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Review Article

Short Literature Survey on Fiber-Reinforced Hybrid Composites

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ABSTRACT

Conventional leaf springs used in the automobile industry are usually produced from high-carbon steel. But, it has some drawbacks such as susceptibility to corrosion, high weight, long-term fatigue problems, etc. So, to overcome these issues, the automotive industry has started to replace conventional leaf springs with polymer composite-based mono-leaf springs. Recently, hybrid fiber-reinforced polymer composite leaf springs have gained considerable attention due to their better mechanical properties like high strength, high stiffness, low weight, and high corrosion resistance. However, the physical, mechanical, and tribological properties of the fabricated leaf spring mainly depend upon the method of fabrication, properties of the material, type and content of reinforcement, etc. Hence, this review article aims to provide an overview of composite materials, their classification, and the processing of polymer matrix composite. Finally, this review article summarizes the recent investigations carried out by various researchers to achieve high mechanical properties, less deflection, and higher weight reduction.

1. Introduction

Presently, pollution reduction and energy saving have become essential requirements of all automobiles owing to the increasing emission standards and market competition. However, the fuel economy can be enhanced without decreasing the performance of the vehicle, by using lightweight material, appropriate manufacturing methods, and design optimization. Although, conventional leaf springs, which are usually made up of stacking leaves of steel are still used in most vehicles. These leaf springs have high density and weight. In general, its weight accounts for approx. 10% to 20% of the un-sprung weight of the automobile [1]. To overcome this, composite materials were introduced which made it possible for weight reduction of a vehicle, without any change in load-carrying capacity. In addition, the composite material of fiber-reinforced polymer offers a high stiffness-to-weight ratio, high impact resistance, good thermal conductivity, high resistance to corrosion, and stability over a wide temperature range with high damping capacity [2-4]. It was also observed that at least a 50% reduction in suspension weight can be achieved by replacing a traditional steel leaf spring with a composite leaf spring. Some researchers have already done a lot of research on the design and development of composite leaf springs [5, 6]. However, a suitable

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combination of material, resin, and hardener is required to achieve high mechanical properties along with weight reduction. Moreover, hybrid composites are to be considered more advanced composites than conventional fiber-reinforced type composites [7]. Hybrids can have different combinations of matrix and reinforcing phases like single reinforced fibers with multiple matrix phases and multiple reinforced fibers with single matrix phases [8]. These hybrid composites provide better flexibility with different modulus and higher strength than other fiber-reinforced composites [9]. The high performance of hybrid composites is a result of the combined effects of the individual constituents [10]. In addition, the natural frequency of a hybrid composite leaf spring is two times the frequency of a traditional leaf spring, mainly in the vertical direction [11]. This indicates that the occurrences of resonance will be less in the case of a hybrid composite leaf spring. Further, the stress produced in hybrid composite leaf springs is lesser than in traditional leaf springs. These springs (hybrid composite mono-leaf springs) offered high impact and tensile properties in comparison with traditional steel springs [12, 13]. Due to these attractive properties of hybrid composite mono-leaf springs, a lot of research has been going on over the last few decades.

According to the Web of Science data, a total of 601 research papers on hybrid composite for automotive applications have been published from 2011 to Nov. 2023. The specific details of research publication in distinct journals and the no. of research papers published year-wise on hybrid composite are represented in Fig. 1 (a) and (b).

