1.32	3–3.5	73–81	3.5–5.5	–	5.4–10.3
Epoxies	1.2–1.3	2.75–4.10	55–130	–	55–80	1–5

Because of low cost and simplicity in processing due to low viscosity and rapid cure time, polyesters are generally used for many automotive applications. On the other hand vinyl esters are just like polyesters in regard to their processing attribute, but more costly than polyesters. Their mechanical properties are also superior to the mechanical properties of polyesters. Both polyesters and vinyl esters showed greater mold shrinkage than epoxies and both also have superb moisture resistance as compared to epoxies (Mallick 2010).

6 Manufacturing Technologies Used for Composite Fabrication (Automotive Components)

6.1 Thermoplastic Processing Techniques

6.1.1 Injection Moulding

Injection Moulding Process is related to pressure die casting technique, and used where the precision and accuracy of the parts is prerequisite. This process is basically used to make the parts or components by using thermoplastics polymer but after certain modification, the same process can be used to make the components or parts made by thermosets polymer. In this technique thermoplastic granules are first melted and then injected into steel or aluminum dies. After melting resin achieved highly viscous state and at that time a high moulding pressure is required for injection. The main benefits of injection moulding technique is short cycle times, complex shaped components can be easily made by this technique, superior dimensional tolerances and finishing etc. At present this technique is fully computerized and robotically controlled. On the other hand if we talk about the disadvantages of the process then we found that this process highly expensive, required longer lead times for making moulds, used complex machineries. The Computer-aided engineering can be used for the reduction in the lead times.

6.1.2 Extrusion

Extrusion is the process in which the molten material (polymer) is forced through a die for the production of the sheets, films, hoses, sheaths etc. This technique comes under the category of continuous production and has good economic benefits. Now extrusion becomes fully computer controlled with various functions and parameters such as drying temperatures, pressure and temperature, delivery rate. This process involves or used different types of extruders such as single screw extruder and twin screw extruders which are used to compressed and removes the air entrapped between the polymers.

6.1.3 Blow Moulding

Blow moulding technique used a shaped mould and involves the blowing of a thermoplastic into tube shape. This process is generally used to make hollow items such as, tanks, containers etc. This process gives maximum flexibility in the shapes that can be produced. This process involves a low mould cost. But on the other side it has been observed that the finishing of the articles or items made by this process is poor. To remove this disadvantage, the design team is working on this. This process can be utilized to make multi-layer items. The main application in which this process is suitable is the manufacturing of the fuel tanks.

6.1.4 Thermoforming

This process requires heating material in the form of sheet then takes it to a mould and forming it by the application of the vaccum from inside the mould. This process incorporates very low tool costs, swift set-up and economic short runs. This process is also suitable for the production of layered laminates of different materials. The main demerits of the system include longer cycle times, lower dimensional accuracies. However the advancement in the system in process control provides good dimensional accuracy and stability or regularity in finishing. Thermoforming process is economic and can be used for runs of 200–10,000 units. It has been observed that the machine costs involved in this process is just the half of comparable injection moulding process.

6.1.5 Foam Moulding

Foam moulding also known as steam chest moulding is generally used to manufacture bumper cores, sun visors, door energy absorbing foam and head-rest cores by utilizing expanded polypropylene pellets. In this process, Polypropylene pallets are first blown into the mould. After this a steam is injected into the system which makes a rigid PP structures. The mould is only opened after the required cooling actions. The aluminum moulds are generally used in this technique as they are relatively cheap than others.

6.2 Thermoset Processing Techniques

6.2.1 Contact Moulding

Contact molding generally consists of the two main processes such as hand lay-up and spray-up process. These can be defined as follows:

6.2.2 Hand Lay-up

In this process firstly a mould release agent is generally applied on the walls of the mould after that a coating of gel is applied on this and allow it to cure. After this staggered layers of resin and chopped strand mat (CSM) are applied. On the other hand, woven mats can also be applied alternatively with layers of CSM. After processing for several hours, the same piece should be detached from the mould. In this process no pressure is used and the moulding only has one smooth surface. As this process is very slow and rigorous, large and complexed shape materials can be made with smaller limitation on size. The application of this process is to mould short-run car bodies, especially monocoque designs.

