Composites for Electric Vehicles and Automotive Sector: A Review

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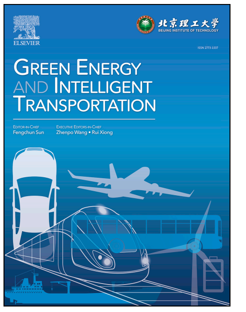

Composites for Electric Vehicles and Automotive Sector: A Review

Adil Wazeer, Apurba Das, Chamil Abeykoon, Arijit Sinha, Amit Karmakar

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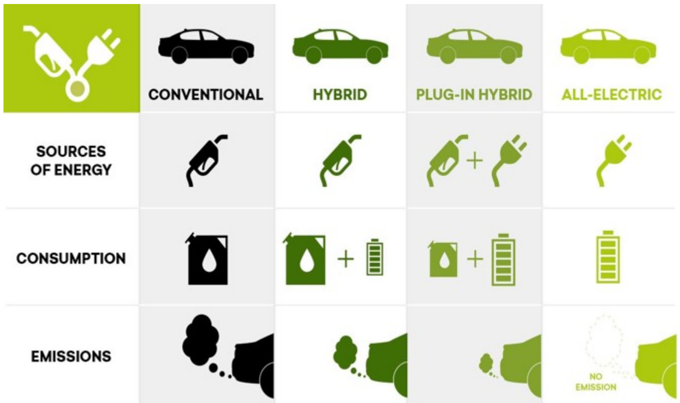
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HYBRID
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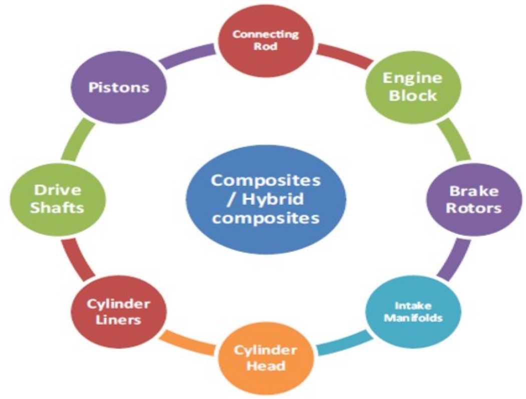
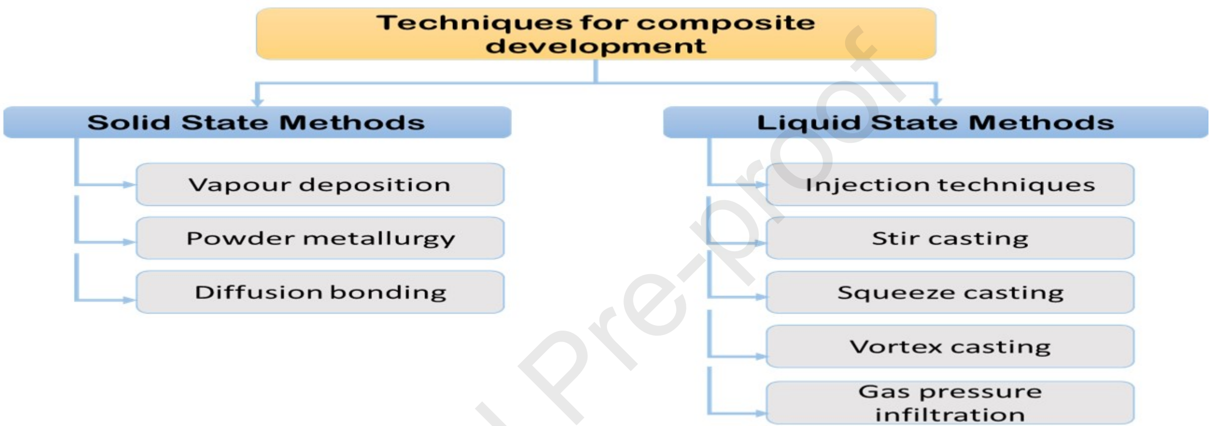

Composites / Hybrid composites
Connecting Rod
Engine Block
Brake Rotors
Intake Manifolds
Cylinder Head
Cylinder Liners
Drive Shafts
Pistons


Techniques for composite development
Solid State Methods
Vapour deposition
Powder metallurgy
Diffusion bonding
Liquid State Methods
Injection techniques
Stir casting
Squeeze casting
Vortex casting
Gas pressure infiltration

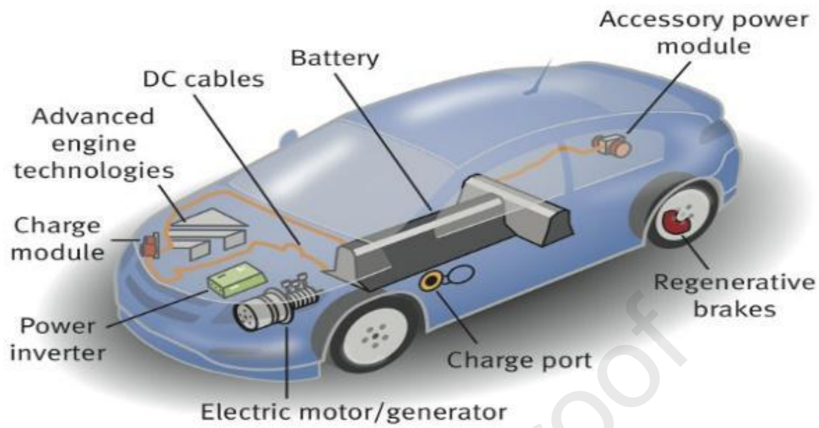


Figure 1: An illustration of the major components of an EV [9].

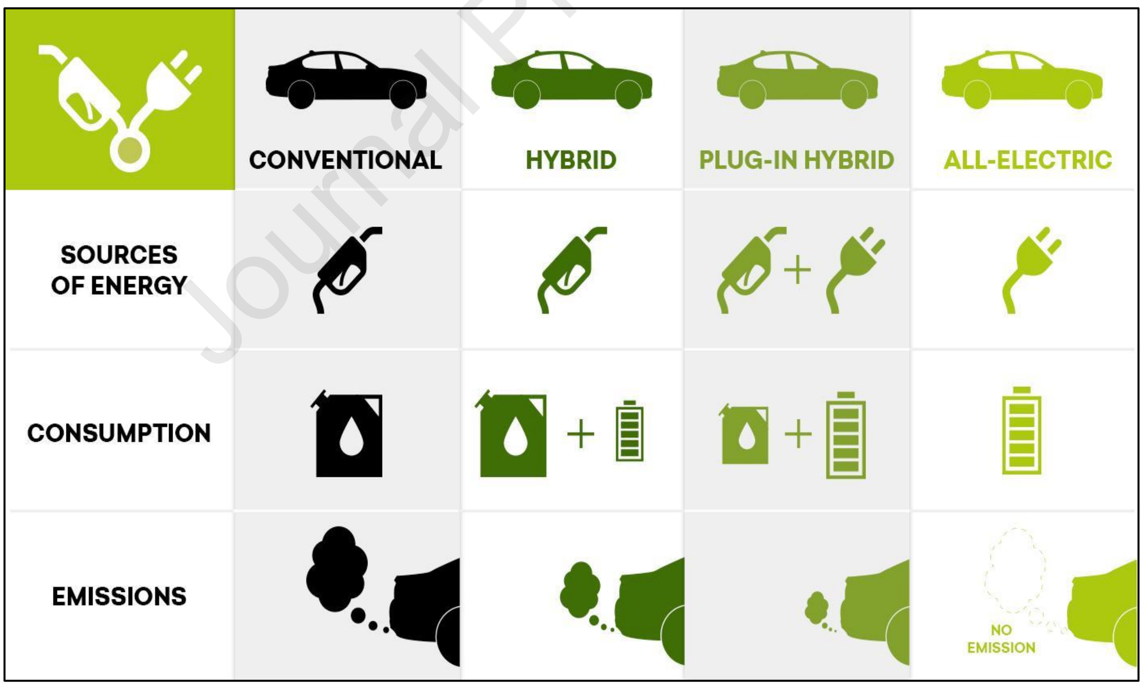
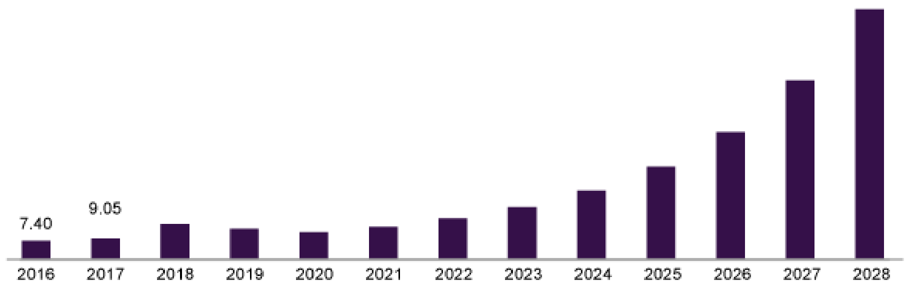


Figure 2: Classification of different vehicle types.



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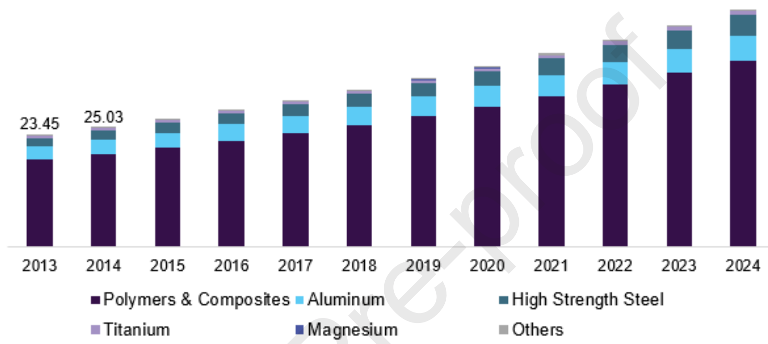

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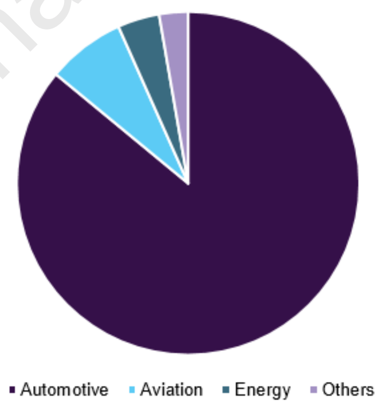

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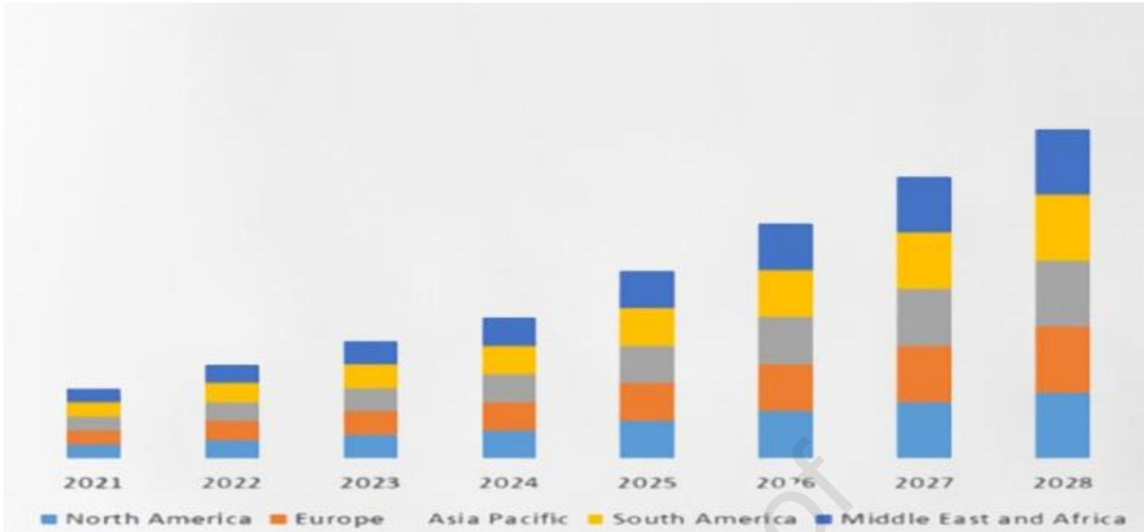
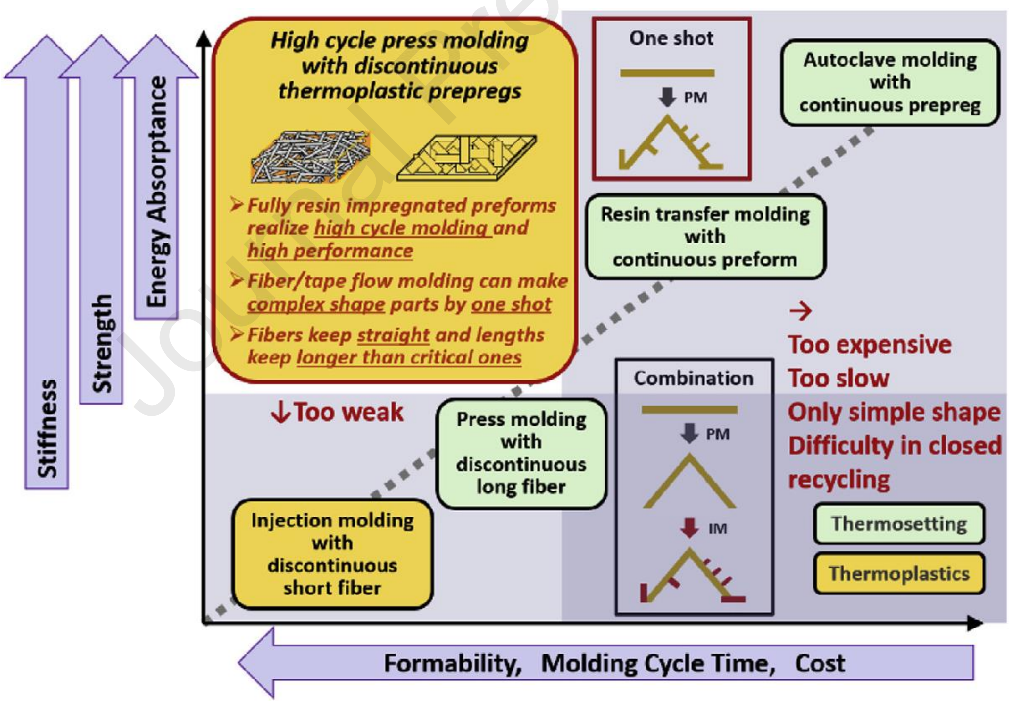


Figure 6: Global high performance market analysis which is expected to account for USD 13806.8 Million by 2028 [29].



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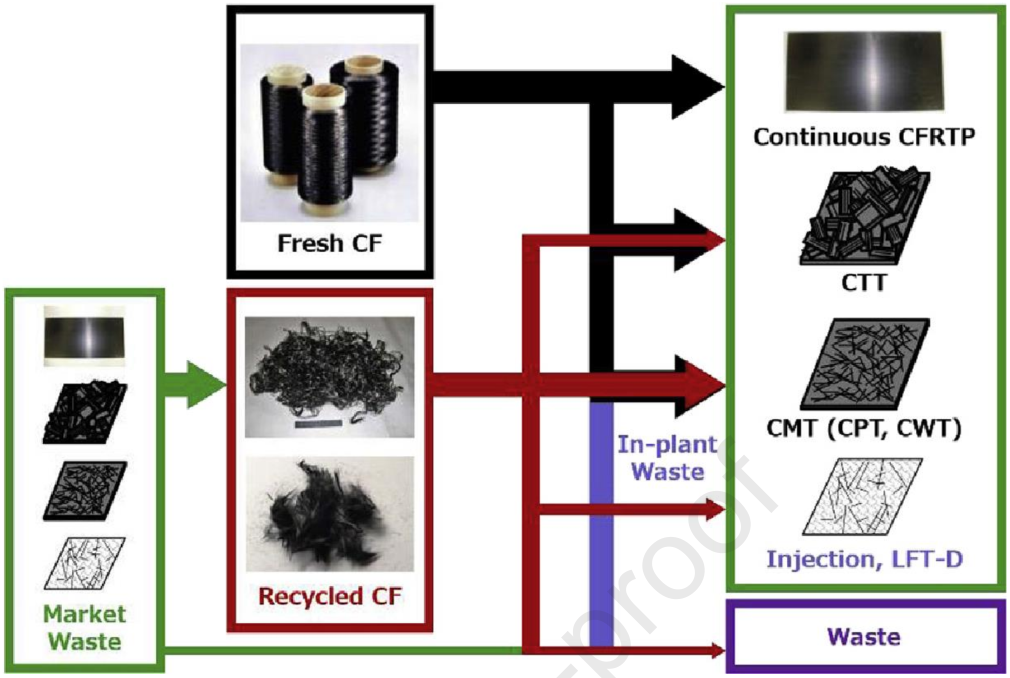

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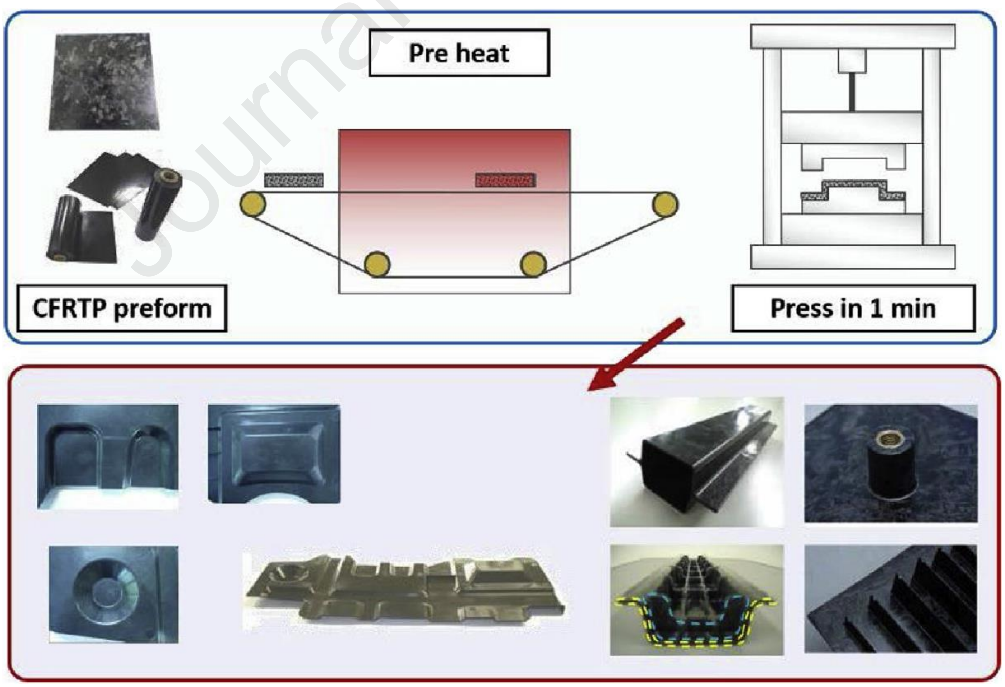
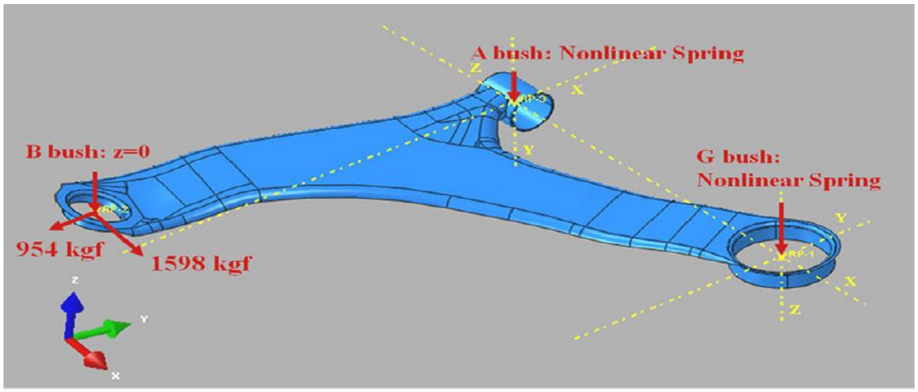
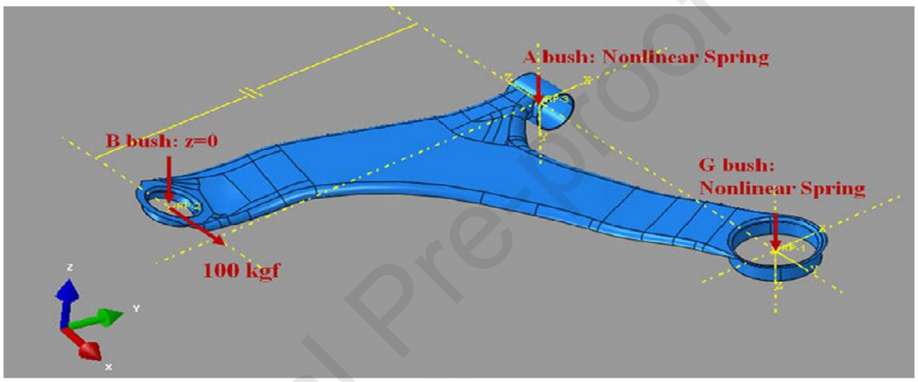


Figure 9: Representations of emerging high-cycle compression molding for bulk production automobile components [44].