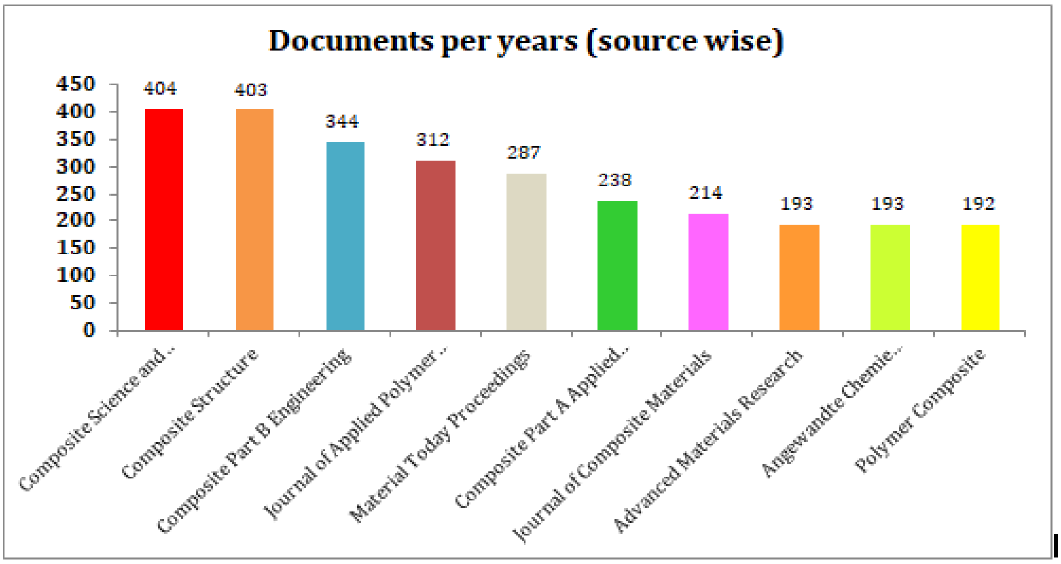

Fig. 1(a). Top ten journals in which research papers on hybrid composite are published (Web of Science).

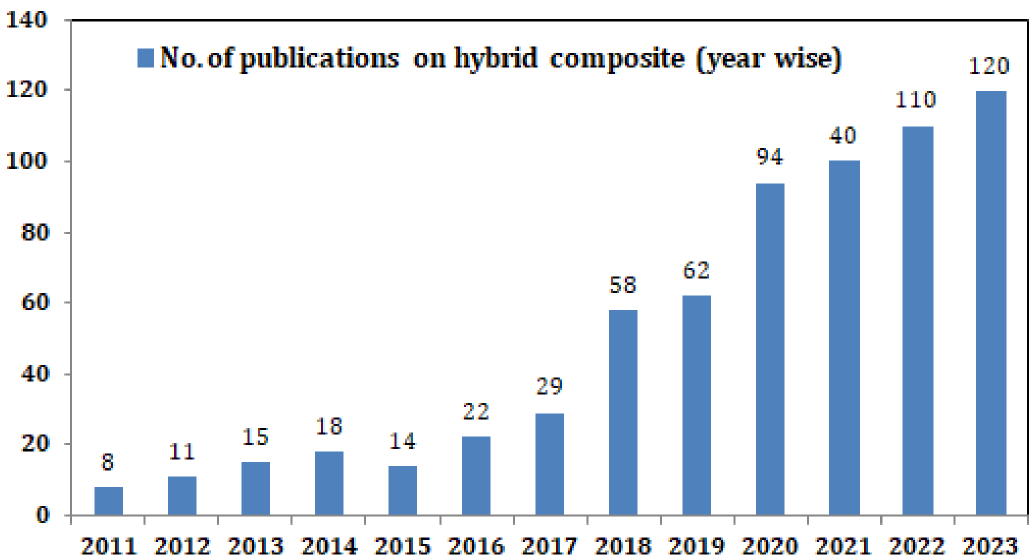

Fig. 1 (b). Year-wise publication on hybrid composite in the automobile sector (source: web of science)

Further, the country-wise contribution of hybrid composite in the automotive sector [14] is depicted in Fig. 2.