6.2.3 Spray-up

This is another contact moulding process, which provides maximum production rates as compared to the hand lay up process. In this process, catalysed and accelerated resin and chopped glass rovings are sprayed simultaneously, with a fixed amount of peroxide catalyst, onto the gel-coated mould surface. This process can be repeated till a layer of the required thickness has been achieved. It has been noticed that both processes, mainly hand lay-up, are slow which is a demerit in long runs. Also as these processes are open mould process, so there may be a chance of the emission of styrene fumes. Nevertheless this can be overcome by using satisfactory ventilation system or low smoke resin systems. Contact moulding processes are sometimes experiences in small run models (e.g., racing cars) and in prototype work.

6.2.4 Compression Molding

Compression moulding generally requires high pressure moulding of sheet moulding compound (SMC). In this process, SMC is provided as a rolled sheet of material, in which glass fibres with upper and lower release film are separated from the each layers of resin. The resin may be Polyethylene etc. The amount of filler content can be limited to 60%. In this system, the material is filled into two steel die surfaces. The hot mould should be closed and requisite pressure is applied so that the SMC can flow into the mould and cure and sufficient strength can be achieved after opening the mould. To achieve uniformity in die matching, a good technical development is needed. It has been observed that the SMC mouldings surfaces are even on both faces and present almost no glassy structure (Mann et al. 1999a, b).

6.2.5 Resin Transfer Molding (RTM)

RTM is generally used for the manufacturing of automotive and aircraft components. In this process, the fibre reinforcement, either long or woven fibres are firstly cut out by using a knife or scissors. The reinforcements are generally known as the preforms are reinforced into the thermoplastic binder and then placed it inside the mould cavity in the closed mould process. After that the resin is being transferred into the mould cavity by means of pressure or vacuum. The resins that are particularly used in this process include polyester, epoxy, vinyl ester, and phenolic (Verma 2015).

6.2.6 Filament Winding

Filament winding is an automated composite fabrication process which involves winding of resin-impregnated fibre or tape around a mandrel to achieve the desired shape. In this process the continuous reinforcement of fibres which passes through a batch of resin to a feeding head and winds around a mandrel of suitable design. The curing of the mandrel is achieved by heating it in an oven or by infrared radiation. Process parameters which are generally considered in this process includes exact filament tow, longitudinal placement, and mandrel winding speed (Mann et al. 1999a, b).

7 Mechanical Properties of Natural Fiber Composites as Automotive Components: A Past Research

It has been observed from the last few years that so many researches were carried out in the field of the use of natural fibers in composites as load bearing components (Du et al. 2012; Akil et al. 2011; Summerscales et al. 2010; Joshi et al. 2004). The credit of the utilization of natural fibers in composites goes to their high strength, cost effectiveness, availability and recyclability.

Natural fibres represents a prospective as a substitution of inorganic fibres like glass fibres, aramid fibres etc. in automotive components like dashboards, door panels, seat cushions and cabin linings (Jacob and Thomas 2008; Koronis et al. 2013; Ashori 2008). Mercedes-Benz utilizes epoxy matrix system with the reinforcement of jute fibers in the door panels in their E-class vehicles (Suddell and Evans 2005a, b).

Wambua et al. (2003), investigated the mechanical properties of different type of natural fibers such as, sisal, hemp, coir, kenaf and jute reinforced polypropylene composites. It has been observed that the tensile properties such as tensile strength and modulus values increased by increasing fibre volume fraction. They also compared the mechanical properties of the natural fibre composites with glass mat polypropylene composites. After comparison it is found that certain properties of the natural fibre composites were superior to those of glass reinforced composites. Based on this it is advised that natural fibre composites have ability to replace glass in those applications where very high load bearing capabilities are not the prerequisite.

The utilization of natural fibres or bio-fibres in automotive components is supposed to improve by 54% per year (EU 2002 Annual Report). Some types of strong, lightweight and cheap natural fibres are come together and replace glass fibre reinforced polymers specifically in interior applications. In general the application part of the natural fibre reinforced polymers is found in door panels, seat backs, headliners, package trays, dashboards etc. There are so many research review papers published by researchers which describe the reinforcement of the natural fibres in polymer matrix and recognized as green composites (Koronis et al. 2013; La Mantia and Morreale 2011; Zini and Scandola 2011). These review papers described the mechanical properties of various natural fibers and their composites. They also discussed that how natural fibers are superior than synthetic fibers from the environmental point of view.