(a)



(b)

Figure 10: Boundary conditions and load cases of lower arm analyses using composite material: (a) Buckling. (b) Stiffness [75] analysis.

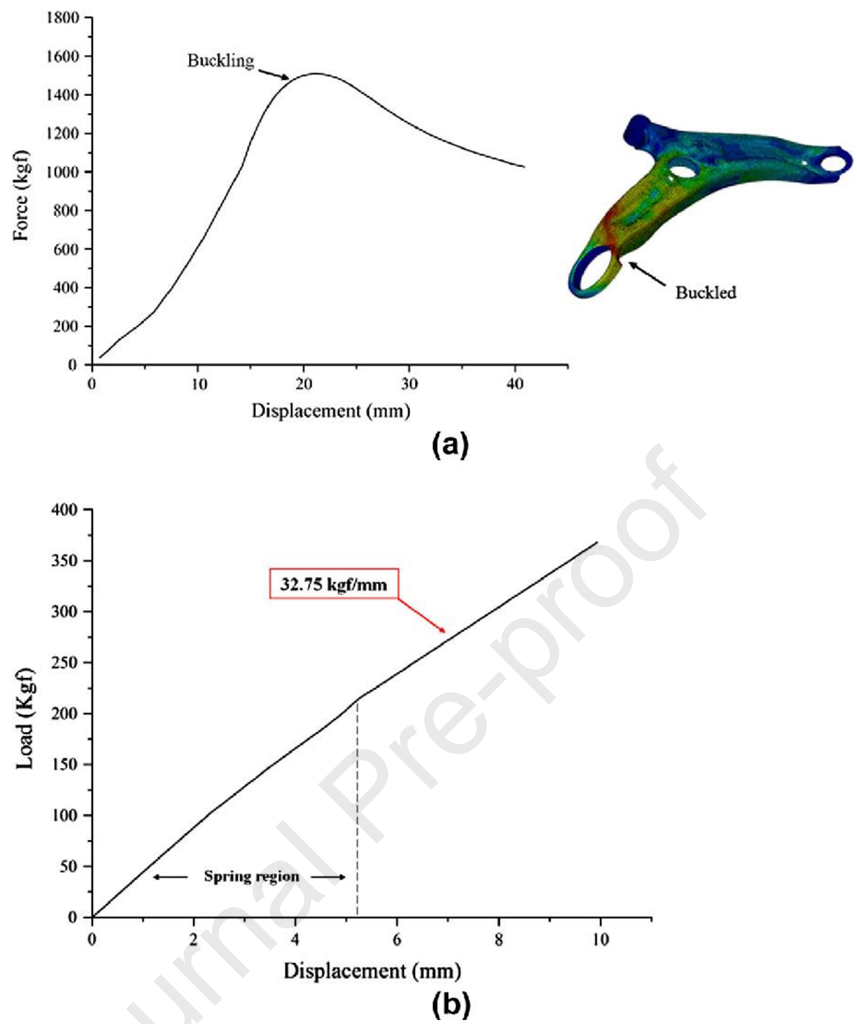
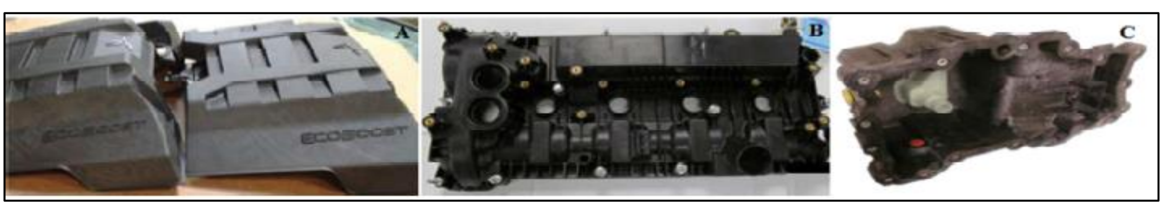


Figure 11: Lower arm model using conventional steel: (a) Buckling (b) Stiffness analysis [75].



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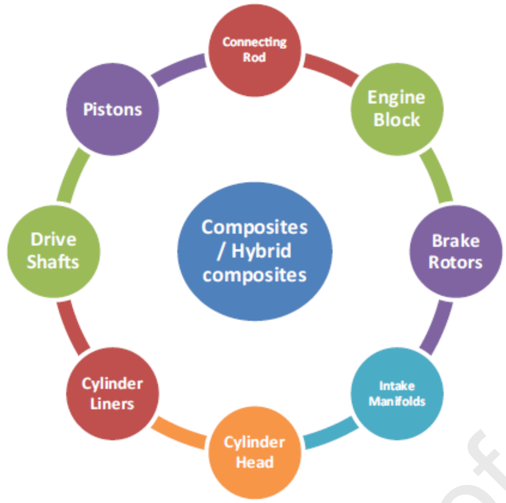

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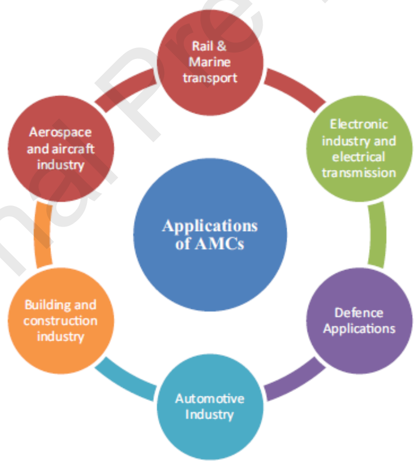
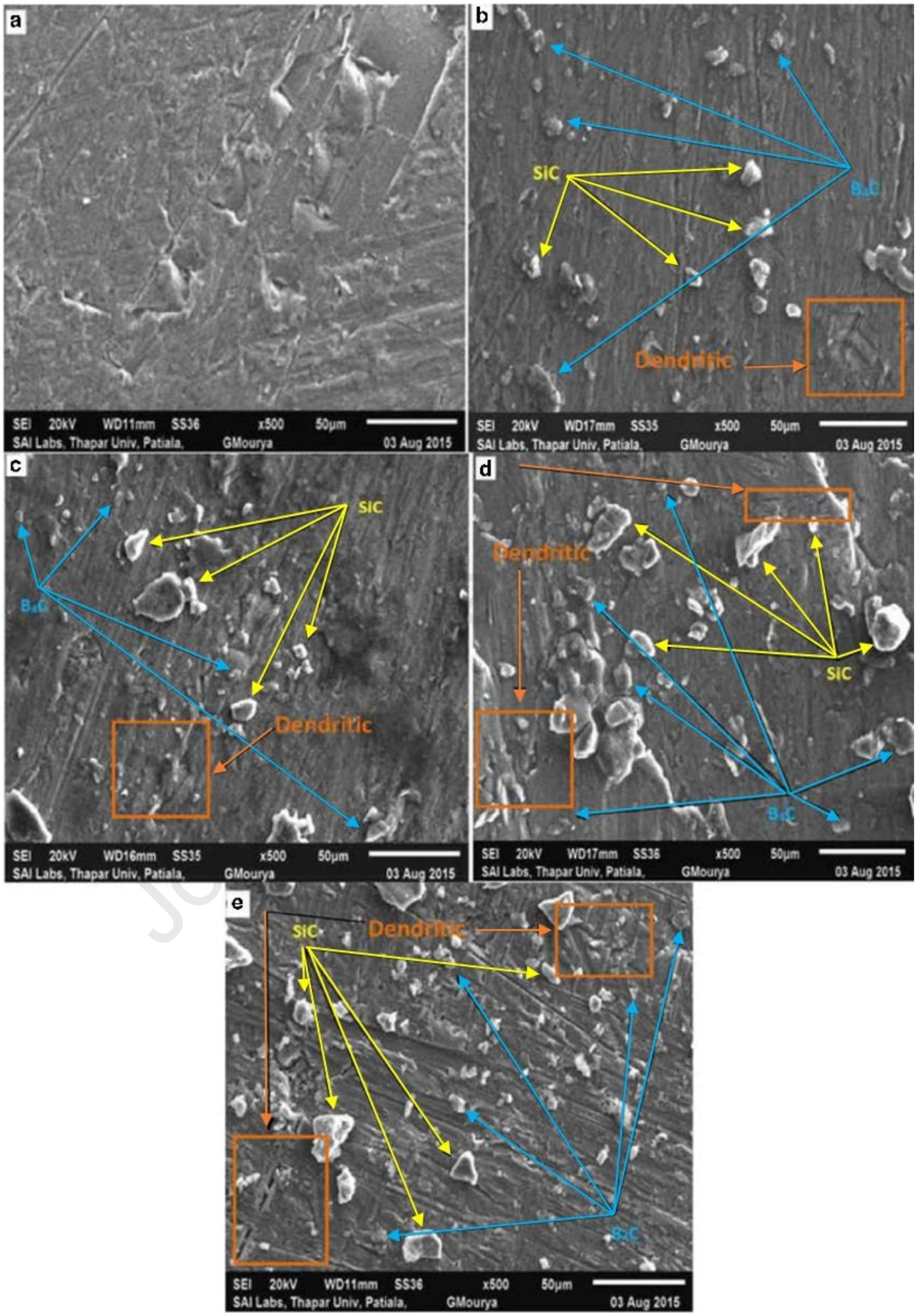


Figure 14: Novel applications of AMCs in different sectors [87].



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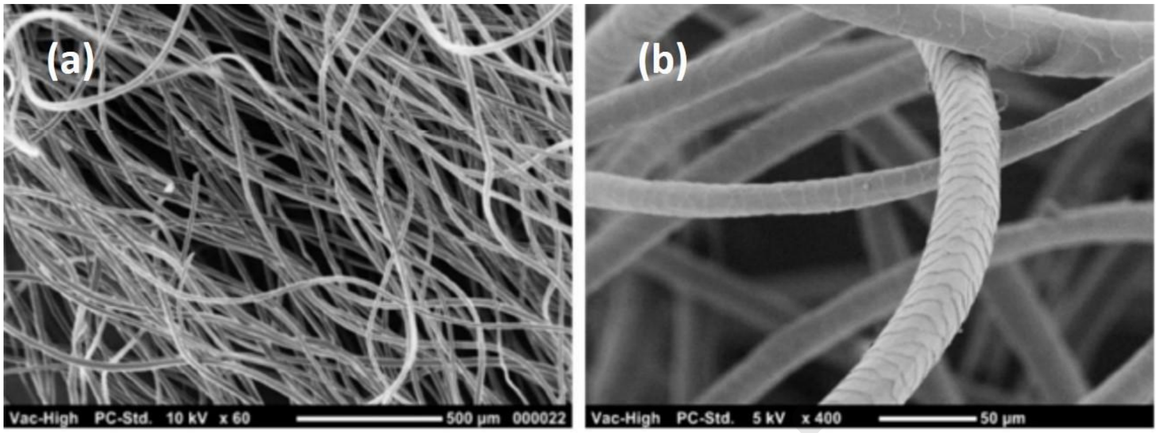

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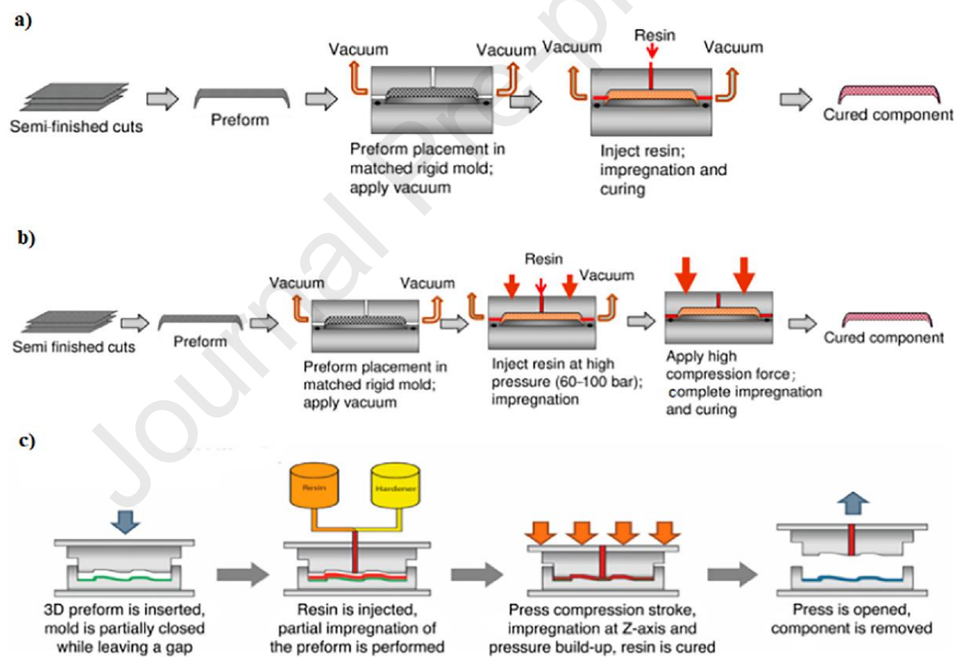


Figure 17: Various resin transfer molding (RTM) methods (a) Low-pressure RTM (b) High-pressure RTM (c) Compression RTM [151].

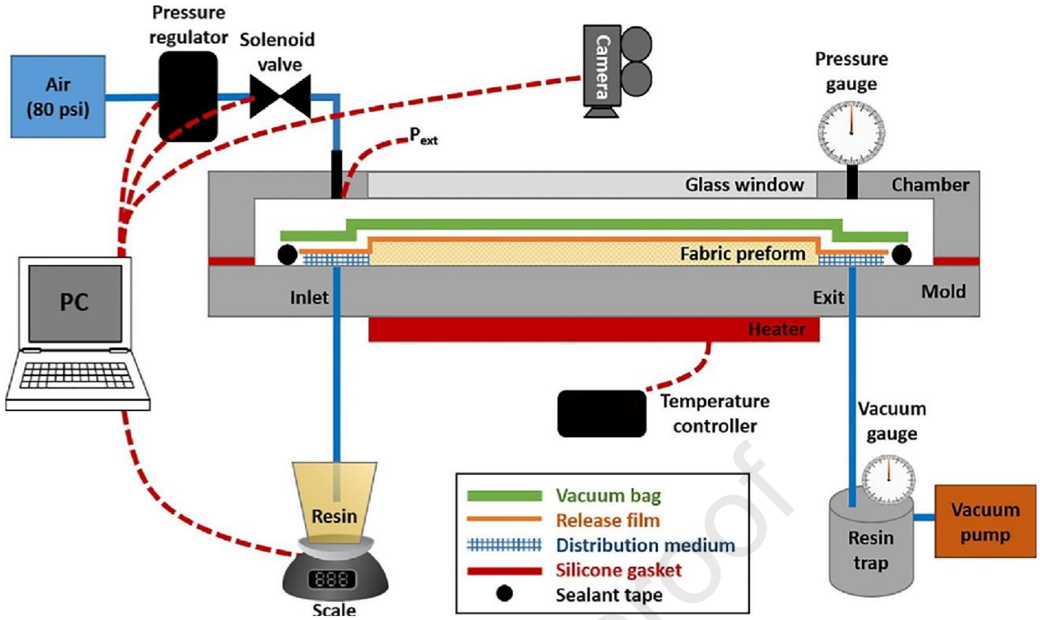


Figure 18: Modified VARI setup with external pressure and preheating of the mold [151, 171].

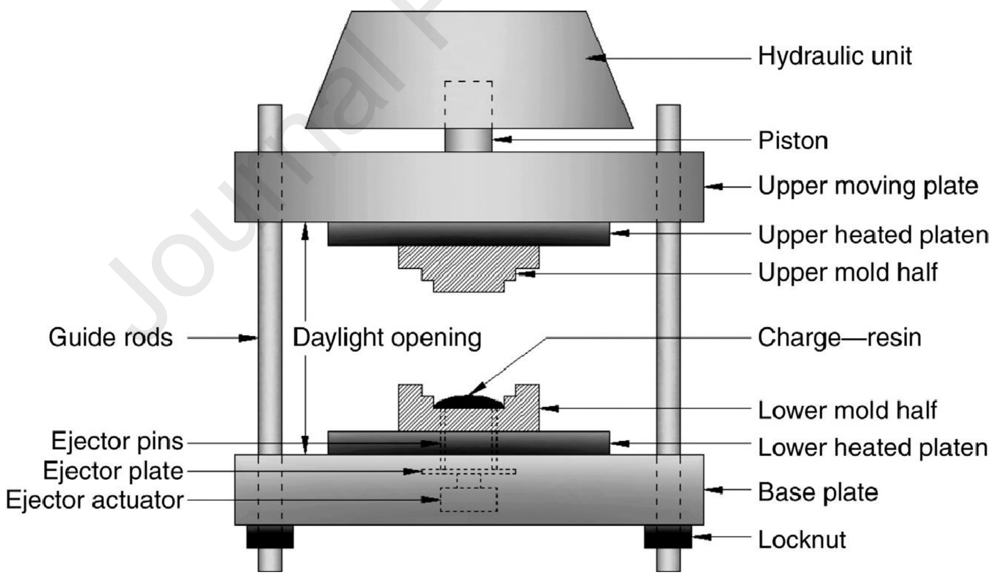


Figure 19: Representative diagram of a typical compression press [174].