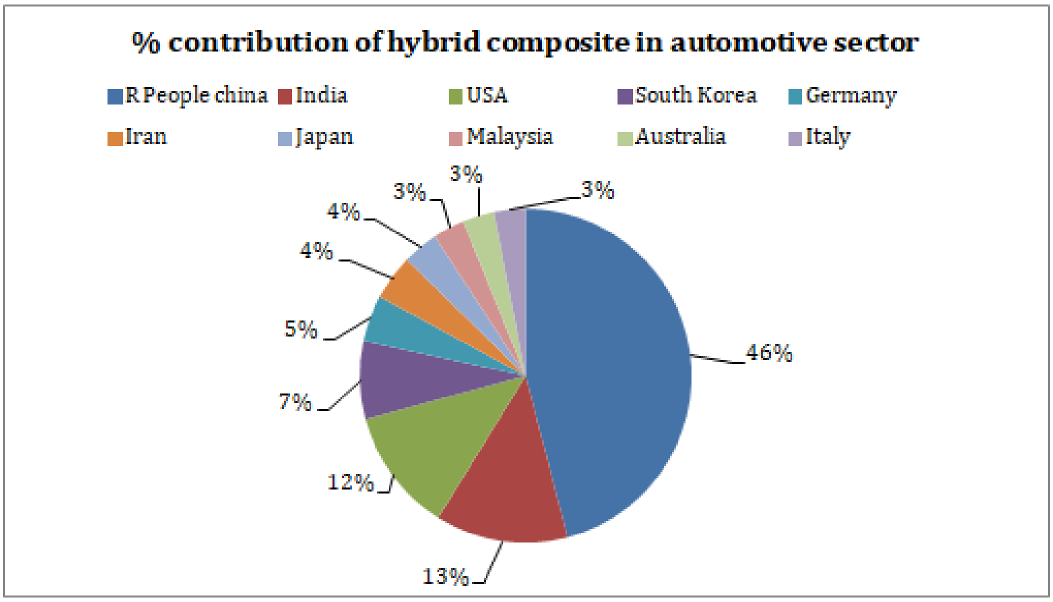

Fig. 2. Contribution of distinct countries in the hybrid composite

From Fig. 1, it is clear that hybrid composite has a lot of scope in the automotive sector. Currently, natural fiber-reinforced polymer composites are widely employed in automobile parts, electrical industries, packing industries, and building materials [15-17]. It is observed that more than 42% of natural fibers are used in packing industries, 8% in the automobile sector, 20% in building and construction and the remaining 30% is used in other applications [18]. However, synthetic fiber-reinforced polymer composite is utilized in distinct parts of aerospace. Some researchers reported that synthetic fiber-reinforced polymer composite decreases by 10 to 50% in weight and 10-20% in cost as compared to the same piece of metal [19]. The application of synthetic fiber-reinforced polymer composite in a distinct part of aircraft [20] is depicted in Fig. 3.

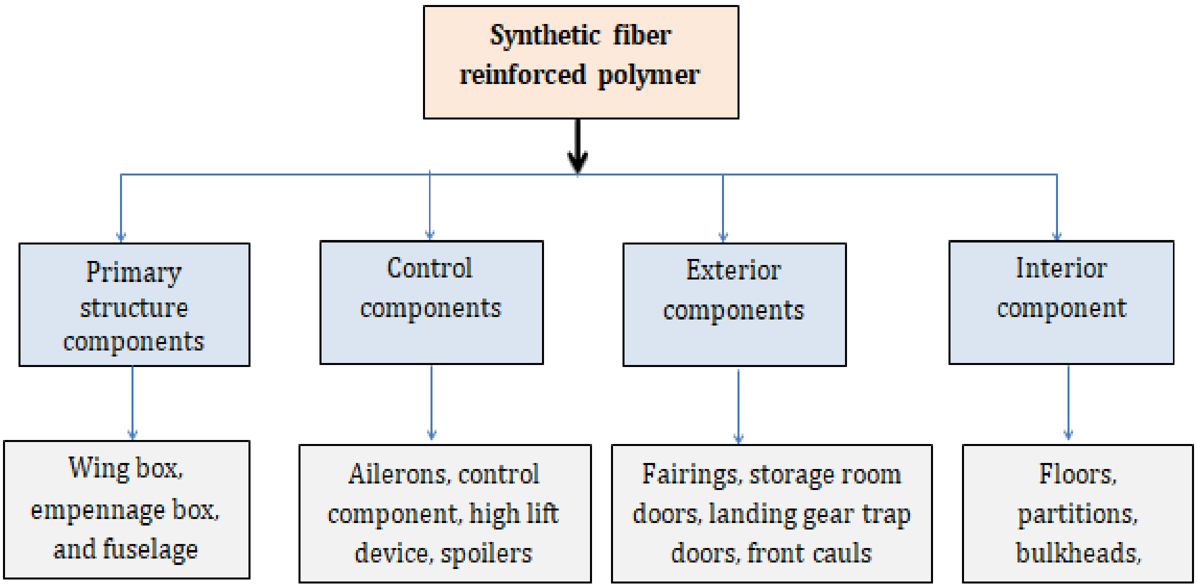

Fig. 3. Application of synthetic-fiber-reinforced polymer in a distinct part of aircraft

However, the use of natural fiber-reinforced polymer composite in distinct parts of the vehicle [21- 23] is summarized in Fig. 4.