Koronis et al. (2013) discussed the possible utilization of bio fibres/natural fibres composites for automotive applications. They have demonstrated that natural fibre reinforced composites have good mechanical properties as compared to synthetic fibre reinforced composites.

Davoodi et al. (2012) reviewed the literature on bumper design and delivered the optimal bumper beam design process. The main focus of the design process is based on the important parameters needed in the design of bumper beam and their most satisfactory values. The outcome of this research can help designers and researchers who are working in the field of bumper beam design and analysis. The design process includes a hierarchy which consists of the conceptual design phase. In this phase various properties of materials and their processing was discussed. These are further considered in the later stage to confirm the performance of the final product. The various factors that should be considered in the material selection of the bumper design are safety regulations, cost effectiveness, performance improvement and reliability. Figure 2 shows the bumper beam design process.

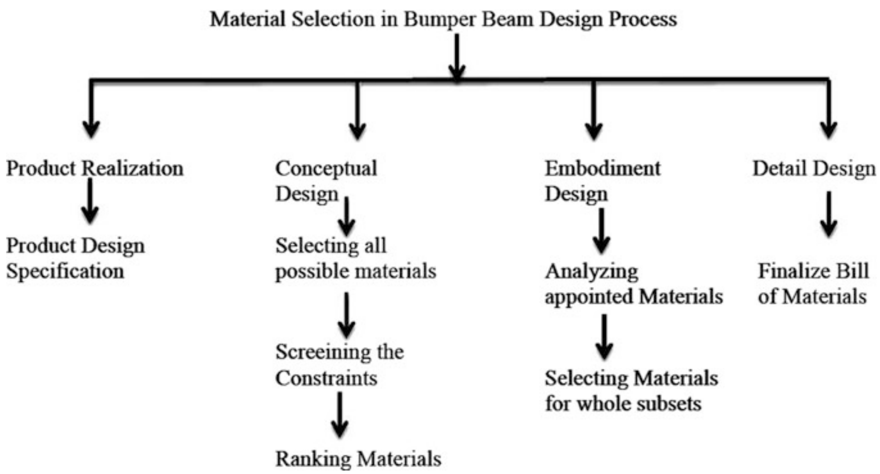

Fig. 2 Bumper beam design process. Reproduced with permission from Elseveir Ltd. (Davoodi et al. 2012)

Ahmad et al. (2014) reported that BMW Company used natural fiber composite since the early 1990s in various models such as 3, 5, and 7 series models. They utilized up to 24 kg of renewable materials in their models. On the other hand BMW utilizes 4 000 tons of bio fibers in their BMW M3 series in 2001. They mainly concentrated on the flax fibres i.e. they utilizes 80% flax fibres in combination with 20% sisal for the improvement in impact resistance. The main application of natural fibre reinforced composites was found in interior door linings and paneling. The applications of Wood fibers were found in seat backrest. The inner board of the door panel of BMW M7 series was made by press molding technique by reinforcing natural fibers in Polypropylene matrix. The application of this composite was found in inner board of the door panel of a BMW M3 series. On the other side Bast fibres were also used in the door panels of the BMW M5 series.

Marzbanrad et al. (2009) used three materials such as aluminum, glass mat thermoplastic (GMT) and sheet molding compound for the development of front bumper beam. The impact modeling was carried out for the determination of the deflection, impact strength and stress distribution. The comparison was made based on the mentioned characteristics for the selection of the best materials, their shape and thickness. They concluded that modified SMC bumper beam minimizes the deflections in bumper beam and stress distribution and maximizes the elastic strain energy.

Notable differences in impact velocities were observed among magnesium, steel and aluminum bumpers and showed by Figs. 3, 4 and 5. From study it has been observed that in case of aluminum bumper the difference between impactor velocity and vehicle velocity will be maximum as compared to magnesium bumper. This means that the maximum kinetic energy will be transferred from the impactor to the vehicle.