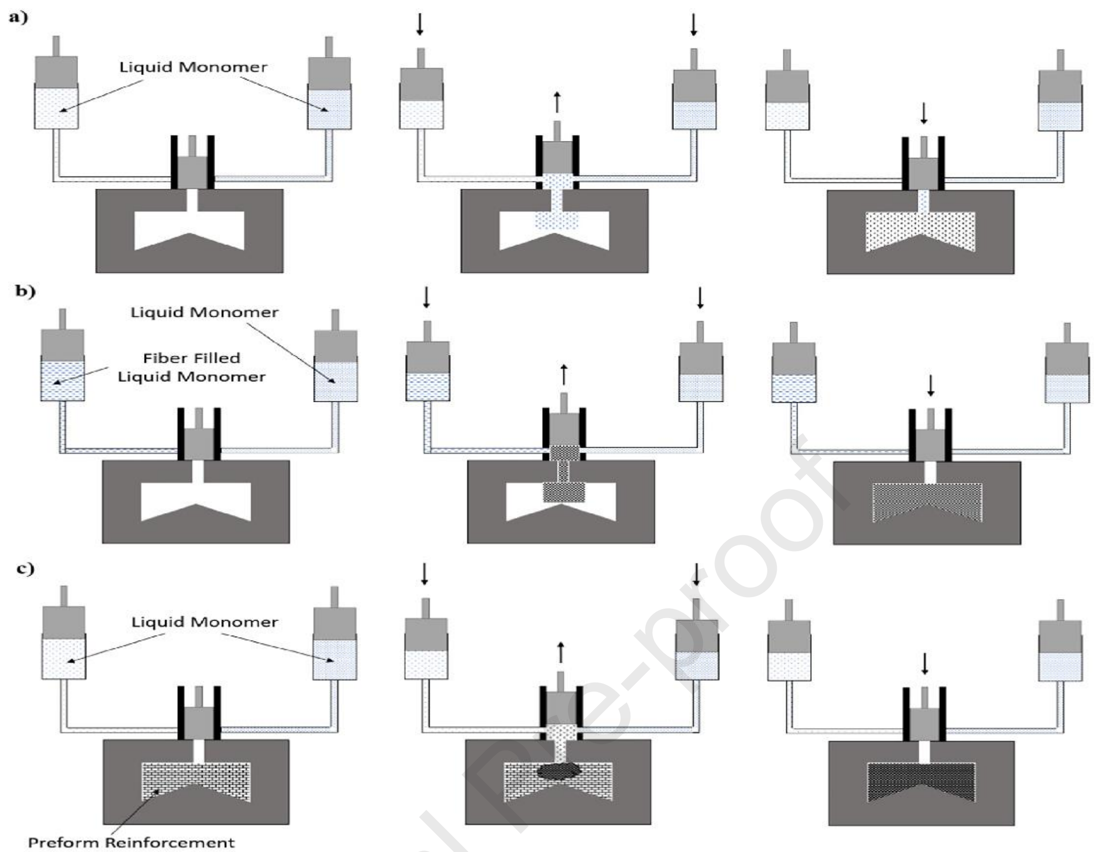
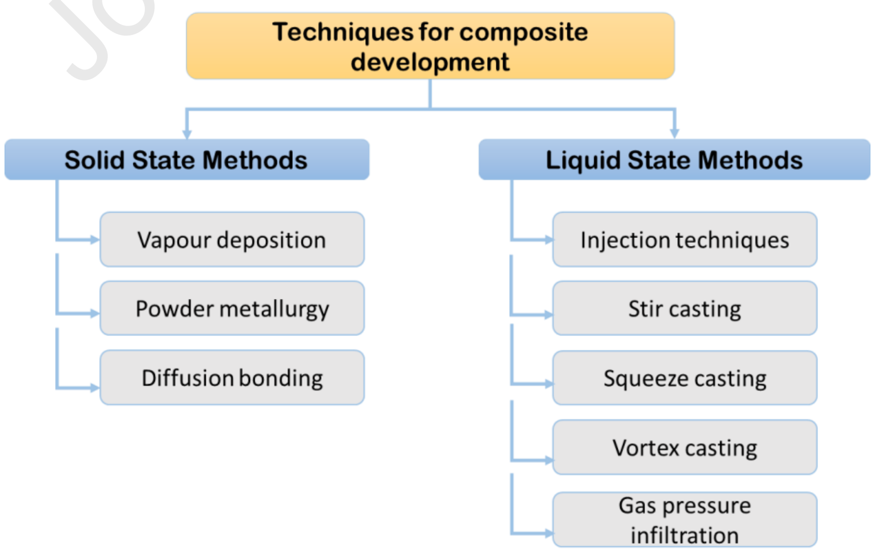


Figure 20: Various reaction injection molding (RIM) methods (a) RIM (no reinforcement) (b) Reinforced RIM, (c) Structural RIM [183, 151].



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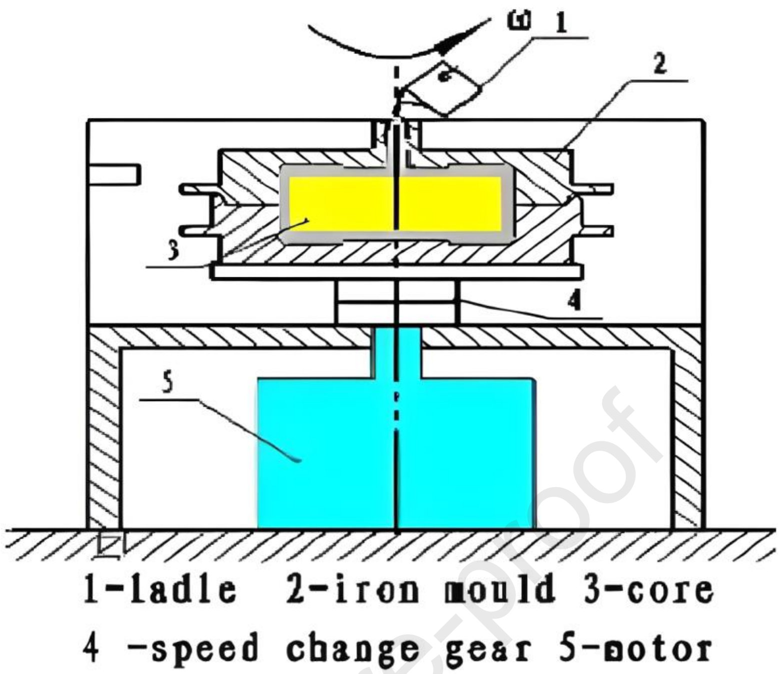

Figure 22. Schematic representation of Centrifugal Casting [189].

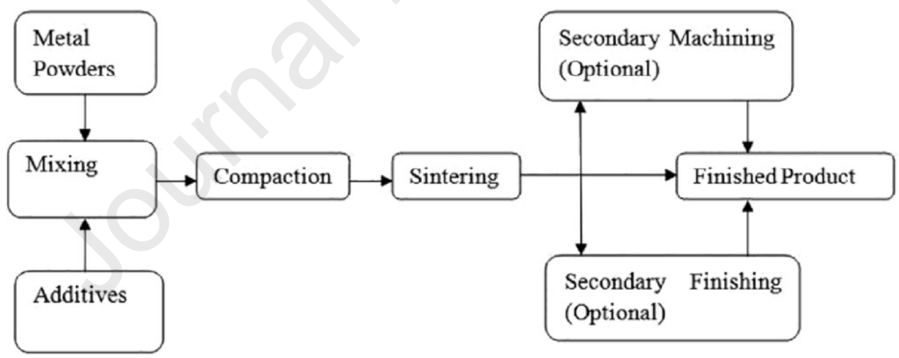

Figure 23: Flow Chart of Powder Metallurgy Process [191].

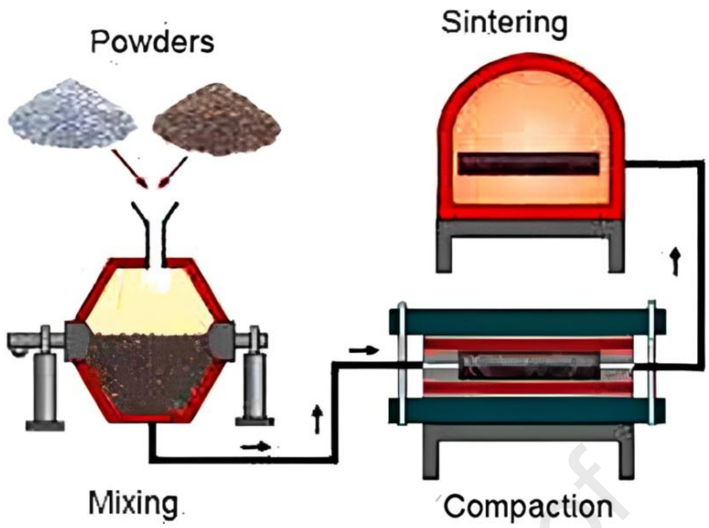

Figure 24: Powder Metallurgy Process [191].

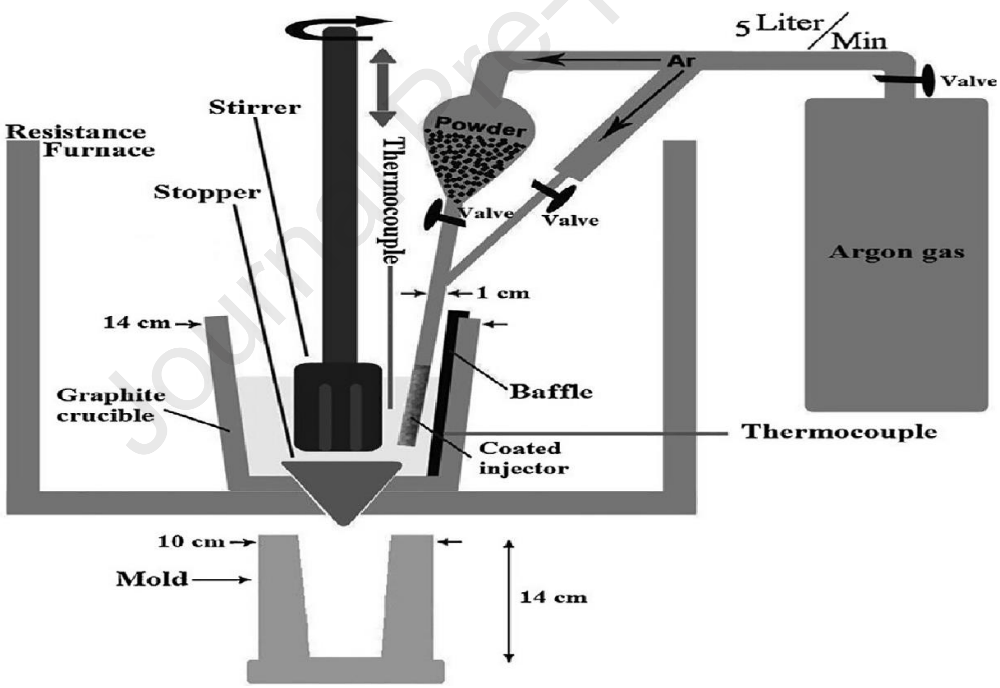

Figure 25: Stir Casting Process [192].

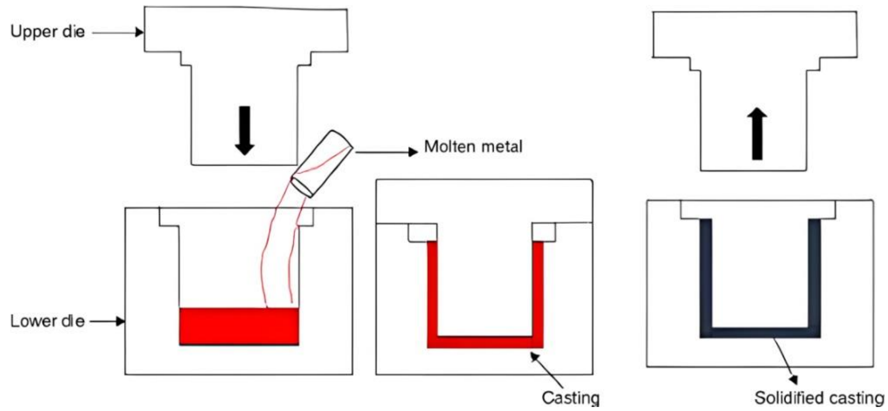

Figure 26: Squeeze Casting Process [194].

Composites for Electric Vehicles and Automotive Sector: A Review

Abstract: The automotive sector is undergoing a significant transformation to address critical challenges affecting consumers and the climate. One of the most difficult tasks is reducing the weight of vehicles in order to minimize energy consumption. A ten percent decrease in curb weight is predicted to result in a six to eight percent reduction in energy consumption. Composite materials having better strength to weight ratio are one of the finest options for planning, designing and manufacturing of the lightweight components. In automobile sector, employment of composite materials would reduce the weight of electric vehicles as well as influence their aerodynamic properties. Therefore, it would decrease the consumption of fuel as well by cutting down harmful emissions and particulate matter. Numerous developments in such technologies are studied over the last decade by automobile establishments and academic researchers. Fiber-reinforced polymers, particularly those established on glass and carbon fibers, have attracted attention of the automobile sector due to their high performance and lesser weight. This paper reviews the applications of various types of composite materials and the fabrication techniques of such composites in electric vehicles and automobiles. Furthermore, a comprehensive data breakdown of the lightweight materials statistics and figures on market analysis of high performance composite is presented. Finally, a discussion is made on the different applications of these composites. Hence, the details presented in this study should be useful for automobile companies to align with NET ZERO global mission while sustaining their businesses.

Keywords: Composites, Electric Vehicles, Fabrication Techniques, Hybrid Vehicles.

List of Abbreviations:

AC: Air conditioner

AMCs: Aluminium matrix composites

BEV: Battery electric vehicles

BIW: Body in white

BMC: Bulk molding components

CAGR: Compound Annual Growth Rate

CF: Composite fiber

CFRP: Carbon fibre reinforced plastic

CFRTP: Carbon fiber-reinforced thermoplastics

CMT: Carbon fiber mat reinforced thermoplastics

CNT: Carbon nanotube

CTT: Carbon fiber tape reinforced thermoplastics

CWT: Carbon fiber card web reinforced thermoplastics

EPA: Environmental Protection Agency

EVs: Electric Vehicles

FEA: Finite Element Analysis

FRPs: Fiber Reinforced polymers

GCMT: Glass/carbon mat thermoplastic

GFRP: Glass fibre reinforced plastic

GMT: Glass fiber mat thermoplastic

HAMCs: Hybrid aluminium matrix composites

IC Engine: Internal Combustion Engine

LFTs: Long-fiber-reinforced thermoplastics

MMC: Metal matrix composites

MT: Metric tons

NCC: National Composites Center

PBS: Polybutylene succinate

PCM: Prepreg compression molding

PET: Polyethylene terephthalate

PHEVs: Plug-in hybrid electric vehicles

PLA: Polylactic acid

PM: Powder metallurgy

PNCs: Polymer-based nanocomposites

PP: Polypropylene

PUR: Polyurethane

RIM: Reaction injection molding

RTM: Resin transfer molding

SEA: Specific energy absorption

SEM: Scanning electron microscopy

SMCs: Sheet molding compounds

Sorona® EP: Poly trimethylene terephthalate

VARI: Vacuum-assisted resin infusion

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1. Introduction

The definition of a composite signifies the materials that are composed of two or more dissimilar constituent materials. Here, metal, ceramic or polymeric materials can serve as the major base materials. Composites simply denote the product material having improved mechanical characteristics owing to its combination of more than two materials when compared with its individual components [1]. Compared with conventional materials, the majority of composites are designed with a view of having high specific strength, less weight, a relatively high resistance to corrosion and so forth. Improved strength, higher fatigue strength, greater physical characteristics, reduced weight, greater surface finish are the major benefits of the composites. Generally in automotive industry, composite materials are lighter in weight when compared with most commonly used metals. Composite materials based on the carbon fiber are the highest functional polymer composite employed in automotive, aerospace, military and sporting commodities [2]. In conventional automobiles, the metals comprise the central structure of the vehicles whereas certain interior parts are fabricated with composites. In recent times, carbon fiber composites are regarded as the most suitable material for the reduction of vehicle weight although it might be expensive unlike traditional metals [34]. The mechanical properties, microstructure and surface morphology of the composites could be enhanced more than aluminium alloys [5]. In general, composite materials are classified as exceptional materials for their application in automotive industry [6]. In electric cars, steel and cast iron account for around half of the material (by weight). While aluminium alloys make up around 9% of the total, plastics make up 11%, and rubber makes up 3%. [7]. In present times, industries are dwelling upon the utilization of renewable sources and further usage of materials that are recyclable, environment friendly and have less harmful global impact [8].

Reduction of emissions and fuel consumption are the major struggling issues of the automobile sector that requires strong solutions. Enormous amounts of greenhouse gases are emitted into the environment as the production of energy relies upon the carbon based fossil fuels. Due to the constant elevation in the power consuming areas globally, the demand for energy has also increased over the last few decades. And because of the high prices of the fuel and also looking into the issue of environmental degradation, consumers are motivated to opt electric vehicles (EVs). Following this, the demand and motivation for using electric vehicles has increased in numerous countries worldwide. EVs are serving as an alternative for diesel, petrol and other fossil fuel powered vehicles as EVs run on lithium-ion batteries which offer facility of hybrid charging and also they are lighter in weight as most components are manufactured from composite materials to increase the fuel efficiency of the vehicle and also they may not need most of the components required by traditional vehicles powered by fossil fuels. Several ride-hailing businesses are engrossed in substituting their internal combustion (IC) engine fleet with EVs.

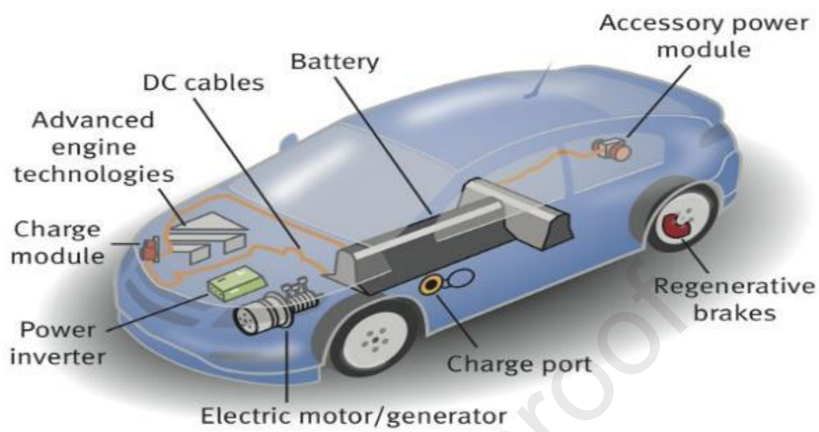

Figure 1: An illustration of the major components of an EV [9].

In order to cope with the issues of energy efficiency, numerous researchers recommended replacement of different vehicle components with alternative lightweight materials which will reduce the vehicle weight while boosting the fuel economy [10-13]. A decline of 1g/km carbon emission is observed on reduction of every 10 kg of vehicle weight thus decreasing consumption of fuel. The lightweight scheme grows to attain a significant approach owing to its proven competence of effective reduction in fuel demand and decline in emissions. Light weighting focuses on reduction of vehicle mass through substitution of material along with redesigning of components while preserving the size of vehicle and further assuring the consumer needs/demands.

Various techniques were employed for investigating the benefits of lightweight materials when compared with conventional ones in IC engine vehicle design [14-19]. Reduction in the environmental effects caused by vehicles is a result of the amalgamation of both EVs and light weight design [20]. Additionally, utilization of lightweight materials in EVs is predictable to be mostly lucrative because enhancement in performance such as drive distances plus battery size containment could be achieved by mass reduction [21].
Therefore composite materials are selected as the potential candidate for the manufacturing of lightweight components with advantages of enhanced mechanical characteristics. There is constant ongoing effort to decrease the vehicle weight as well as to grow cheap manufacturing methods for the production of lightweight materials like carbon fibre reinforced plastic (CFRP). Compounds of carbon fibre demonstrate higher strength, reduced weight, good resistance to vibration, higher rigidity and increased fatigue and corrosion resistance compared to conventional materials [22]. Over the last few years, China has established research on carbon fibre and its composites [23]. Though, its employment in automobile sector is yet lagging behind aerospace and aviation sectors.

Generally, only a limited amount of studies exist regarding this area [24, 25] and therefore there is need for further development to cater the growing demand for EVs.Figure 2 presents a classification of different vehicle types.