Hosseinzadeh et al. (2005) suggested that composite structures are generally reduce the weights of the passenger cars and making vehicles more fuel efficient. They observed that the Bumper beams are the main structures of the passenger vehicles from the safety point of view which ultimately protect them from the

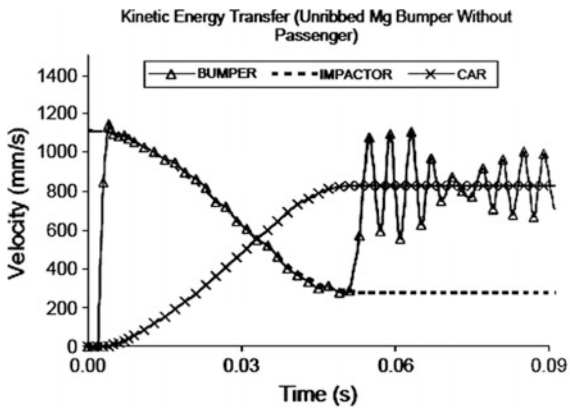

Fig. 3 Kinetic energy transfer in magnesium bumper (Marzbanrad et al. 2009)

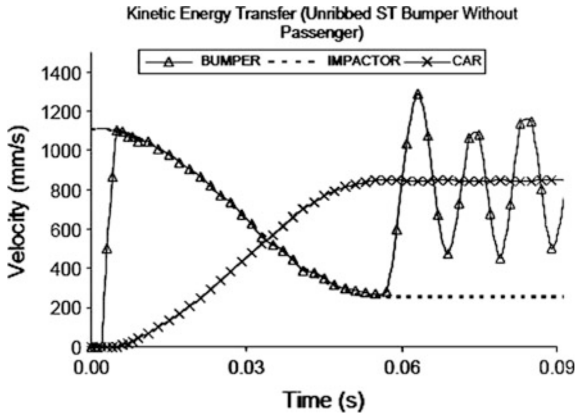

Fig. 4 Kinetic energy transfer in steel bumper (Marzbanrad et al. 2009)

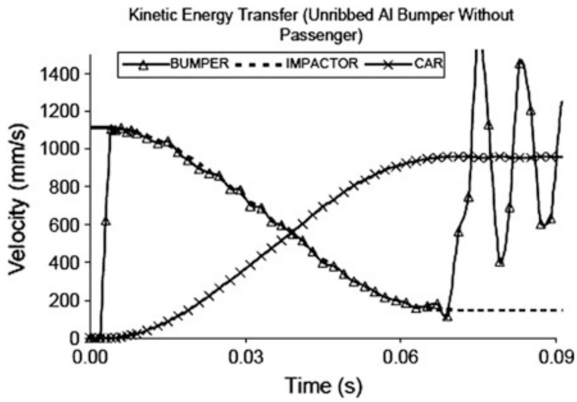

Fig. 5 Kinetic energy transfer in aluminum bumper (Marzbanrad et al. 2009)

collisions i.e. front and rear collisions. They have made a front bumper by utilizing glass mat thermoplastic matrix material and then model them by using the various software available by using LS DYNA ANSYS 5.7 according to the E.C.E. United Nations agreement.

The GMT bumper was fabricated by using short fiber glass fibers. The size of the fibers was maintained as 12–25 mm long. These fibers were then mixed/reinforced with the thermoplastic resin. The GMT bumper used in this research is a structure made from short fiberglass fibers, 12–25 mm long randomly mixed with thermoplastic resin. The thickness of the fabricated Glass Mat Thermoplastic sheets is 1-mm with different fiber mats such as continuous, randomly laid, unidirectional and mixtures of these arrangements with particular attributes (Glass Mat Reinforced Thermoplastics Processing Guidelines). About three to four arbitrary laid chopped fibre sheets are positioned in a die and heat formed by a press. After this the molten resin ultimately flows in the cavities of the dies and take its shapes. The main purpose for the use of thermoplastic resin is because of their facileness in melting and recycling properties. On the other hand loose tolerance in manufacturing bound their uses in places where good accuracy is the prerequisite. To stop the deflection of the lateral surfaces (which ultimately make the structure rigid), the ribs or strengthening plates of thickness 5 mm were placed in the vertical direction. These ribs are formed in the concave cavities of the dies and makes die design complicated. Figures 6, 7 and 8 showed the observation of the kinetic energy and linear conservation. The observation in this case generally termed as the impact velocities between "with passengers" and "without passengers" conditions. It is generally observed that the impactor weight is equal to the car weight without passengers, therefore its velocity becomes zero as car reaches the initial velocity of 4 km/h. on the other hand if we considers the car with passengers, the impactor is unable to transfer the momentum completely to the structure weighing more (see weights in Table 3).

Ashori (2008) suggested that the Wood–plastic composite (WPC) is a very favorable and feasible green material to attain endurance without any toxic chemicals. The wood plastic composites was termed as a composite which is composed of by utilizing natural or plant fibres as reinforcement in the polymer

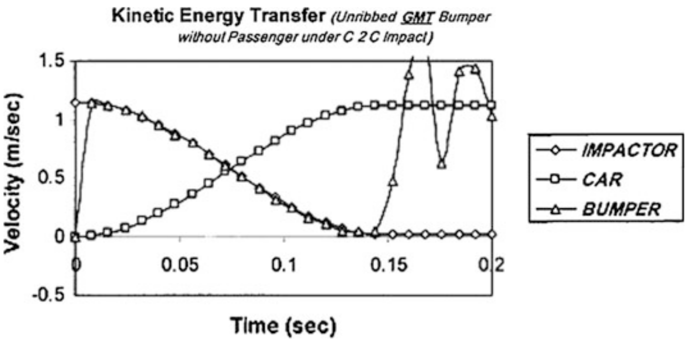

Fig. 6 Kinetic energy conservation in GMT bumper (Hosseinzadeh et al. 2005)

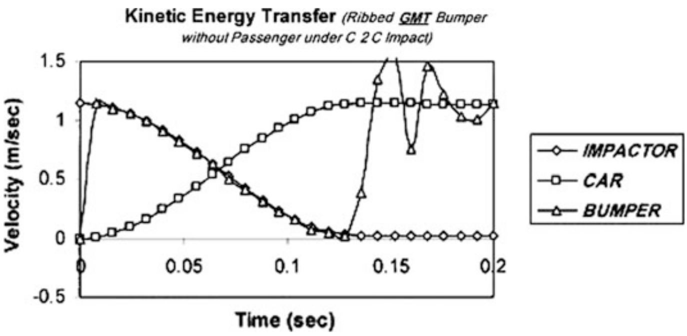

Fig. 7 Kinetic Energy Transfer (Ribbed GMT Bumper without passenger under C2C impact)

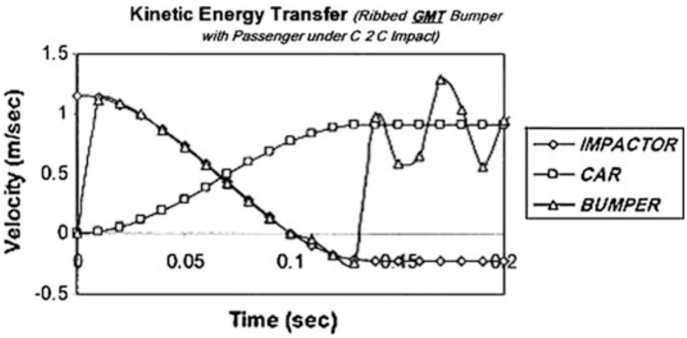

Fig. 8 Kinetic Energy Transfer (Ribbed GMT Bumper with Passenger under C2C impact)

Table 3 Material properties of the model (Hosseinzadeh et al. 2005)

Material	E (GPa)	υ	Sy (MPa)	ρ (kg/m^3)
Steel	210	0.3	700	7850
Aluminum	70	0.33	480	2710
GMT	12	0.41	230	1280
SMC	20	0.33	309	1830
PEP	1.2	0.4	27	900

matrix materials such as thermosets or thermoplastics. The advantage of utilizing natural or plant fibres to reinforce plastics is that as these are having high strength, high stiffness, less cost, low density and biodegradable in nature, and renewable annually. As in present scenario automobile manufacturers are focusing on recyclability and biodegradability of the parts, so we can find good scope of green composites in the field of automobile sectors.