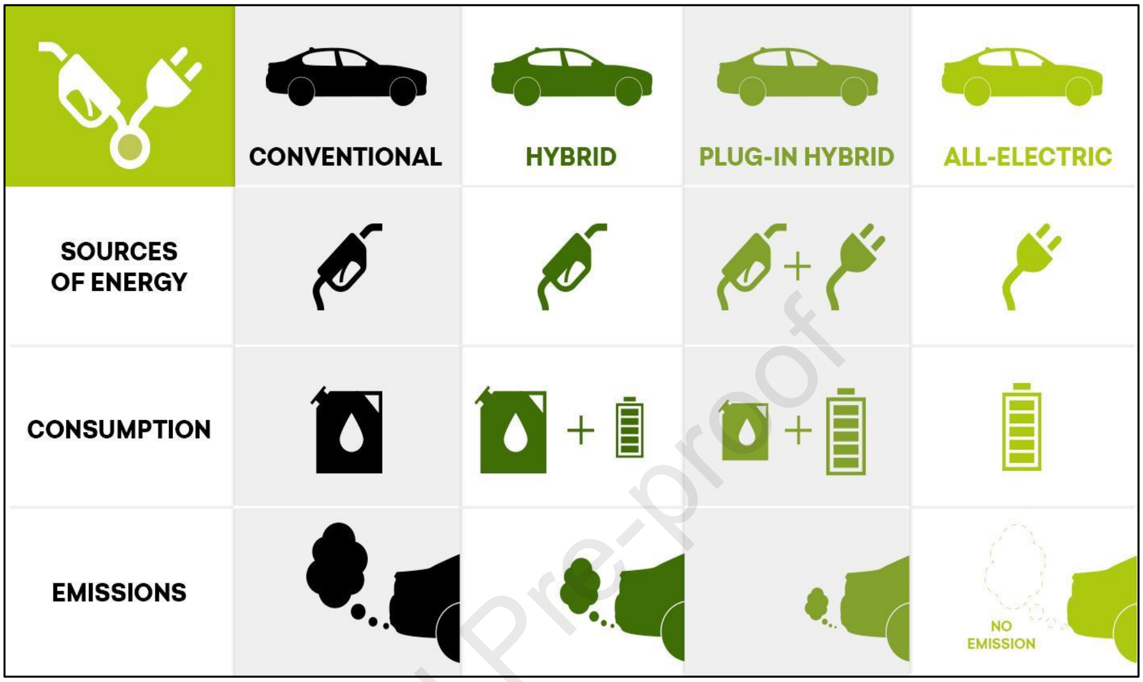

Figure 2: Classification of different vehicle types.

Now considering the statistics of the EV and automobile sector, the estimated value of the international passenger electric cars market was around USD 120.81 billion in 2020 and is predicted to grow at a compound annual growth rate of about 32.5% between 2021 and 2028 as presented in Figure 3. At present time, there is a considerable drop in the sales of passenger cars globally due to the restrictions triggered by COVID-19 in 2020s' first half and the automobile sector declines following the opposing impacts of lockdown. Nevertheless, amid this chaos the market achieved a landmark year in sales attaining approximately 3.0 million units in 2020, nearly an increment of 40% more than the year 2019. In 2020, China bagged the worldwide electric car sales of around 30%. And also it would demonstrate high level of momentum with the support of the growing public EV network with a predictable increase in customer demand over the projected period [26].

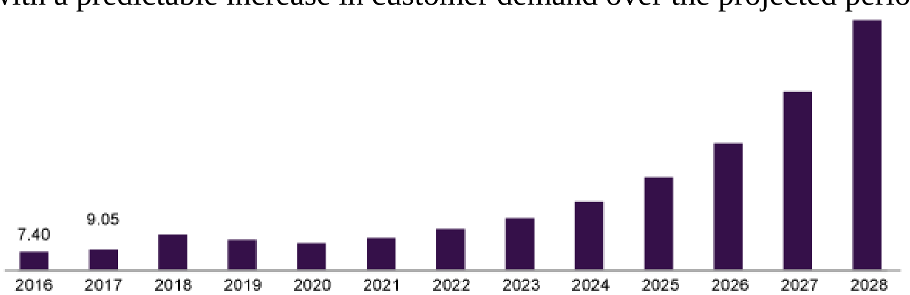

Figure 3: US electric passenger cars market size, 2016-2028 (USD Billion) [26].

The battery EV division accounted for the biggest share of revenue of more than 60% in the year 2020 and is estimated to uphold its supremacy over the predicted time. Since 2021, in the U.S., more than 15 different battery powered electric vehicles (BEV) models are offered. Battery powered electric vehicles are anticipated to observe a higher growth owing to its range concern when compared with plug-in hybrid electric vehicles (PHEVs). Concerning the segment of BEV Tesla Model S having upgraded variety is prevalent, while model 3 demonstrating reduced cost per km is the most proficient. The vendor achieved above 70% of sales in BEV segment in the year 2020. The PHEVs sector is likely to roll the maximum CAGR of over 32% in revenue over the forecasted period. Such progress could be credited towards the proposals from government authorities throughout the industrialized and developing economies for promoting the usage of EVs. PHEVs employ batteries to provide power to the electric motor and alternate fuel for powering the IC engine. Establishments like Volkswagen Group are concentrating on elevating the sales of their plug-in electric car. In January 2020, the company publicized an increment of around 60% in the sales of its plug-in electric car when compared to year 2018 [26].

2. Lightweight materials market statistics

Light weighting of vehicles is one of the current prime concerns for the automation industry as they are concentrating much effort towards enhancing the efficiency and development in the pollution reduction. Higher safety, more comfort at a cheaper rate and increased fuel economy are the key aspects demanded by the consumers. Lightweight materials can increase the vehicle performance considering drive distances. Consumption of energy would be decreased by employing lightweight composites for manufacturing of vehicles. It is assessed that by reducing the weight of a vehicle by 25%, nearly 250 million barrels of crude oil could be conserved per year. Application of composite fiber materials might decrease weight to approx. 10- 30% [11, 27]. The market volume of the worldwide lightweight materials was projected around USD 113.78 billion in the year 2016 and is estimated to record a CAGR of 8.9% over the predicted period of time. The increment in vehicle demand in North America (Figure 4) is expected to boost the growth of market over the years. The development in this area is determined on account of the existence of prime auto manufacturers in countries like the U.S. and Canada. Additionally, the presence of manufacturers of renewable energy equipment is anticipated to propel the market in this region.

The market is distributed into products such as high strength steel, aluminium, magnesium, titanium, polymers and composites. Composites and polymers conquered the entire market and this tendency is expected to continue over the years. The response for the product is likely to propagate because of its capability to reduce vehicle weight by 50% and increase the efficiency of fuel to around 35% [28].

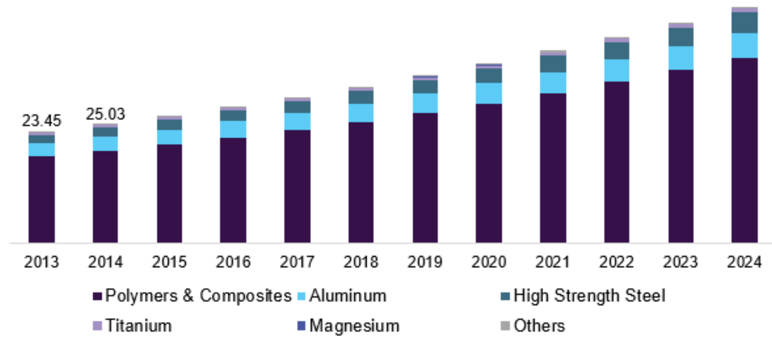

Figure 4: North America lightweight materials market size, by product, 2013-2024 (USD Billion) [28].

Automotive, energy and aviation are the prime sectors for the market of lightweight materials. In the year 2016 (Figure 5), the automobile industry ruled the global market of lightweight materials with a share of nearly 86% of revenue [28].

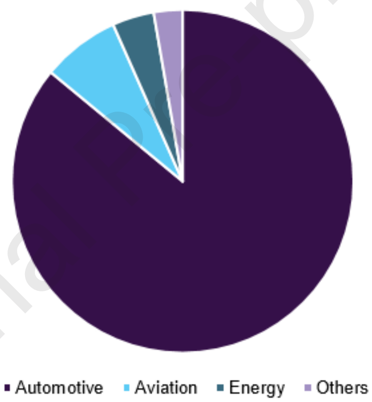

Figure 5: Lightweight materials market share, by application, 2016 (%) [28].

Direct implications on several factors by the lightweight material application are observed such as consumption of fuel, agility and driving dynamics. The lightweight material employment in aviation industry is predicted to lift up its requirement over the years. Also, utilization of lightweight materials in windmill manufacturing for the generation of wind energy which is a prime source of renewable energy is also gaining effect. The market for the lightweight materials is reasonably competitive because of the existence of prominent companies like Cytec Solvay Group; Toray Industries Inc., Alcoa Inc., and SABIC Industries. The quality of market is quite disintegrated and noticeable due to the increase in number of acquisitions and mergers. To increase the market demand, investment for enhancing the product quality is carried out by companies. Over the years, there is a high probability of rise in the manufacturers of polymers and composites owing to the increased utilization in automobile and aviation industries. The fast growing wind energy component industry has fascinated several contestants since they have initiated various product additions that are utilized in manufacturing blades [28].

The global demand was dominated by the Asia Pacific owing to its rising automobile and aviation sector. Countries like China and India are making progress on their local market because of the huge demand for passenger vehicles. Increasing awareness regarding renewable energy is likely to shoot up the demand of product for energy applications. Higher budgets of defense in these areas probably increase the magnesium and titanium requirement. The product demand is progressing quickly in the region of Latin America due to an increment in the number of manufacturers of lightweight materials. Additionally, the growth of market in European region is projected to increase because of the presence of manufacturers of aircraft and wind energy components in this region. North America consumes a huge amount of high strength steel because of its analogous characteristics as conventional steel. Utilization of aluminium in the region is high because of the demand of aviation and automotive applications [28].

Generally high strength steel is primarily employed as a direct alternative for conventional steel in lightweight applications. It is mostly preferred in the automobile industry and shows potential to decrease vehicle weight by 25%. Recycle value of high strength steel is enhancing its demand which is expected to drive the growth of market in coming years.

3. High Performance Composites Market Analysis

The market of high performance composites is estimated to achieve progress during the projected period of 2021-2028. Analysis of the statistics reveal the growth to stretch to an expected value of around USD 13806.8 million by the year 2028 and show a CAGR of nearly 6.10% (figure 6) [29].

The aspects like rising glass and CFRP composites demand in airbus airplane and cumulative utilization of high performance composites in the blades of wind turbines are the major factors powering up the growth rate of market of high performance composites. Moreover, the development in automotive industry and growing sales of aircrafts influence the market growth rate of high performance composites. But, the higher costs of raw material as well as the prices of fabrication and assembly disrupt the progress of the market of high performance composites.

The market of high performance composites is expected to dominate the Asia-Pacific region due to the promising regulations boosting their employment in numerous industries throughout the projection period in the region. North America, instead, would remain displaying profitable growth because of the existence of major automobile companies [29].

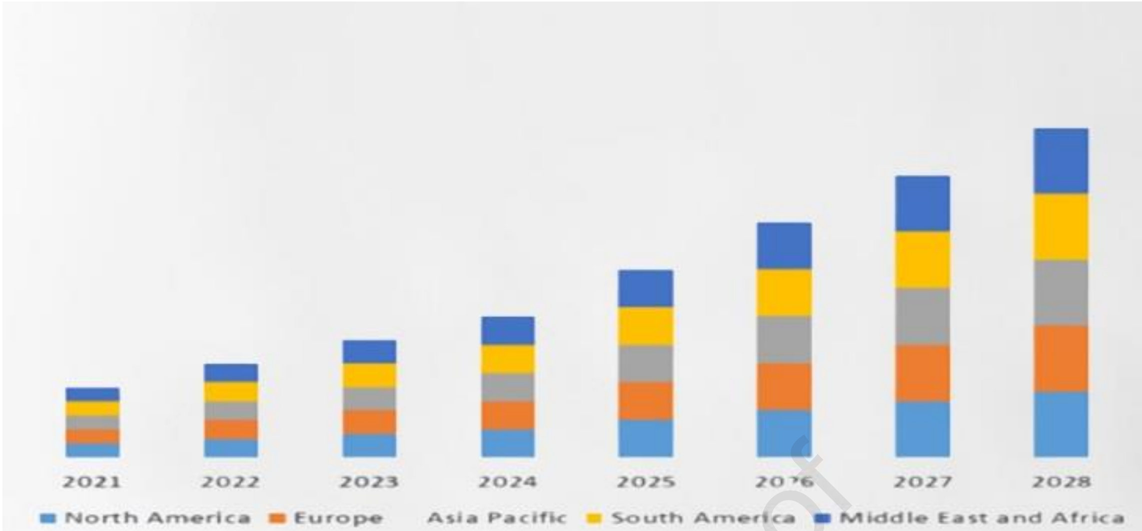

Figure 6: Global high performance market analysis which is expected to account for USD 13806.8 Million by 2028 [29].

India also plays a vital part in manufacturing high quality passenger vehicles and motorcycles employing composites materials. World Bank reports reveal that for each 1000 populations North America, China and India have 786, 69 and 18 motor vehicles. This report of World Bank also illustrates a potential growth in transportation industry for countries like India and china. It was projected that Indian Railways utilized approx. 10,000 MT of composite materials concerning various interior usage in freight segments. Government of India declares that around 30% of parts should be procured from Indian industries in aerospace division. Composites industry in India consumed nearly 3 lakh metric tons in the year 2015 which rose rapidly to around 4.18 lakh metric tons in the year 2020 having a CAGR of 5.8 %. Indian composite sector is elevated to approximately 3.6% CAGR in the years 2011 to 2015 [30-33].

4 Composites for EVs and automobiles

4.1 Fiber Reinforced Composites

During the process of growth of polymers, reinforcing materials have attained the position of second most prime component [34]. Researchers have been carried out for numerous reinforcing agents on account of improving the matrix material performance like dimensional stability, mechanical characteristics and thermal resistance [35, 36]. Generally, reinforcing materials appear as flakes, particles and fibers. Carbon fiber is considered to be the most encouraging among the group of various fibers that are employed in polymer matrix composites. The global revenue for the CFRP composite was estimated to increase from 28.2 billion USD to nearly 48.7 billion USD [37].
Fiber reinforced plastic (FRP) composite is another kind of composite consisting of fibers plus matrix [38]. The blend of higher strength and stiff fiber plus the lightweight matrix demonstrating higher fracture toughness results in fresh composite material. These materials show the diverse physical characteristics of its components [39]. For designing

the properties, the orientation of fiber in and along the directions of loading could also be executed [40, 41]. The composite is extensively employed in engineering sector for load-bearing structures like automobile, aircraft, building construction and marines [42]. Regarding the automobile and railway sector, the composites are considered to be the foremost choice for manufacturing bodies of automobiles so that the complex profile of the vehicle could be generated easily [43].

In Japan at the National Composites Center (NCC), for a project based on composites the technology of CFRP composite is utilized in replacing all elements of the chassis of a vehicle manufactured from aluminium alloys [44]. Figure 7 represents the progress route of CFRTPs during the project carried out at NCC to achieve superior performance, inexpensive, formable, and eco-friendly parts. Figure 8 shows the emerging intermediate materials namely carbon fiber mat reinforced thermoplastics (CMT), chopped carbon fiber tape reinforced thermoplastics (CTT), carbon fiber card web reinforced thermoplastics (CWT) and carbon fiber paper reinforced thermoplastics. Figure 9 shows the representations of emerging high-cycle compression molding for bulk production of automobile parts.

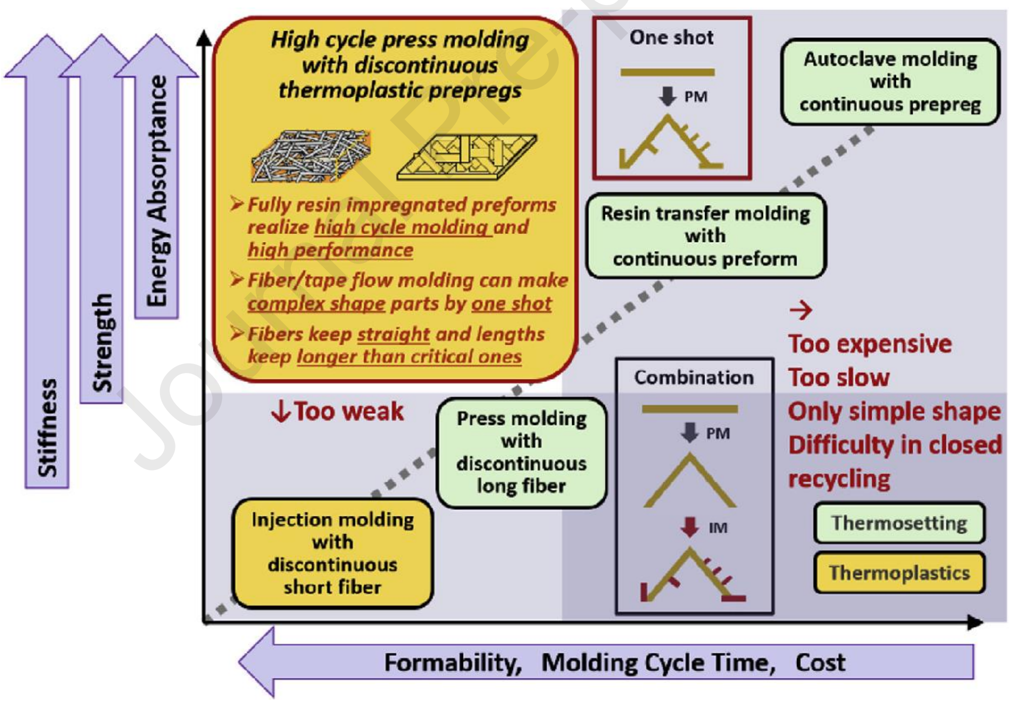

Figure 7: Progress route of CFRTPs in the NCC Japan project to achieve superior performance, inexpensive, formable, and eco-friendly components [44].

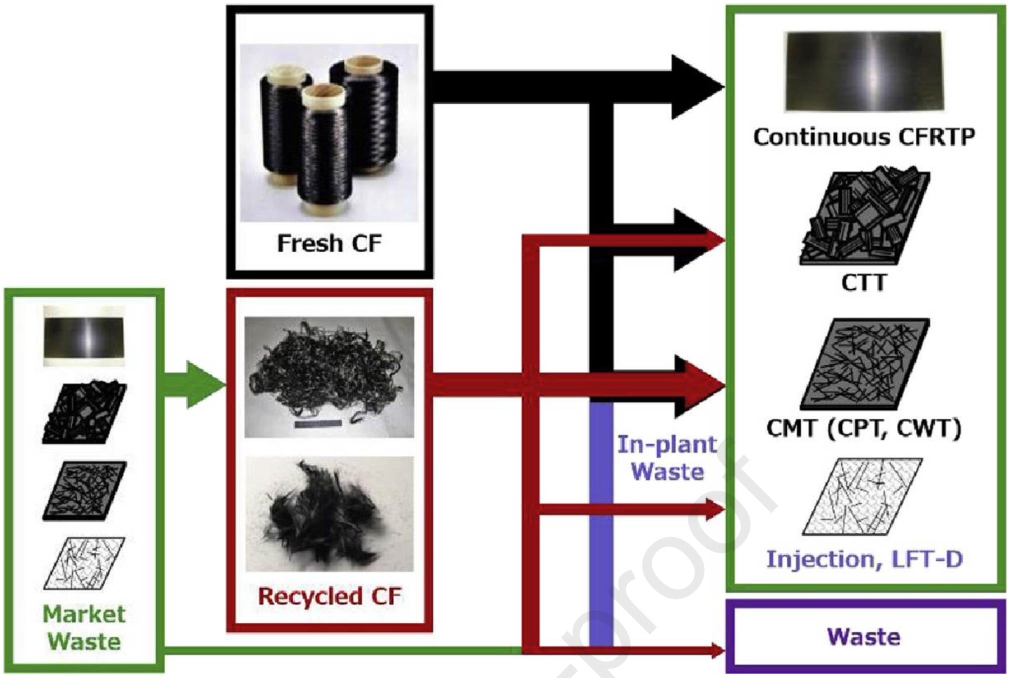

Figure 8: Emerging intermediate materials in the CFRTP project: chopped carbon fiber tape reinforced thermoplastics (CTT), carbon fiber mat reinforced thermoplastics (CMT), carbon fiber paper reinforced thermoplastics and carbonfiber card web reinforced thermoplastics (CWT) [44].