There are so many automobile manufacturers are available in the market utilizes natural or plant fibres for making automotive components such as: Audi, Opel, Daimler-Chrysler, Fiat, Ford, Mercedes Benz, Renault, Volvo, BMW etc. (Bismarck et al. 2006). The specified amounts of plant fibers used for different applications in the automotive industry are as follows (Ellison and McNaught 2000):

- Front door linens: 1.2–1.8 kg.
- Rear door linens: 0.8–1.5 kg.
- Boot linens: 1.5–2.5 kg.
- Parcel shelves: up to 2.0 kg.
- Seat backs: 1.6–2.0 kg.
- Sunroof sliders: up to 0.4 kg.
- Headliners: average 2.5 kg.

8 Natural Fibre Composite Applications in Automobile Sector

Natural fibers can be derived from agricultural plants and are frequently used for making ropes, hand bags, etc. Natural fibres can be classified into three groups: (i) bast fibers, e.g. flax, hemp, jute and kenaf, (ii) leaf fibers, e.g. sisal, pineapple and banana, and (iii) seed or fruit fibers, e.g. cotton and coir.

8.1 Interiors of Automotive

The German automotive industries such as BMW, AUDI and Daimler Chrysler are the first industries which utilizes the applications of natural fibres in the automotive parts or components. Now, almost all automobile industries or manufacturers integrate natural fiber composites in their automotive components. At present the German industries are the superior in utilizing natural fibres in their automobile sectors. Table 4 shows the applications of the natural fibre composites used by the major automobile tycoons of Germany such as DaimlerChrysler, Mercedes, Volkswagen Audi Group, BMW, Ford, and Opel (Suddell and Evans 2005a, b). DaimlerChrysler, a major manufacturer of automobile sector, targeted to use

Table 4 Automotive manufacturers, car models, and components utilizing natural fibers (Suddell and Evans 2005a, b)

Automotive manufacturer	Model and applications
Audi	A2, A3, A4, A4 Avant, A6, A8, Roadster, Coupe: seat backs, side and back door panel, boot lining, hat rack, spare tyre lining
BMW	3, 5 and 7 series and others: door panels, headliner panel, boot lining, seat backs
DaimlerChrysler	A, C, E and S-series: door panels, windshield/dashboard, business table, pillar cover panel
Fiat	Punto, Brava, Marea, Alfa Romeo 146, 156
Ford	Mondeo CD 162, focus: door panels, B-pillar, boot liner
Peugeot	New model 406
Renault	Clio
Rover	Rover 2000 and Others: Insulation, rear storage shelf/panel
Saab	Door panels
SEAT	Door panels, seat backs
Vauxhall	Astra, Vectra, Zafira: headliner panel, door panels, pillar cover panel, instrument panel
Volkswagen	Golf A4, Passat, Bora: door panel, seat back, boot lid finish panel, boot liner
Volvo	C70 V70

Table 5 Well-established interior automotive components utilizing natural fibers (Suddell and Evans 2005a, b)

Automotive component	Typical weight of fibres (kg)
Front door liners	1.2–1.8
Rear door liners	0.8–1.5
Boot liners	1.5–2.5
Parcel shelves	<2

maximum amount of natural fibres in their vehicles or cars. Johnson Controls Inc., manufactured the interior components like dashboards and door panels by utilizing natural fibres in polypropylene matrix exclusively for the DaimlerChrysler (Controls 2000). Currently the utilization of the natural fibres in the automobile industries such as BMW are limited to about 8–13 kg per vehicle however the limitation of use of natural fibres in Ford company is from 5 to 13 kg per vehicle (Taylor 2002).

Table 5 showed the applications of natural fibres (by weight) for making automotive components. The main difference between the American market and the European market lies in the use of wood and Kenaf which effectively grows in United States. In year 2000, Audi launched a light weight car manufactured by all-aluminum body and their door trim panels were manufactured by polyurethane reinforced with flax or sisal fibre mat. These panels not only showed extremely low mass per unit volume but also have very high-dimensional stability.