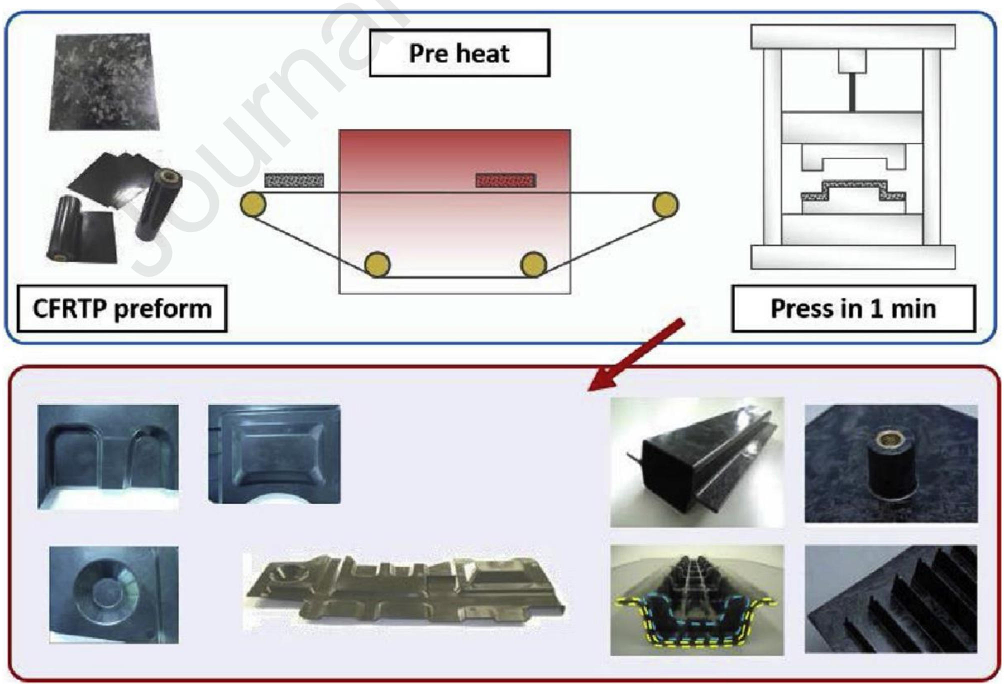

Figure 9: Representations of emerging high-cycle compression molding for bulk production automobile components [44].

In order to decrease the weight of vehicle by 10%, uses of alternative lightweight material with sufficient stiffness and mechanical properties like composite was recommended. Additionally, the composite finds application in the sensitive locations where more strength is required such as in crash management structures [45], composite rail frames [46] plus in suspension mechanisms [47]. Actually, composites could be a critical advantageous substitute for various budding metal components such as vehicle body structures, roof structure, bumpers [48, 49]. Added FRP composite benefit is, its ease of manufacturability in complex shape generation. The intricate car body shape is not only for attracting attention through fine art but also for considerably decreasing the coefficient of drag and increasing the aerodynamic performance [50, 51]. FRP composite plays a significant role in creating high performance EVs [52].

For enhancing the polymer product performance such as thermal resistance and mechanical properties along with widening its applications, several additive components like nano-fillers are employed with an extensive variety of polymer matrix [53, 54]. Consequently, polymer-based nanocomposites (PNCs) have achieved cumulative attention in recent times [55-57]. The polymer composites composed of inorganic nanoparticles like calcium carbonate [58] and carbon nanotube (CNT) [59], could deliver a wide range of performance for diverse uses in mechanical reinforcement, thermal conductivity and heat distortion temperature [60].
Higher weight reduction capability, more specific strength, high absorption of impact and more stiffness are the features offered by CFRP when compared with traditional metals like aluminium and steel. Hence, automotive industries are switching to use composite materials specifically CFRP for several years. Widely used composites in present times are glass, carbon and aramid fibers. They are a kind of natural fibers and are sub characterized as polyester and nylon fibers. Furthermore, glass fibers are low in stiffness and heavier when compared with carbon fibers. Henceforth for highperformance application, carbon fibers are utilized [61, 62]. In several vehicle parts carbon fibres find their application. In view of enhancing the strength and considerable weight reduction and frame size, carbon fibre reinforced composites are employed [63]. Isaiah [64] recommended that in order to achieve noteworthy reduction in weight of vehicle by around 60%, steel should be substituted with CFRP composite. The specific energy absorption (SEA) of the designed sliced carbon fibre composite material was at maximum when compared with different composites analyzed, which further demonstrates the material's crashworthiness. It was estimated that for ensuring safety of the passenger during a crash at 35 mph (15.5 m/s) only 4.27 kg of chopped carbon fibre will be required at particular positions in the vehicle [65]. CRFP composites offer high strength when compared with several structural materials having comparatively low densities [66].

In recent times, carbon composites are used by several automakers for the manufacturing of car roofs, floor panels, composite passenger cells, cabin frames, transmission tunnels, roof pillars, front and rear bumpers and rear floors. Examinations reveal that CFRP could be a potential substitute for steel body in white (BIW) unibody [67], however for wheel rims, bumper supports, car roofs, door modules, air intake manifold systems and trunk lids, etc. GFRP must be considered the best option for both mechanical characteristics as well as cost constraints. However, the lack of energy efficient and high-speed production, inadequate designing tools, higher material price and issues concerning recyclability and reparability has immensely reserved their application in the automobile sector [68].

In a research by P Kumar [69] on automobile bumpers considering three dissimilar designs namely primary design of bumper with steel, with the foam addition and with the honeycomb supplement, demonstrates a superior strength to weight ratio when compared with steel. In addition to manufacturing of bumper, an extensive range of other potential application in automobiles is offered by the composite materials such as suspension, body panels, braking system, and steering mechanism. Bambach in his study recommended a novel methodology for reinforcement of roof structure of vehicles by connecting carbon fibres to the surface of steel. The carbon fibres bonded to the roof of a passenger car increases the strength to weight ratio twice [70]. Presently, high end vehicles for sports utilize huge quantities of CFRP components which are generated around 500 units annually [71]. CFRP has the characteristic to be shaped in any form that includes intricate and larger orientation. Its amenability permits to achieve much stylish appearance on the exterior [71]. Hyoung and team established that the automotive lower arm made of composite shows two folds more stiffness and buckling strength on comparison with lower arm made up of traditional steel and also a reduction of 50% weight [72].

Wang et.al [73] in the year 2018 examined structures of CFRP composite sandwich treated at elevated temperatures with core as aluminium honeycomb structures. The study focused on the impacts of thickness of core material and density on composite sandwich honeycomb structure characteristics. Three-point bending tests were used to determine stiffness and bending strength while panel board peeling experiments were performed to know the strength of panel peeling. The strength of material could be enhanced by augmenting the thickness or density. On the other hand optimal density or values of thickness increases the bending stiffness. Additionally, change of stiffness is higher than the strength due to alteration of thickness or density. Density of 101 kg/m^3 and 20 mm thickness of the aluminium honeycomb core showed higher strength, stiffness with decrement in mass. Refining interfacial characteristics between the core material and panel board could increase the force of panel peeling.

Ghassemieh [13] studied and presented detailed data of materials employed in vehicle manufacturing. The author debated the characteristics of every material to be recognized in automotive sector. In the article she briefly reviewed various material alloys, magnesium, steel and composites. The author considered the possible utilization of these materials in numerous vehicle components. Additional group of materials considered were natural and synthetic fibers as reinforcement with composites and plastics. On the other hand, synthetics are widely used in comparison to conventional composites in automobile sector owing to its environmental concerns. Production Cost is one of the major limitations for composite materials where total cost of the vehicle is a concern factor. A review of the manufacturing and generation of various automobile components was also demonstrated by the author.

Petersson et.al. [74] In the year 2013 established numerous novel approaches of generating carbon composite materials accessible for the design and planning of production equipment of automobile industry by introducing a material design and model which associates flexibility, with comparatively lesser cost and higher functionality thereby decreasing the weight to around 60%. Carbon composite materials are the only substitutes showing outstanding material properties. The author showed that it is conceivable by material change to attain both improved performance and light automobile production equipment simultaneously, which further results in elevated productivity.

In 2014 Kim and other researchers [75] designed a lower arm for automobile component using carbon-epoxy composite. It was noted that buckling strength and stiffness was twice compared to the conventional metal while the weight of the lower arm was half. Figure 10 demonstrates the boundary conditions and load cases of the lower arm analyses using carbon-epoxy composite. While the same analysis results are shown with conventional steel material in figure 11.

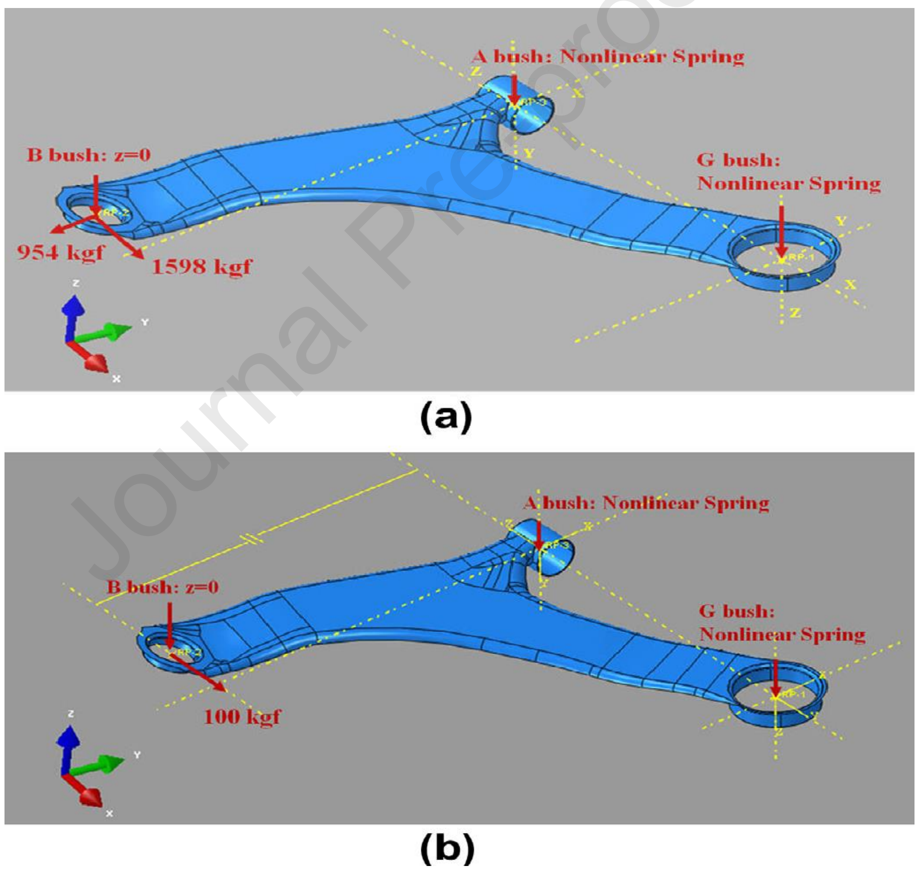

Figure 10: Boundary conditions and load cases of lower arm analyses using composite material: (a) Buckling. (b) Stiffness [75] analysis.

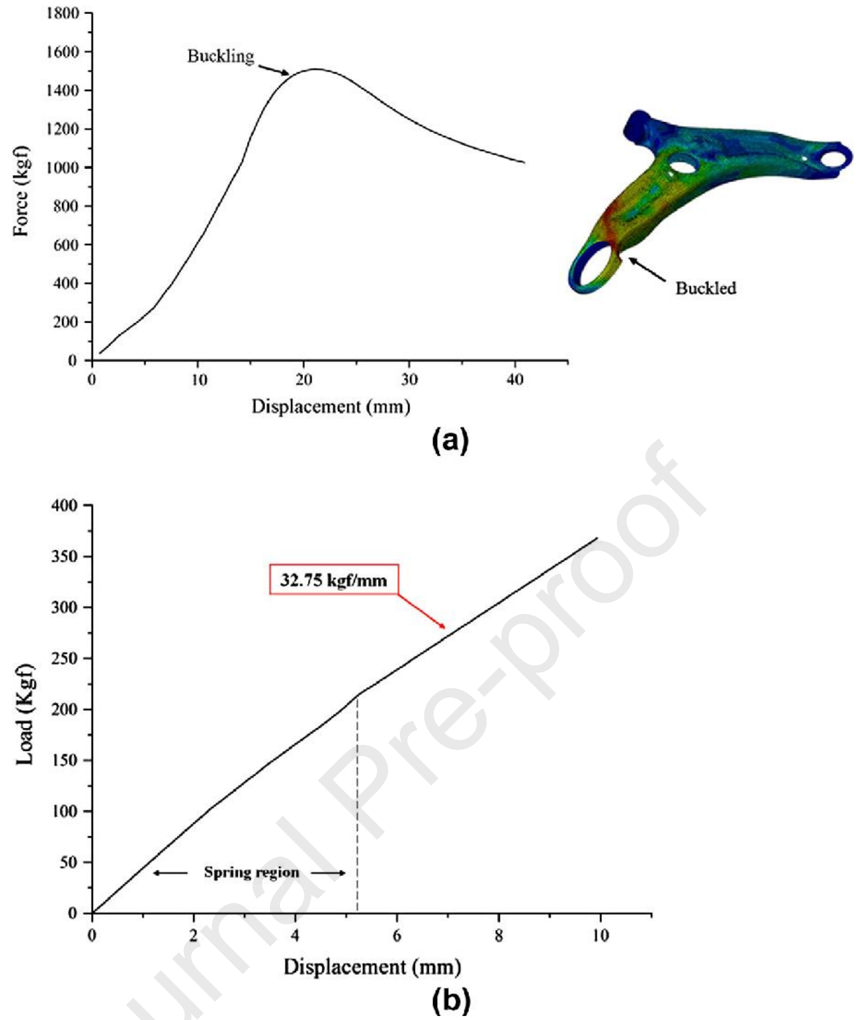

Figure 11: Lower arm model using conventional steel: (a) Buckling (b) Stiffness analysis [75].

Do-Hyoung Kim et.al [76] examined different designs of glass/carbon mat thermoplastic (GCMT) and computed different mechanical characteristics. The µGA algorithm along with impact simulation was employed for the optimal designing of the GCMT bumper beam for all material. Optimum design selection of the quantity of carbon fiber and performance of impact is according to the weight. Further the manufacturing of the real bumper beam is carried out by using final design and its measurement of its impact performance. It was observed that the optimally planned GCMT bumper beam demonstrates 33% lower weight on comparison with traditional bumper beam alongside showing better impact strength.

The application of carbon fibre reinforced plastic material delivers the finest prospective to appreciate concepts of lightweight. Carbon fibre reinforced plastic shows exceptional specific strength, fatigue characteristics and stiffness when compared with regularly utilized metals. In automobile sector, the benefits of carbon fibre reinforced plastic are in weight reduction, integration of parts and its reduction, durability, crash worthiness, toughness plus engaging aesthetics.

Table 1: Summary table of the fiber reinforced composites for automobiles.

Authors	Application	Material/s	Results	References
P.Kumar et.al. (2014)	Automobile bumpers	Steel with foam addition and honeycomb supplement	Superior strength to weight ratio	[69]
Bambach et.al. (2014)	Roof structure	Connecting carbon fibers to steel	Two times increment in strength to weight ratio	[70]
Hyoung et.al. (2014)	Lower arm	Carbon composite	Two times increment in stiffness and buckling strength	[72]
Petersson et.al (2013)	Automobile component	Carbon composite	60% lesser weight	[74]
Kim et.al. (2014)	Lower arm	Carbon-epoxy composite	Two times increment in stiffness and buckling strength	[75]
Do-Hyoung Kim et.al. (2015)	Bump beam	Glass/carbon mat thermoplastic (GCMT)	33% lower weight and better impact strength	[76]

4.2 Metal Matrix Composites

One of the widely employed matrix for metal matrix composites (MMC) is aluminium which can normally be reinforced withAl_2O_3, SiC, B, C and B_4C. For the manufacturing of composite materials based upon aluminium, methods such as centrifugal casting, powder metallurgy and stir casting are widely used. For producing connecting rod for the automotive application, aluminium oxide reinforced aluminium is extensively used. In order to make wing panels of aircraft, application of aluminium reinforced with SiC whiskers is used. Graphite fibers in aluminium matrix are utilized for helicopter and missile. Magnesium matrix along with graphite fibers are used for structures of satellite and space. Numerous conventional auto components such as brake drum, connecting rod and piston stem are replaced with composite material based on metal matrix [2].

Composite materials based on titanium are reinforced with titanium carbides and further fabricated by technique of powder metallurgy. Huge applications of titanium alloys exist where there is demand for components with higher strength. Titanium-based composite materials are applied for making internal combustion components and valve stem. Composite materials based on nickel have higher mechanical characteristics than conventional alloys. Nickel alloy is produced by methodology of powder metallurgy and typically employed in the manufacturing of turbine blades [77]. Better mechanical characteristics and density are displayed by magnesium alloys which makes it a potential candidate for application as a composite material. Silicon carbide along with magnesium is applied for making novel material through techniques of stir casting and squeeze casting [77].

Copper based composite materials show good mechanical characteristics and usually are fabricated by the powder metallurgy scheme. The key benefit of this method is the achievement of homogenous dispersion of smaller particles. Graphite fibers in copper matrix are used in electrical and bearing products [77]. The requirement of advanced nanocomposite material is elevating in the production sector owing to its light weight and better mechanical characteristics. In present times, polymer nanocomposite materials are extensively used. Many nanomaterials under examination are nanofibers, nanoparticles, nanoplatelets, nanowires and nanotubes. Electronic sector also utilizes nanocomposites for storing data and communication purposes. The prime benefit of nanocomposites over micro composites is its capacity to enhance properties and deliver multifunctional operation.

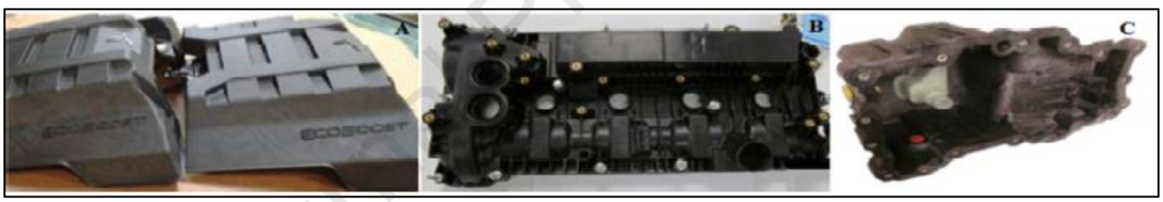

Figure 12: Different automobile components manufactured from metal matrix composites A) Engine covers, (B) cam covers and (C) oil pan [78].

4.3 Aluminium based Hybrid Composites

Aluminium matrix composites (AMCs) are widely employed in aerospace, aviation and automobile industries due to their superior tribological and mechanical characteristics [79-81]. The continuous urge for durable, lightweight and high performing equipment is fulfilled by the application of AMCs [82-84]. AMCs deliver improved characteristics in comparison with traditional alloys. Government’s norms for emission and increased costs of fuel had driven the automobile industries to design efficient and lighter vehicles [85]. Automotive components produced from lightweight composites demonstrate a momentous decrease in consumption of fuel [86]. Figure 13shows the diverse components of automobile produced by aluminium-based hybrid composites of AMCs.