8.2 *Exteriors of Automotive*

The German company namely DaimlerChrysler has expand its research and development speculation in flax-reinforced polyester composite for exterior or semi exterior applications (Automotive Industries 2000). A truck with flax-based exterior skirting panels is now in production. Tests performed by the DaimlerChrysler Research Centre, Germany showed that these composite components resist impact without breaking into fragments, which is a main crash worthiness test of vehicles. It has also been noticed that the developed composites are weather resistant. In Germany, by considering the environment point of view car producers are targeting to manufacture each and every part of their vehicles either recyclable or biodegradable. The research scientists at DaimlerChrysler made the exterior components of the vehicles that must be able to resist extreme such as exposure to wetness and chipping. The first use of natural fibres for making standard exterior components is flax-reinforced engine/transmission cover of the Mercedes-Benz Travego travel coach. The benefit of using natural fibres includes a 10% weight reduction of the engine/transmission cover and a reduction in cost of around 5%. At present the inclusive use of natural fibers such as flax, hemp, and kenaf are growing at the fastest rate. On the other hand the use of jute and sisal is actually decreasing. Flax, hemp, and kenaf are used frequently due to their outstanding combination of economic and functional properties.

9 Advantages of Natural Fiber Composites in Automobile Sector

The natural fibres showed considerable advantages as compared to conventionally used glass fibers in the automotive sector. The significant feature here is that these advantages are achieved without a particular change in material functional performance like degradation of their mechanical or acoustic properties. The most important advantages include:

- Cost effective: The cost of natural fibers are between 25 and 50% lesser than glass fiber composites.
- Weight reduction: It has been noticed that the weight of injection-molded ABS car door panels is 9 kg however the same panels manufactured by natural fibers weigh only 5 kg with same mechanical properties.
- Light weight (less than half the density of glass fibers): This is also an important environmental benefit as ∼85% of energy usage is when a vehicle is being driven. Plant fibers have a maximum density of 1.5 g/cc (that of cellulose), which results in high specific strength and stiffness and hence low component weight.
- Safer: Safer crash behavior.
- Good acoustic properties.
- Good thermal insulation.
- Identical strength values to glass fiber composites.
- Displayed outstanding formability.
- Natural fibers are superior to glass fibers from a health point of view.
- Abundantly available worldwide.

The main reason for the utilizations of natural fiber composites is the cost and weight. Although, natural fibers also showed considerable environmental benefits as compared to glass fibers, which includes:

- Ecological sustainability.
- Less energy requirements for production.
- End of life disposal. Can be composted at the end of their life.
- Carbon dioxide neutrality. As natural fibers are derived from plants and plants ultimately have carbon dioxide neutrality properties, i.e., carbon dioxide do not recur into the atmosphere when they are combusted.

Technically natural fibers do not have good mechanical properties as compared to synthetic fibres. Natural fibres showed variations in strength properties. This depends upon the regions where they have grown, which is not noticed with synthetic fibers. However, natural fibres showed only half the density of synthetic fibres.

10 Disadvantages of Natural Fiber Composites in Automobile Sector

The prospective of natural fibre as a reinforcement is substantially declined by its hydrophilic nature which is an unavoidable disadvantage and the lack of adhesion ability between natural fibers and the matrix materials being employed (Van de Weyenberg and Verpoest 2002). In this regard, notable efforts are currently being administered towards enhancing the mechanical properties of natural fiber-reinforced composites through optimization of the adhesion strengths between the natural fibers and the polymer matrix (Thomas 2002). As we can see there are various types and qualities of the natural fibres available in the world. These varieties or qualities are mainly depends upon the growing conditions of the environment. Also another drawback of these fibres are their processing techniques which ultimately affects the technical application part of these fibres into matrix (breakage of the fibre or crack development in the fibre after retting or processing). The natural fibers also showed reduced impact strength, which ultimately a result of a fiber defects present into the material during the growing or fibre processing stages.

11 Conclusion/Summary

Globally many researchers are following the useful applications of the natural fibres in the composites applications on a very large scale. As an outcome, most of the parts/components for the automobile industries are now manufactured by using natural fiber reinforced composite materials. The main matrix materials utilized for the development of these composites are Polypropylene and Polyester matrix. The important natural fibres utilized by automotive industries are flax, hemp, and jute fibres. At present the inspiration of using these fibres has been marketing and cost instead of technical needs. Accordingly, the end products are restricted to lesser strength interiors automotive parts. The main disadvantages of these materials are hydrophilic (due to the use of natural fibres) and lower impact strengths. Although, many efforts are being carried out to enhance the mechanical properties of these materials in such a manner that they can be utilized in exterior components which generally require high impact strength and become hydrophobic in nature. Ultimately the truth is, the use of natural fibres experiencing high level revolution and also have a potential to replace synthetic materials.

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