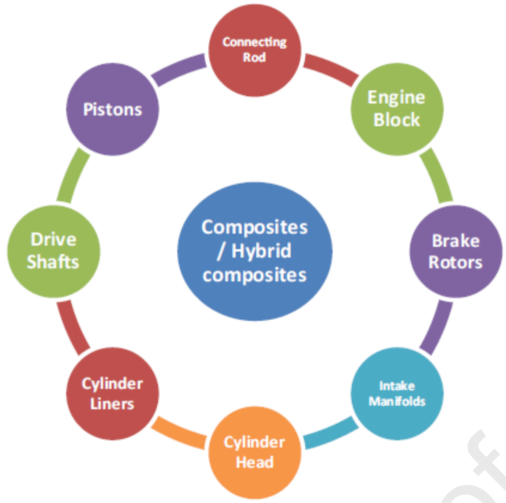

Figure 13: Automotive parts which are commonly developed from composites/hybrid composites [87].

Ceramics particulate reinforced aluminium matrix composites demonstrate huge potential for replacing heavier ferrous material in the automobile industry to decrease the weight of vehicle along with enhancement of efficiency plus good control on emission. Uses of lightweight composite can reduce the total weight of vehicle by 15-40% [88]. Aluminium alloys of diverse groups are characterized by the combination of Al with numerous alloying element in varying amounts [89]. The novel applications of aluminium matrix composites in various areas are presented in Figure 14.

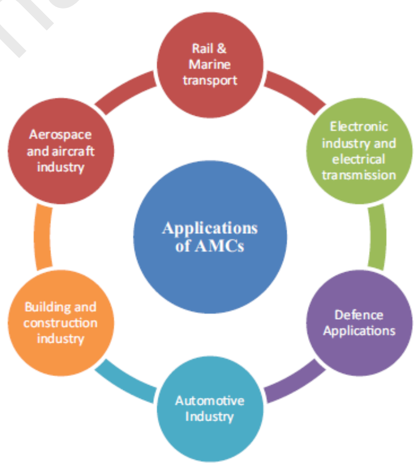

Figure 14: Novel applications of AMCs in different sectors [87].

In order to improve the tribological and mechanical characteristics of AMCs, the frequently used reinforcements are alumina (Al_2O_3) [90], silicon carbide (SiC) [91, 92], boron carbide (B_4C) [93], titanium carbide (TiC) [94], graphite (Gr) [95], and carbon nanotubes (CNTs) [96]. Greater stiffness and strength, enhanced characteristics at elevated temperatures, lightweight, increased electrical conductivity, controlled coefficient of thermal expansion, enhanced abrasion and wear resistance are the advantages of composite materials

consisting of aluminium matrices when compared with traditional aluminium alloys [97, 98].
Chandrasekar et al. [99] investigated a number of parameters that influence the mechanical characteristics of fibre metal laminates. Though, soft Al alloy characteristics are improved by adding reinforcement but certain restrictions are also observed [100]. Observations demonstrate that upon addition of particles of ceramic, it improves the elastic modulus and density of resulting composites [101]. This is due to greater density and elastic modulus of particles of ceramic when compared with aluminium alloy. As a result, some properties of succeeding composites, such as toughness, machinability, and brittleness, are deficient [102, 103].
Numerous researches were engrossed upon evolving hybrid aluminium matrix composites (HAMCs) with diverse reinforcement materials [104]. Researchers established improved or similar characteristics of hybrid composites when compared with single reinforced composites at a cheaper rate [105, 106]. This attracts attention towards HAMCs as several authors predicted the high perspective of generating cheaper and high performing hybrid aluminium based composites. The application of double reinforcement, elevated the mechanical characteristics up to certain degree of reinforcement wt. %, which later started showing negative results [107]. In 2013 Viswanatha and team [108] inspected the morphology and mechanical characteristics of A356 AMCs reinforced with SiC/Gr reinforcement. The technique utilized for the fabrication of composites was liquid metallurgy. On increment in the SiC wt. % reinforcement, substantial development in tensile strength and hardness was perceived. Constant dispersion of Gr and SiC particles were seen. Reddy et al. [109] presented a novel group of hybrid composites consisting of FA and E-glass short fibers. Microstructural examination exposed homogeneous dispersion of particles of reinforcement and around 32% increment in tensile strength and two times increase in hardness was observed.

Yilmaz and Buytoz [110] studied Al hybrid composites having 10% Al_2O_3 and variable wt. % of particles of graphite. The outcomes revealed that on increasing the percentage of graphite by more than 1%, there is a decrement in composite hardness. Abdul Saheb [111] designed Al-based hybrid composites consisting graphite particles at 5, 10, 15, 20, 25, and 30 wt. % of SiC and 2, 4, 6, 8, and 10 wt. % of graphite. Results demonstrate that the hardness of composite increases on increasing the percentage of particles of ceramic. The peak hardness was achieved at 25 wt.% of SiC and 4wt% of Gr. The SEM images of a study of hybrid aluminium composites at various reinforcement wt. % is are shown in the figure 15 [112].

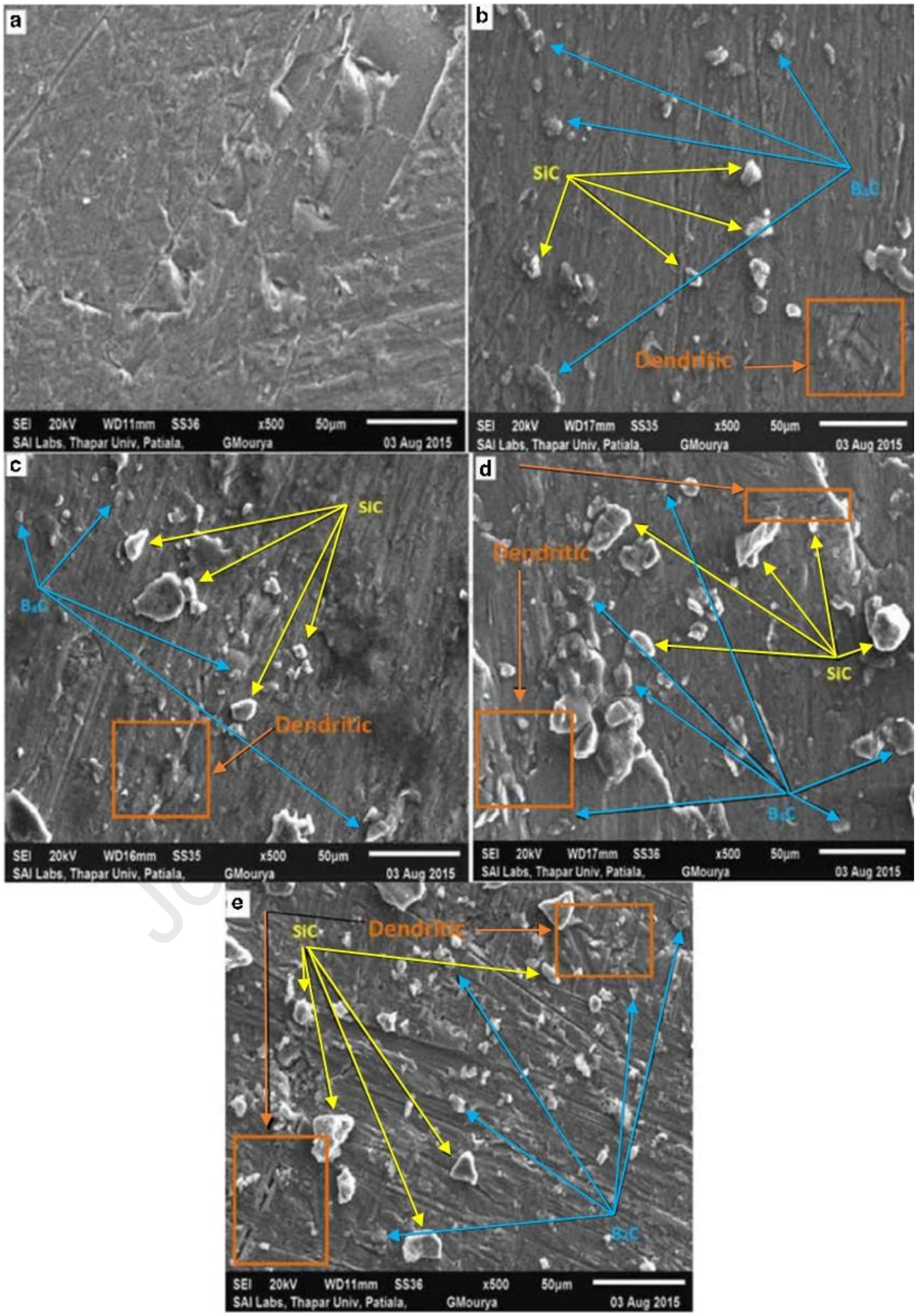

Figure 15: SEM images (a) AA6082- (0% $SiC+B_4C$), (b) AA6082- (5% $SiC+B_4C$), (c) AA6082- (10% $SiC+B_4C$), (d) AA6082- (15%$SiC+B_4C$), and AA6082- (20% $SiC+B_4C$) [112].

Xie et al. [113] examined the viability of a fresh group of hybrid composites based on Al by integrating reinforcement of bimodal sized glass. To overcome the restrictions of fine metallic glasses, application of bimodal sized reinforcement was done. They achieved a realistic equilibrium between ductility and strength. Decrement in ductility was detected but overall strength of fabricated composites was increased. In the year 2020 Kumar et al. [114] studied hybrid composites of A356 along with FA and RM by the method of friction stir casting. The tribological and mechanical characteristics of the generated composites were examined. Superior ductility and wear resistance was observed in the hybrid composites. Kumar et al. [115] designed hybrid composites of Al-SiC/Gr. Extreme hardness was achieved at around 6 wt. % of SiC and 2wt % of Gr. It was observed that on increasing the quantity of graphite further there is a decrease in strength.

Hybrid aluminium matrix composites are widely used in numerous applications and have already displayed their capability in bridging current requirements of materials for advanced engineering purposes. Morphologies of hybrid composites generated at various wt. % of particles of reinforcement are mostly constant with homogeneous distribution. Hybrid composite strength could be improved by adding hard particles of reinforcement as well. It was observed that ceramic particles like aluminium nitride, silicon carbide, boron carbide and alumina would considerably increase the mechanical properties of such composites.

Table 2: Summary table of Aluminium hybrid composites for automobile applications.

Authors	Matrix	Reinforcement	Processing route	Results	References
Vishwanatha et.al. (2013)	A356	SiC/Gr	Liquid metallurgy	Increased tensile strength and hardness	[108]
Reddy et.al. (2014)	Al7075	FA/E-glass short fibers	Stir casting	32% increment in tensile strength and two fold increment in hardness	[109]
Yilmaz & Buytoz (2001)	Al alloy	Al_2O_3/Gr	Stir casting	Increased hardness	[110]
Abdul Saheb (2011)	LM25	SiC/Gr	Stir casting	Increased hardness	[111]
Xie et.al. (2020)	Al alloy	Bimodal sized glass		Increased ductility and wear resistance	[113]
Kumar et.al. (2020)	A356	FA & RM fibers	Stir casting	Increased ductility and wear resistance	[114]
Kumar et.al. (2020)	AA6063	SiC/TiC	Stir casting	Increased hardness	[115]

4.4 Sustainable and Bio-Composites

Natural fibers could be impregnated with both thermosetting as well as thermoplastic matrix, appearing as an effective substitute to glass/carbon fibres and also aluminium [116], which in its place demands higher electricity for production. Nevertheless they are widely employed in current research studies for showing higher structural performances. For the uninterrupted novelty intended towards sustainability, the current industrial research anticipates resolutions that permit greater technological functioning, focused particularly towards the environment. The cheaper material and the criteria of being produced by most of the developing countries, many of such fibres are raising attention towards bio-materials which are progressively applied largely in automotive and aerospace sectors [8]. Natural Fibre Composites or bio-composites are not a novel discovery, since they were observed and employed in industries from the start of the 20th century [117].Most of the bio-composite materials utilize recycled materials [118] or fibres obtained from rapid growing plants like hemp (Cannabis sativa) [119] or flax (Linum usitatissimum) [120]. Bio-composites serve various kinds of applications in automobile sector such as [121]: e-bikes, body-shell of micro-cars, frame structural components and automobile interiors.

In recent times, the application of flax fibres as reinforcement has increased acceptance because of an increase in demand for developing sustainable materials [122]. Application of flax is not limited as a unidirectional reinforcing fiber [123] but also as knitted reinforcing phase [124]. It is observed that woven composites show higher complex micro-mechanical characteristics than unidirectional fiber reinforced composites [125]. Flax fibers are lately utilized in natural composites (polypropylene, polylactic acid) or epoxy-based resins [126]. Composites made of flax fibres comprising thermosetting, thermoplastic and biodegradable matrix demonstrate better mechanical characteristics [127, 128]. Various scholars inspected bio-composites made from various natural fibers like jute [129], hemp [130–133] and kenaf [134, 135] or hybrid bio-composites namely jute/rubber [136] and hemp/straw [137]. One more hybridization like carbon/hemp hybrid bio-composites was illustrated [138]. Several bio-based composite examples are debated [139] for a PLA/hemp composite that is totally recyclable. It is also essential to note that bio-composites could be contrived from regular and bio based epoxy resins [140].
An economic, prospective and sustainable solution for sound and heat insulation in automotive sector could be the use of waste and virgin wool fibres. Wool is considered as an animal protein fibre. It is normally odour resistant, flame retardant, soft, better aesthetic look, and thermally/acoustically insulating. Moreover, it is capable of absorbing water (up to 30% of its weight without feeling wet) for potential application to control the humidity inside the car [141]. SEM images of wool fiber with various different magnification factor are represented in Figure 16.

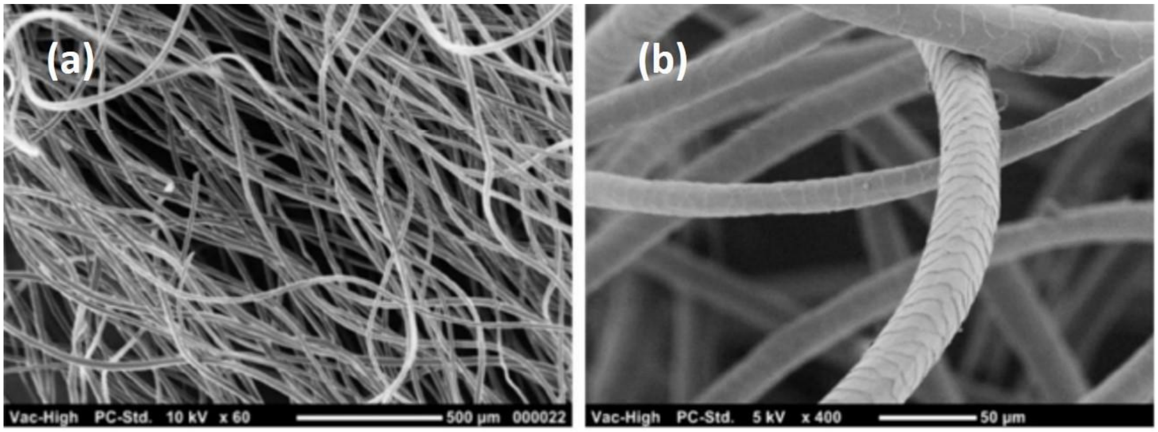

Figure 16: Scanning electron microscopy (SEM) images of (a) low magnification of wool fibres; and (b) high magnification of wool fibres [141].

Apparently, bio-composites are highly user friendly and intensely adaptable to the market. This explains both the higher flexibility of the operational procedures for completion of composite shells, plus achievement of higher performance with advanced bio- materials concerning both mechanical characteristics and appealing product [8].

Table 3: Current applications of sustainable biocomposites in automotive industry [142].

Company	Model	Biofiber	Matrix	Applications
Audi	A2, A3, A4, A6, A8, Roadster, Coupe, Q7	Wood Fiber, Flax, Sisal	PP, Epoxy PUR	Seat backs, side and back door panels, boot lining, hat rack, spare tire lining
BMW	3, 5 and 7 series	Kenaf, Flax, Hemp,wood fiber	PP	Door trim panels, headliner panel, boot lining, seat backs, noise insulation panels, dashboard
Citroen	C5	Wood Fiber, Flax	Epoxy	Interior door paneling
Fiat	Punto, Brava, Marea, Alfa Romeo 146, 156	Flax, Sisal, Hemp, Cotton, Coconut fiber	PP	Door cladding, seatback linings, and floor panels, Seat bottoms, back cushions and head restraints

Ford Motors	Ford Flex, Ford Focus BEV, Freestar	Wood fiber, Wheat Straw, Coconut Coir Soy, Rice Straw	PP, PUR	Interior storage bins, load floor, foam seating, headrests, headliner
General Motors	Cadillac DeVille, Chevrolet Impala, GMC Envoy, Trail Blazer, Terrian, Opel Vectra	Wood, Kenaf, Flax, Cotton	PP, Polyester	Seatbacks, trim, rear shelf, cargo floor, door panels, package trays, acoustic insulator, ceiling liner
Honda	Pilot	Wood Fiber		Floor area parts
Land Rover	2000, others	Kenaf	PP	Insulation, rear storage shelf/panel Door panels, seat backs
Mercedes -Benz	A-Class, C-Class, E-Class, M-Class, R-Class S–Class	Abaca/banana, hemp, flax, sisal, Jute	PUR, PP, Epoxy	Door Panels, seat cushion, head restraint, underbody panels, seatbacks, spare tire cover, engine and transmission cover
Mitsubishi	Concept Car	Bamboo	PBS	Interior Components
Renault	Clio, Twingo	Jute, Coir	PP, PUR	Rear parcel shelf
Toyota	Prius, Raum	Kenaf, Bamboo, Corn, Starch	PET, Sorona EP, PP, PLA	Luggage-compartment, speakers, floor mats, Instrument-panel, air-conditioning vent, spare tire cover, shelves
Volvo	C70, V70	Flax	Polyester	Seat padding, natural foams

PP—Polypropylene, PUR—Polyurethane, PLA—Polylactic acid, PBS—Polybutylene succinate, PET—Polyethylene terephthalate, Sorona® EP—Poly trimethylene terephthalate

5. Manufacturing techniques for FRPs

5.1 Resin Transfer Molding (RTM)

Resin transfer molding abbreviated as RTM is regarded as the utmost suitable technique for the mass production of intricate and complex geometries where size of composite components varies from small to medium in the automobile industry. Current progress in the traditional method of RTM results in the expansion of sustainable possibilities in the automotive industry to withdraw this technical skill [143-145]. Less capital investment, reduced cost of operations and lower emissions owing to closed mold methodology are the benefits delivered by the RTM method. The achieved composite components are prepared as mold and no additional dealing is required. Resultant composites exhibit better surface finish on each side as well as a higher fraction volume percentage could be accomplished [144]. Though, due to the resin reinforcement restrictions, RTM is narrowed down to small and medium sized parts. The limitations are due to the time of flow and void formation in intricate and large components. For improving the efficiency of manufacturing plus the physical functioning of components, it is mandatory to evade inclusion of void [146]. Industries as well as research institutions are dwelling to transform the RTM working principle through improvement in impregnation schemes and mechanizing the complete arrangement for higher volumes of production [147-150].Figure 17 shows the various resin transfer molding (RTM) methods (a) Low-pressure RTM (b) High-pressure RTM (c) Compression RTM [151].

Numerous industrial usage requires RTM employment such as application of thermosets, and epoxies for prime molding resin [152]. The rising progress of composites in automobile sector has increased alarms for upgradation of raw materials. Current developments in the growth of ultra-fast-curing epoxies has boosted the practice of RTM through reduction of curing time to 30-120 s for different automobile equipment [153]. Also, thermoplastics have extended educational and manufacturing responsiveness owing to their advantage of recyclability [154-157].

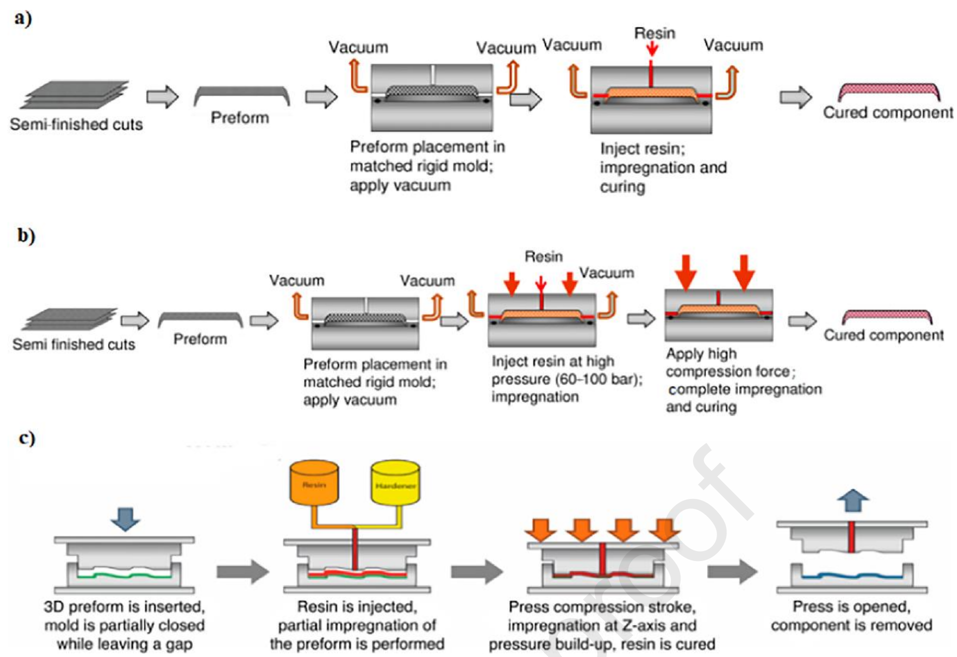

Figure 17: Various resin transfer molding (RTM) methods (a) Low-pressure RTM (b) High-pressure RTM (c) Compression RTM [151].

High-pressure RTM can be described as an advanced form of typical RTM for decreasing the time of impregnation through high pressure (around 150 bar), which results in the decrease of cycle time of RTM for major automobile equipment to < 10 min. The utilization of higher pressures permits greater fiber content to approx. 70%. The major limitations of high-pressure RTM are expensive tools and probable shifting of dry fibers that could result in probable reduction of the component's mechanical performance [158-161]. The introduction of pressure-controlled RTM was to cope up with the difficulties of high cavity pressure in the process of compression RTM while injection. It makes use of implanted pressure device to dynamically govern the values of pressure while cavity filling takes place with an adjustable mold gap height [162].

5.2 Vacuum-Assisted Resin Infusion (VARI)

Vacuum-assisted resin infusion or VARI technique is analogous to the process of RTM regarding its form, with an exception of replacement of its upper mold with a soft material such as plastic films that can support the vacuum, this results in the reduction of cost of tooling when compared with RTM [163, 164]. In this method dry fabric sheets are arranged into mold and enclosed with a vacuum bag with the help of sealing tapes, and further the resin is permeated into dry fibers. A high permeable channel is positioned onto the stacked sheet in order to yield suitable flow of resin [165, 166]. Since the process of RTM is complicated and is not economical for huge production therefore VARI method is opted and found a more promising and cheaper option with better surface finish and composite quality when applied in production of huge structures like turbine blades, hull of a ship and automobile components [167, 168]. The volume fraction of fiber via method of VARI is regarded in close proximity to autoclavecured prepregs due to its lesser consolidation pressure and compressibility features of reinforcement of fiber [163].

Formation of voids and dry spots could occur due to the imperfect resin infusion and leakage sensitivity in VARI. Additional limitation of VARI is the non-homogeneous laminate thickness that could result in dissimilarities in volume fraction of fiber because of variable pressure of compaction through laminate [169]. Current progresses in VARI such as reduction of time of curing cycle by employing fast curing epoxy, improving variations of volume fraction of fibers in laminate, refining injection approach for bigger components, and dropping cases of formation of voids, have amplified the process of infusion. Zhang et al. [170] studied and decreased the VARI cycle time through quick curing epoxy resin and further molded and performed fiber preheating to cut the filling time of mold.

In the year 2017, Yalcinkaya et al. [171] improved the VARI technique by utilizing external pressure and mold preheating. The external pressure setup in the vacuum bag was around 138 kPa for different time periods subsequent post-filling to improve the laminate's mechanical characteristics, however upholding presence of void below 1%. The applied pressure over different time periods demonstrates that pressure must be employed at the appropriate time. At 5 min and 10 min, application of 138 kPa pressure displays improved stiffness, flexural strength and fiber content. VARI setup with external pressure and preheating of the mold is shown in figure 18.

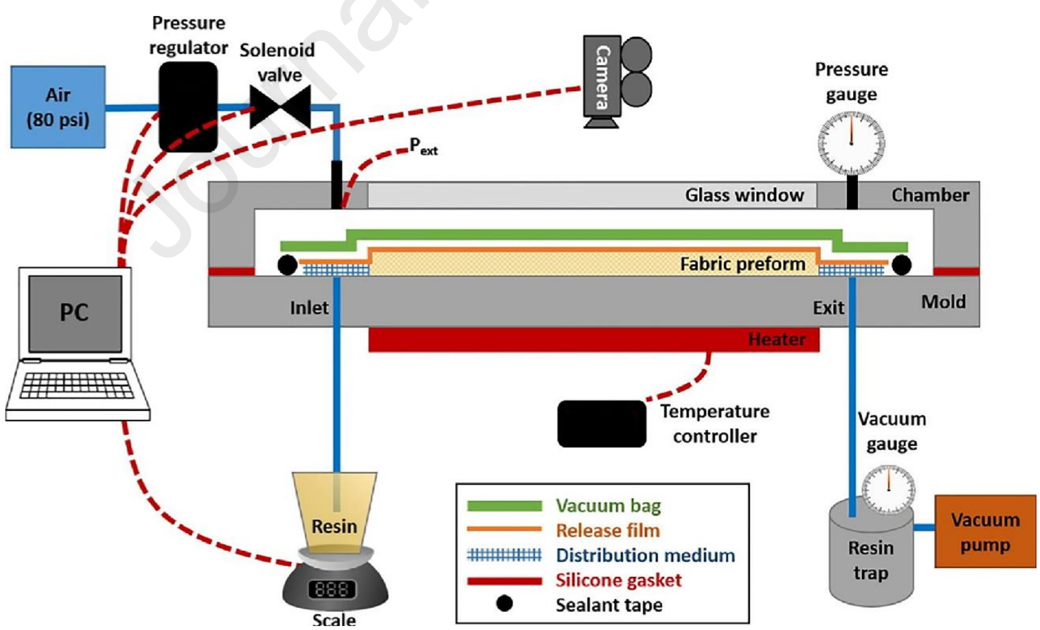

Figure 18: Modified VARI setup with external pressure and preheating of the mold [151, 171].

VARI is regarded as the major cost reducing technique concerning the cost of tooling and equipment in comparison with other methodologies like RTM. Consequently by the application of this method it would be beneficial to produce large components in order to prevent huge costs of molding. VARI does not include the expenses incurred by heavyweight presses, costly resin injection systems and upper molds. The expense of maintenance and energy is also less in comparison with RTM method due to less number of equipment in process. The mechanical characteristics of components achieved from VARI are analogous to other techniques used for manufacturing of composites [172]. However, VARI involves longer cycle time when compared with the compression RTM method.

5.3 Compression Molding

The most widely applied technique for automotive manufacturing is compression molding which is utilized for applications like structural and non-structural purposes. The process consists of the transformation of a mat preform i.e. a mixture of fiber and resin into the desired product by employing corresponding metal molds [173-175]. Figure 19 represents the representative diagram of the key components of a typical compression press [174].

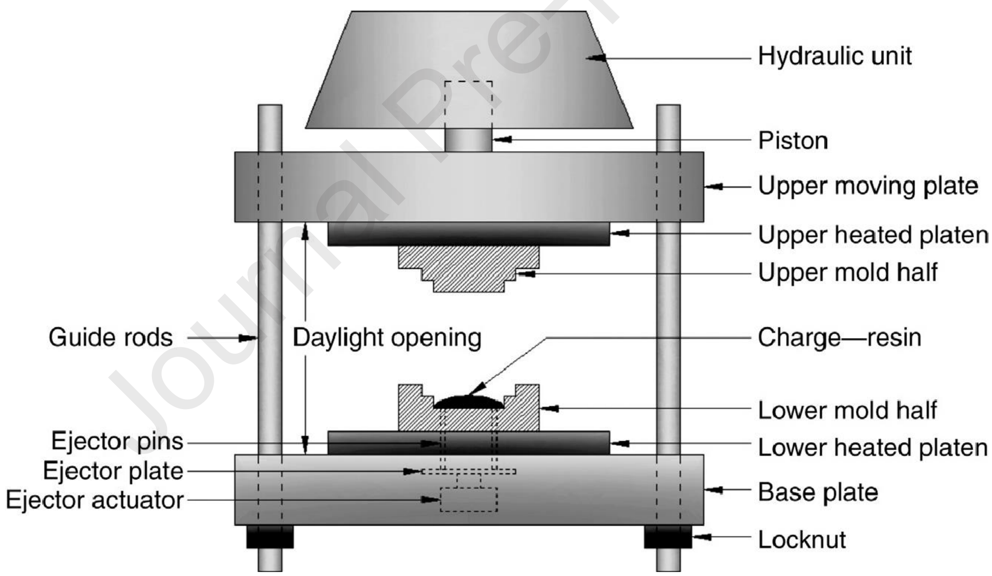

Figure 19: Representative diagram of a typical compression press [174].

SMCs i.e. sheet molding compounds defined as sheets which are generated through thermoset prepregs and chopped fiber treated by compression or injection molding depending upon the design complexity, strength and size. The cost efficient molding and simplicity of automobile components is an outcome of the outstanding flow characteristics of SMCs. SMC is treated in heated molds of steel, typically under pressures below 100 bar with the utilization of hydraulic presses. Fiber content and molded part shape of the yielded component is the result of the amount of pressure applied. Components such as roofs, doors, trunk lids, support and spoilers of automobiles are manufactured by SMCs [176]. The model of Mercedes-Benz Actros consists of around 30 parts made of SMC whereas in the case of Renault Espace model it has a complete external body panel composed of SMCs

resulting in extensive operations [177]. The raw material for bulk molding components (BMC) is different from SMC as it includes chopped flakes and chips of prepreg, unlike an unbroken SMC sheet [178].
Glass fiber mat thermoplastic or GMT is a completely computerized technique for high volume manufacturing of composite components. It consists of chopped, continuous and unidirectional mats of fiber having nearly 40% fiber content in a matrix of thermoplastic. Blanks of GMT are structured, heated, and transported to mold for pressing, with the help of a high-speed hydraulic press. The molded component is detached, and a secondary process like milling, cutting, or drilling is executed if necessary. The utilization of higher pressures of around 5–30 MPa are done which is variable and depends upon the usage. GMT applications in spare wheel wells in different models of BMW, Audi, Volkswagen and Mercedes are studied [179].

Ease of process of manufacturing makes compression molding beneficial along with quick cycle time, capacity to yield intricate structures, and cost efficiency. Though, there is demand for huge initial investment considering costly presses, molds and material planning systems. The components produced from compression molding show mechanical characteristics inferior to RTM process, though they are similar to VARI method. Current researches were carried out for improving formerly charged materials through quick curing epoxies, decrease in complete cycle time plus growth of fresh charged materials. Long-fiber-reinforced thermoplastics or LFTs as well as prepreg compression molding (PCM) were in recent times labeled as most favorable charged materials in order to attain components with higher strength via compression molding [180].

Cost efficiency of the process of compression molding relies on factors like equipment, material type, automation level and cost of energy. The raw material employed in presses like bulk molding compounds (BMC), SMC, GMT, prepreg, or LFT affects the initial capital investment. Looking into requirements of pressure in the process of compression molding, cost of energy, press and robots could be computed from study done by Baskaran et al. [159].

5.4 Reaction Injection Molding (RIM)

Reaction injection molding (RIM) is described as a liquid injection molding technique. It is regarded as a low-pressure method which permits two responsive components to interact and produce a polymer, which further are stoichiometrically blended and injected in the cavity of mold [181]. Usually, two constituent (isocyanate and polyol) based thermoset resin of polyurethane is employed for the molding of structural automobile components [182].

The fiber reinforcement in RIM exhibits reinforced and structural RIM. Structural RIM is analogous to RTM in which resin is injected in the cavity of mold that has previously adapted a uniform fiber preform layout. In reinforced RIM, injection of chopped fibers is done in the cavity of mold using one resin component. The RIM, structural RIM, and also reinforced RTM is demonstrated in Fig. [183, 151].Figure 20 shows the various reaction injection molding (RIM) methods (a) RIM (no reinforcement) (b) Reinforced RIM, (c)

Structural RIM.

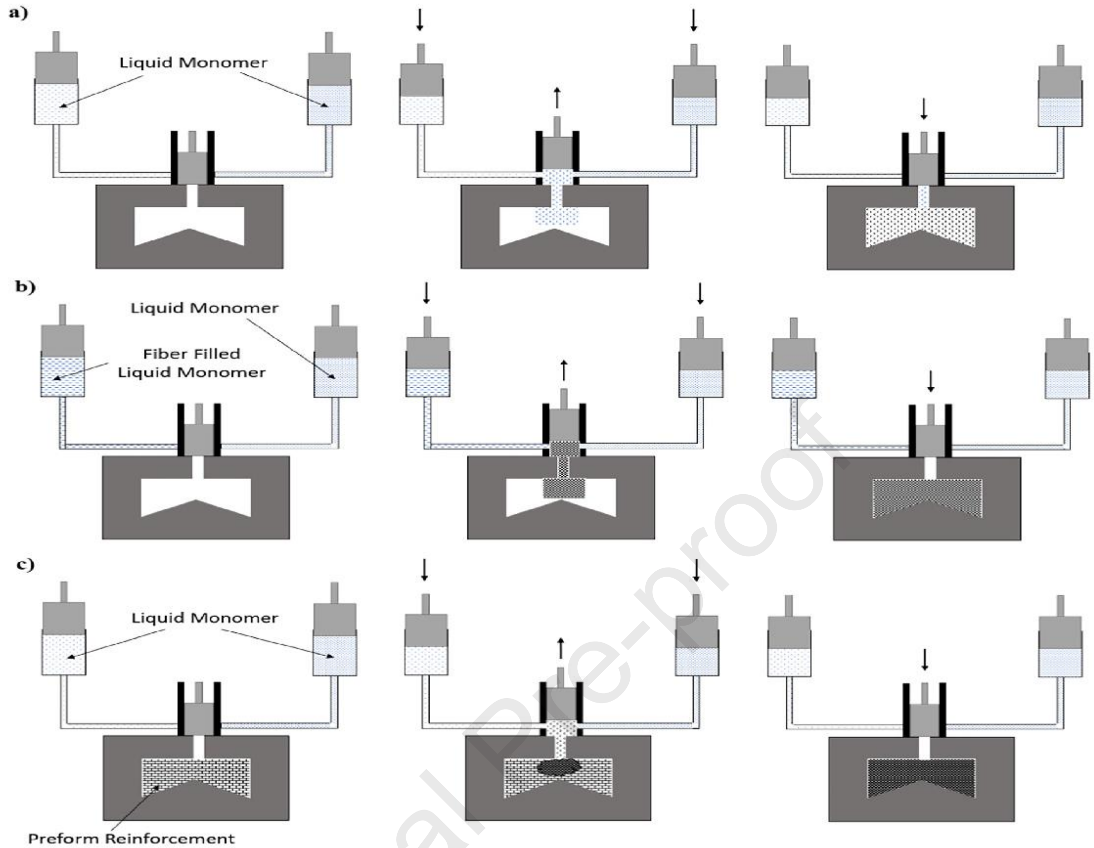

Figure 20: Various reaction injection molding (RIM) methods (a) RIM (no reinforcement) (b) Reinforced RIM, (c) Structural RIM [183, 151].

Presses working on low-pressure require less consumption of power, therefore resulting in lower cost for operations when compared with RTM method. The structural RIM time cycle is lesser when compared with conventional RTM techniques and is studied to be less than 2 minutes for larger automobile bumpers [184]. Structural RIM is appropriate for larger reinforcement of fiber of around 50–60% [67]. For generating reinforced foamed plastic components reinforced RIM is a good option. The glass fibers or chopped carbon reinforcement could enhance the physical and mechanical foam characteristics [185].

Latest developments in RIM are concentrated upon the RIM technique structure optimization and double component resins of thermoset. Additionally intricate design of mold for numerous applications requires developments in flowability of alternative resins and polyurethane thermoset resin [186, 187]. Consistency of structural RIM by utilizing numerical and experimental methods is tested in various researches [67]. The prime challenge of employing structural RIM is generation of superior class that demands post-mold paint curing for external components. Therefore when there is a need for superior quality of finish, structural RIM is applied. Structural RIM is used in the automobile industries for producing seatback frames for vehicle models like Chevrolet Corvette [188].

Several different structural applications such as BIW are studied in the literature [67].

6. Metal Matrix Composite Fabrication Techniques

The different methods for generating metal matrix composites are discussed in this section.

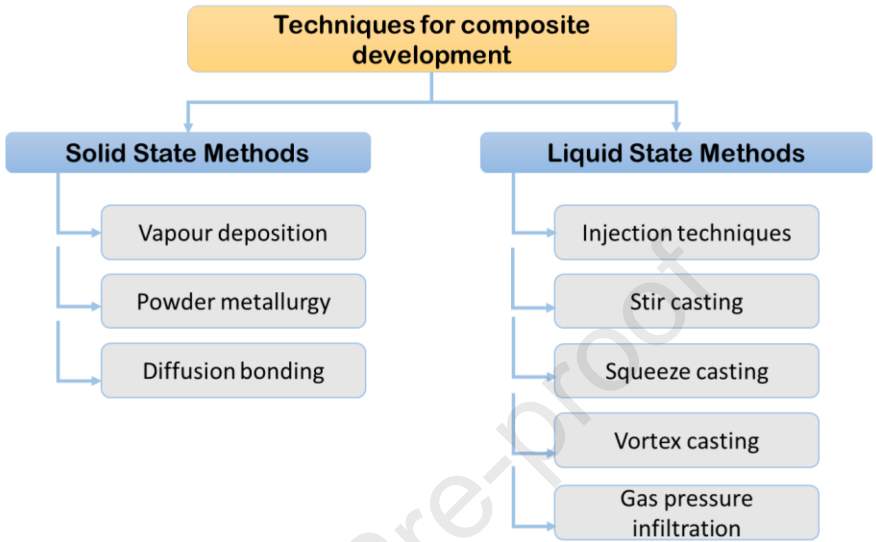

Figure 21: Techniques for development of composites.

6.1 Centrifugal Casting

In centrifugal casting methodology, in a fast rotating mold the molten metal is transferred for generating castings. The molten metal is forced out away from the center via centrifugal force into action by substantial pressures towards the face of the mold. The process consists of horizontal axis and vertical axis mechanism. In case of vertical centrifugal casting, the mold rotates about its axis whereas the metal is discharged in it. Constant pressure of the centrifugal force acts on the metal as it gets solidified. While in horizontal centrifugal machine the metal is scattered throughout the mold length while pouring and traveling from the horizontal axis, although spinning mold is static. In one case of horizontal centrifugal casting, there is a static ladle but mold is mobile. This arrangement is shown in Figure 22. The technique is economical and simple in processing. Better flexibility in functioning is achieved through castings made with this approach. Centrifugal casting method is employed for producing fine-grain structure and components having greater mechanical strength. The major limitation of this method is its inability to cast alloys. The method is utilized for fabricating parts such as bearings, brake drums, pistons, liners, vessel body, valve stems and sleeves.

The composites based on aluminium having flexible characteristics are reinforced by particles of AlB_2. Composites showing variable characteristics of Al-5%B and Al-2%Mg-2%B were generated by the process of centrifugal casting. Examination of hardness and microstructure was also done. Greater hardness in the region is observed due to separation of AlB_2 particles towards the region of casting. Volume fraction of particles of AlB_2 under investigation reveals strong dependency on magnesium present in the structure of composite [189].

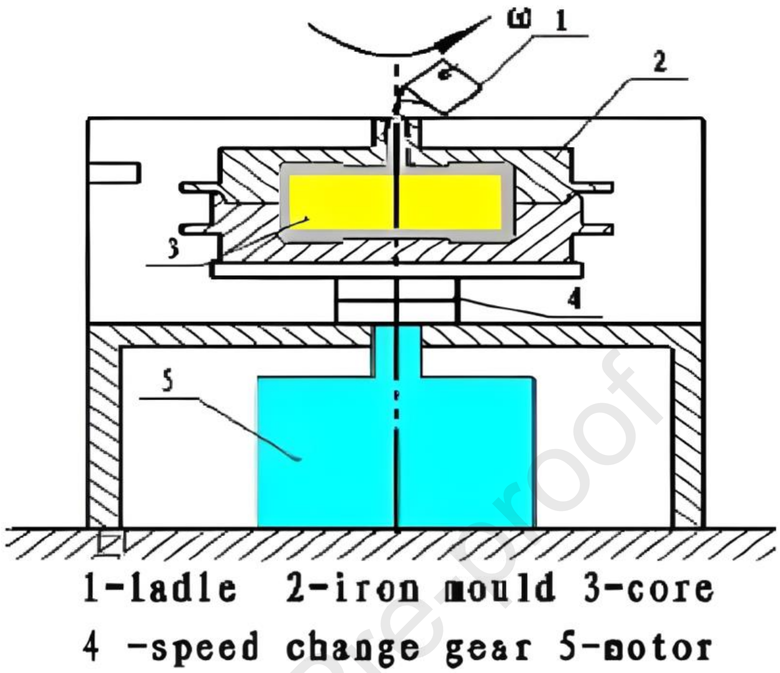

Figure 22. Schematic representation of Centrifugal Casting [189].

6.2 Powder Metallurgy (PM)

The technique of powder metallurgy is much more complex when compared with other approaches in terms of production of composites. The process is cost-effective only for higher rates of production. The PM technique includes the compaction of fine powdered materials into a die with the application of large pressures to obtain a preferred profile. Further the component is sintered which further delivers higher strength and the required component density. Figure 23demonstrates a flow chart of the PM process.

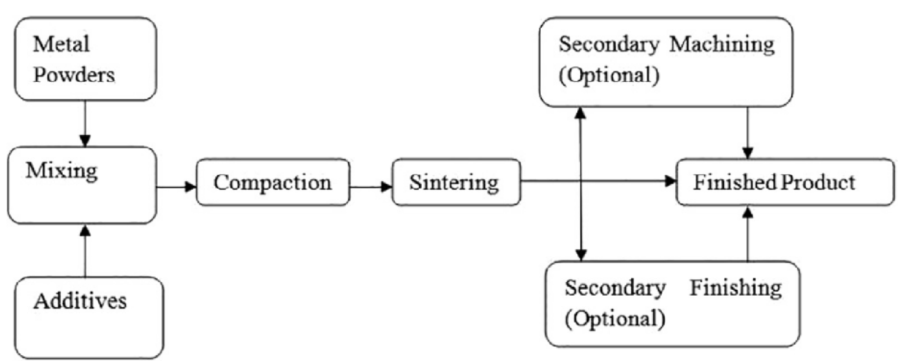

Figure 23: Flow Chart of Powder Metallurgy Process [191].

Components produced from powder metallurgy are primarily utilized in automobile industries for producing tools, hardware, sports goods, agricultural equipments, industrial & business systems, and defense applications. PM is also extensively applied for producing cams, piston rings, gears, bushing, impellers and connecting rods. The common materials utilized in powder metallurgy are copper, iron, nickel, aluminium, brass and titanium. The process is demonstrated in Figure 24.

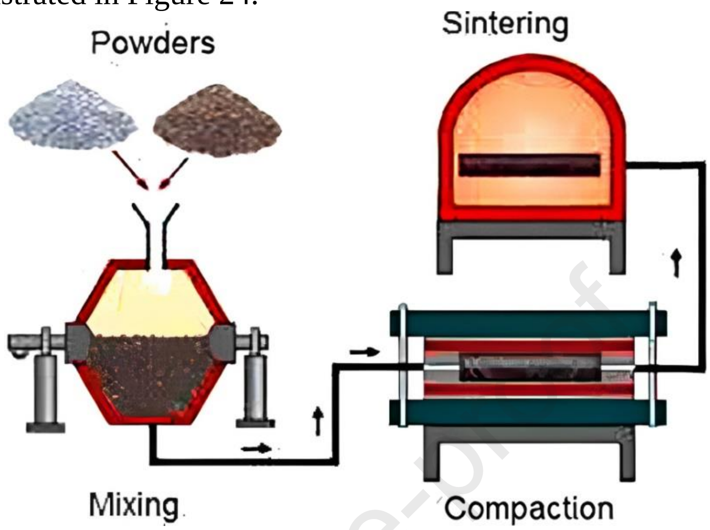

Figure 24: Powder Metallurgy Process [191].

In a study, matrix composite of particles of boron carbide reinforced aluminium 2024 are fabricated anda uniform blend of the composite was achieved between boron carbide and aluminium additionally the outcomes showed improved bond strength and better morphology [190]. The PM routes along sintering of mechanically ball milled alloys for producing Al-SiC-B_4C based composites are also studied [191].

6.3 Stir Casting

This method can be stated as the economical and simplest for the production of metal matrix composites. This is a fabrication scheme for composite material where reinforcement material is blended with molten metal using a mechanical stirrer. Further the liquid form of metal matrix composite is discharged into a mold according to the traditional process of casting. During this several factors impact the composite microstructure and characteristics. Process of stir casting is displayed in figure 25.
The foremost intent of this method is producing a uniform mixture. The significant parameters which affect the casting characteristics are pouring temperatures, rotation speed, pouring speed and life of mold. Refinement is enhanced by increasing the stirrer speed but also causes instability at lower speeds. Avoiding higher speeds is advised in order to prevent tearing phenomenon. Temperature of pouring also plays a vital role in the liquid metal solidification. The higher temperature of molten metal encourages columnar growth while lesser temperature endorses the higher refinement of grain.

In order to guarantee the easiness of metal flow and avoiding cold laps, the temperature of pouring molten composite should be adequately higher. The lower pouring speed encourages directional solidification and decreases the possibility of tearing; however higher speed of pouring causes extreme rejection and turbulence. The utilization of preheated die yields refined castings in comparison with co-sand mold however it is just a secondary necessity for the formation of structure.

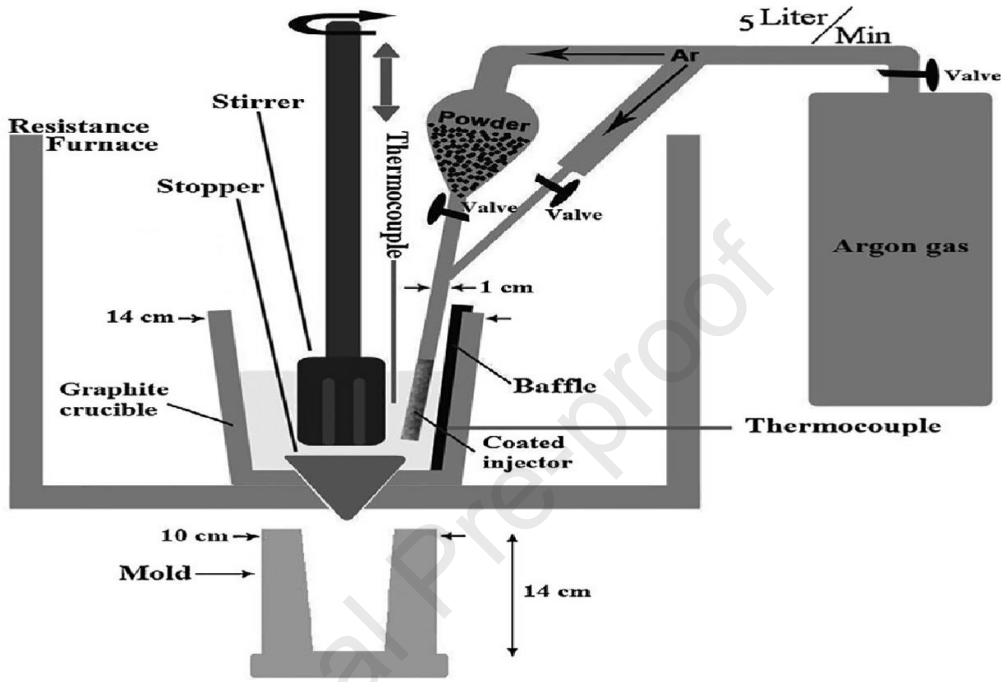

Figure 25: Stir Casting Process [192].

The process of mechanical stir casting is employed for producing and solving issues of poor particle mixing showing higher porosity of matrix by generating metal matrix nano composites via electromagnetic stir casting applied to recover from the issue of mechanical stir casting [192]. In a study, the traditional melt stir technique is used to produce 11 wt. % boron carbide as reinforced material along with 6061 Al matrix for making the novel composite. The entire process of producing composites was achieved at 750°C temperature [193].

6.4 Squeeze Casting

Squeeze casting method is employed for generating composites of fibers of ceramics produced under pressure. Direct and indirect squeeze casting methods are available. This method is applied for manufacturing of components of composites that are simpler in geometries and of lesser price. The indirect method is employed in developing distinctive composite components however manufacturing cost is high. The process of squeeze casting is applied in manufacturing of automotive parts such as chassis frames, front steering knuckles, nodes and brackets. The process of squeeze casting is illustrated in figure 26.
In this technique, liquid metal is pressurized and further allowed to solidify which results in the development of desired geometry. The microstructure of parts generated by this method is appropriate for various problematic applications. It is an easy and cheaper

technique and could be automated when compared with other processes of casting. When this procedure is used, the highest mechanical qualities of casting are achieved. The study demonstrates the principles and technique of squeeze casting that could be used to practice the castings of composite of discontinuous fiber-reinforced metal matrix [194].

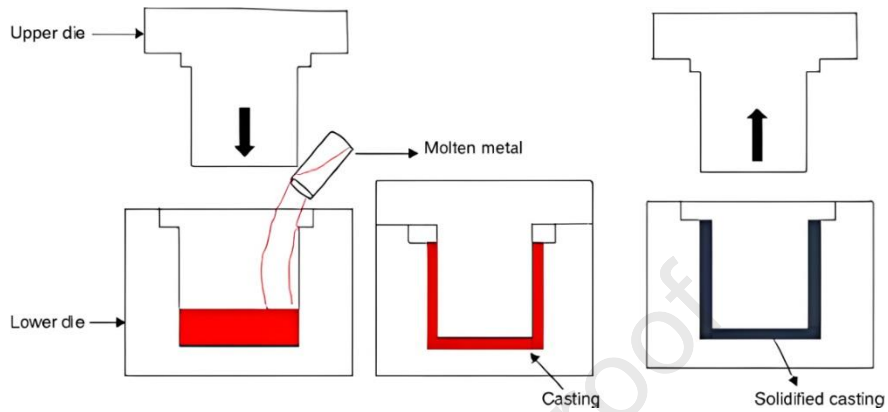

Figure 26: Squeeze Casting Process [194].

Table 4: Comparison between fabrication techniques of hybrid aluminium matrix composites [87].

Method	Application	Process parameters	Advantages	Limitations
Stir casting	Commercially used for producing Al-based composites	Stirrer speed and time, wetting agent, pouring temperature and speed, preheating of reinforcement material	High porosity, simple, cost-effective	Tearing occurs at lower speeds
Squeeze casting	Suitable for making automotive components	Applied pressure level, die preheating temperature, pouring temperature, duration of pressure application	Superior mechanical characteristics, easy, suitable for components with simple shape, economical	High tooling cost, Low cycle time

Gas pressure infiltration	Used to produce rods, tubes and beams	Alloy composition, temperature, time	High quality fiber, Used to manufacture larger components	Low production rate,higher production and processing costs
In-situ processing	Mostly used for aerospace and automotive components	Temperature, reaction time and mass fraction	Strong interfacial bonding, thermodynamically stable reinforcement, Higher wear resistance	Choice of the dispersed phases is limited
Powder metallurgy	Used for high strength application and for small objects	Powder compaction, sintering temperature and time and particle size	High strength and density,complex shapes could be produced	High tooling cost, and raw material cost
Diffusion bonding	Used for blades, sheet and other structural components	Bonding temperature and time, bearing pressure	No discontinuity and less porosity, good strength	High initial setup cost, time consuming

7. Applications of composites

Composites could be employed in automobile, aeronautical and defense applications, and currently are used in luxury buses owing to better strength and metallurgical characteristics. The Powder metallurgy, squeeze casting and stir techniques are applied for developing the composite materials or parts depending upon the type of material.

Composite materials and specifically metal matrix composites are predominantly applied for the production of lightweight components in the automobile industry. Fabrication of the connecting rod is performed by a stir casting scheme. The elementary mechanical properties of this were also studied [195]. The PM process is applied for generating SiC/Al-Si based pistons used in compressors. Analysis of mechanical properties of SiC-Al-Si metal matrix pistons used in AC compressors of automobiles was done. It was recommended that the material employed in the piston of automobile AC compressor must demonstrate higher strength, less resistance to wear and reduced weight [196]. The centrifugal casting technique is utilized for fabricating composite pistons based on Aluminium alloy with reinforcement of SiC. The various factors of composite were studied. The microstructures and macro morphologies of pistons were also examined. The examination revealed the magnitude of hardness, resistance to wear and coefficient of thermal expansion through the axis [197].

The several kinds of gears that are regarded as crucial components in power transferring systems in an automobile and in many machineries are manufactured through metal matrix composites. Aluminium metal matrix composites (AMCs) are favored owing to their lesser density. They are employed in lightweight part manufacturing because of the enhanced characteristics. In a study of AMCs the work materials opted were Al 6106-T6, Al 7050-T7451, Al 6061-T6 and Al 7075-T651. FEA or Finite Element Analysis was carried out on various spur gears applying above mentioned materials and comparison of the outcomes was done [198].

A crucial shock absorbing component in a vehicle is leaf spring. The study of fracture of the leaf springs which were employed in buses of Venezuela was examined [199]. The geometrical study and analysis of mono leaf spring were performed. It was revealed that in comparison with leaf spring, the mono composite leaf spring shows lesser values of stress, greater stiffness ranging between 25% and 65%, greater frequency of 27 to 67% and reduction in weight of about 73% to 80% [200]. FEA software was applied for analyzing and optimizing the simple and parabolic leaf spring with changing loads. In the study, prime attention was upon decreasing weight of vehicle and further increasing and preserving the mechanical characteristics of the auto components [201].
It was necessary to produce engines and vehicles having enhanced fuel potential and being lightweight. The automobile sector witnessed the exceptional properties of composite materials in automobile parts and also in engines with poppet valves. The valve components were planned and produced for achieving maximal functioning since engine valve components operate at elevated temperatures and stresses impacts the life of valve parts. The powder metallurgy was applied for manufacturing of the valves in automobiles and researchers desire to upsurge the use of PM. Considering a study on this, the observations demonstrate that blend compositions by 15%, 20%, 25% and 30% of SiC were designed by powder metallurgy method and valves were produced using a mixture of die and powder stacked in layer form [202].

8. Discussions and prospects

Switching to EVs is pushing automobile manufacturers to embrace novel technologies and new working methods, in order to enhance the performance and shrink the industry's environmental footprint. Discovering economical, lightweight materials and more sustainable manufacturing approaches would be the important aspects in the race to produce future EVs.

Advanced technologies for composite manufacturing could prove a milestone for automobile industry. Composite materials composed of FRP are considered as suitable alternatives to substitute heavy metals and build superior energy-efficient vehicles. Composite material employment in the structures of the automobiles have progressed very much recently. The striking blends of numerous options of reinforced composites and tailored techniques for composite manufacturing have brought up an innovative manufacturing period for the automobile industry. Novel technologies offer speedy processing time, superior control of resin impregnation in composites, and much detailed physical and mechanical characteristics.

Several manufacturing techniques like RTM, VARI, RIM and compression molding were disclosed by various studies leading to many improvements as offered in this study. Each technology contains certain merits and drawbacks and is suitable for definite type of material, performance requirements and structural configurations. Though, many manufacturing approaches still tackle certain challenges in order to become a part of the conventional automobile industry owing to cost issues of high-performance materials like carbon fiber and the absence of progressive joining methods for assembling composite parts. Additional issues concerning formation of void and control of resin flow involves more accurate designing tools. The increasing global fiber demand in the automobile sector is estimated to drop in near future. Still, concerns regarding modeling and assembling besides more promising techniques still prevail. Therefore, there is essential requirement for more research and practical foundation of composite manufacturing approaches in the automotive sector.

9. Conclusions

The utilization of composite for EVs and in automobiles has been discussed in this paper. In the automobile sector the utilization of composites will reduce the weight of EV plus influence the aerodynamic properties while reducing the consumption of fuel. The review evidence of previous years and current times reveals high capabilities of composites for manufacturing auto components for the automotive industries. The comprehensive data reveals that the requirements for fuel economical vehicles and electric vehicles have seen a rise mainly over the last 5 years. In order to cope up with the requirement of greater strength and lightweight components and parts, the automotive industry concentrates upon studies regarding composite based auto components as they can deliver increased strength, more resistance and higher fatigue life. Pertaining to such properties, the study of composite in EVs and automobiles is timely and essential. Hybrid composites microstructure generated at varying wt. % of reinforcement were observed to be stable having uniform distribution.

It seems that most of the automobile producers prefer to switch from old conventional steel components to lightweight materials to sustain their businesses along with current market trends. Currently the composites sector requires showcasing their innovative characteristics with the application in metals. The evolving drifts in lightweight automobile companies are applying composites based on fiber for engineering different classes of light vehicles. Recent technical development in the use of cellulose and bio-composites have resulted in the redesign of traditional and premium lightweight vehicles. Carbon fiber-based composite materials would be obtainable at lesser rates by recycling methods for providing a reasonable direction for development of lightweight hybrid composite materials in future.

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Data availability

The data and materials used to support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Composites for Electric Vehicles and Automotive Sector: A Review

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Abstract: The automotive sector is undergoing a significant transformation to address critical challenges affecting consumers and the climate. One of the most difficult tasks is reducing the weight of vehicles in order to minimize energy consumption. A ten percent decrease in curb weight is predicted to result in a six to eight percent reduction in energy consumption. Composite materials having better strength to weight ratio are one of the finest options for planning, designing and manufacturing of the lightweight components. In automobile sector, employment of composite materials would reduce the weight of electric vehicles as well as influence their aerodynamic properties. Therefore, it would decrease the consumption of fuel as well by cutting down harmful emissions and particulate matter. Numerous developments in such technologies are studied over the last decade by automobile establishments and academic researchers.Fiber-reinforced polymers, particularly those established on glass and carbon fibers, have attracted attention of the automobile sector due to their high performance and lesser weight. This paper reviews the applications of various types of composite materials and the fabrication techniques of such composites in electric vehicles and automobiles. Furthermore, a comprehensive data breakdown of the lightweight materials statistics and figures on market analysis of high performance composite is presented. Finally, a discussion is made on the different applications of these composites. Hence, the details presented in this study should be useful for automobile companies to align with NET ZERO global mission while sustaining their businesses.

Keywords: Composites, Electric Vehicles, Fabrication Techniques, Hybrid Vehicles.

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Highlights

1. Application of diverse varieties of composites in automobile industry is seeing an upsurge owing to its multifunctional characteristics.
2. Discussion on weight reduction of the automobile components as weight reduction will enhance several operating parameter including fuel efficiency.
3. Future challenges and opportunities concerning the composite application are discussed.
4. Further research on novel materials for its applicability in rising upcoming prospects are laid down.

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