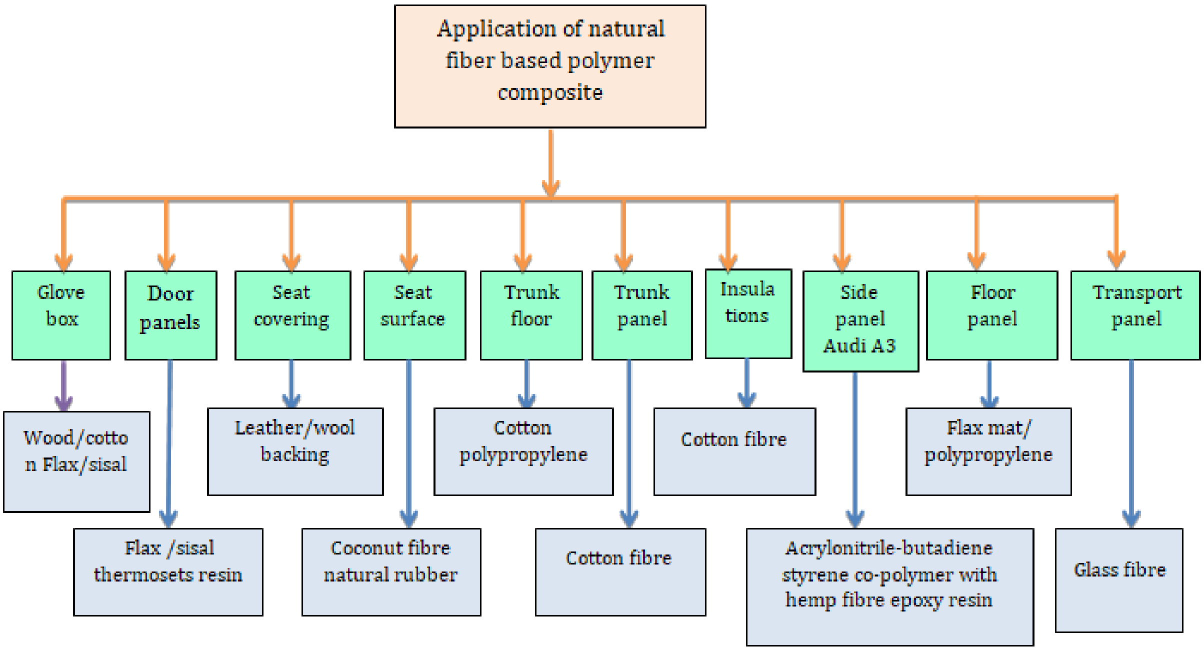

Fig. 4. Application of natural fiber composite in distinct parts of the vehicle

However, for open mold fabrication of composite various techniques such as hand lay-up method, spray-up, automated tape lay-up, filament winding, tape Lay-up, Vacuum bagging, autoclave curing, match die molding, resin transfer molding, reaction molding, prepreg, sheet molding, and pultrusion etc. are used. Among all these methods, the Hand Lay-up method is the most widely used because this method is the simplest composite molding method. It has simple processing, low tooling cost, and a wide range of part sizes, etc. [24]

Hence, this review article aims to provide an overview of composite materials including their types, types of fibers, matrix materials, and processing of polymer matrix composite. Finally, this review article summarizes the recent investigation related to the mechanical properties of polymer composite-based leaf springs fabricated using the hand lay-up technique.

1.1. Composite Material and their Classification

Composite materials are materials made up of two or more components that have significantly different physical and/or chemical properties. When two or more essential materials are combined, a new substance emerges with properties distinct from the individual constituents to achieve optimum properties like high strength, more energy absorbing capability, stiffness to weight ratio with more flexibility in material and structural design. Composite materials are stronger and more cost-effective than traditional materials [25]. The variations in mechanical properties of a hybrid composite can be seen by changing some stacking sequences of different laminates and their volume ratio [26]. The composition of composites [27] is depicted in Fig. 5.

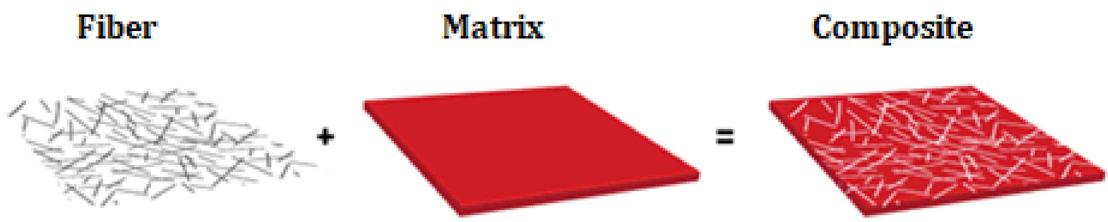

Fig. 5. Composition of composites

Composite materials have been classified according to the type of reinforcing composite materials [28] as shown in Fig. 6.

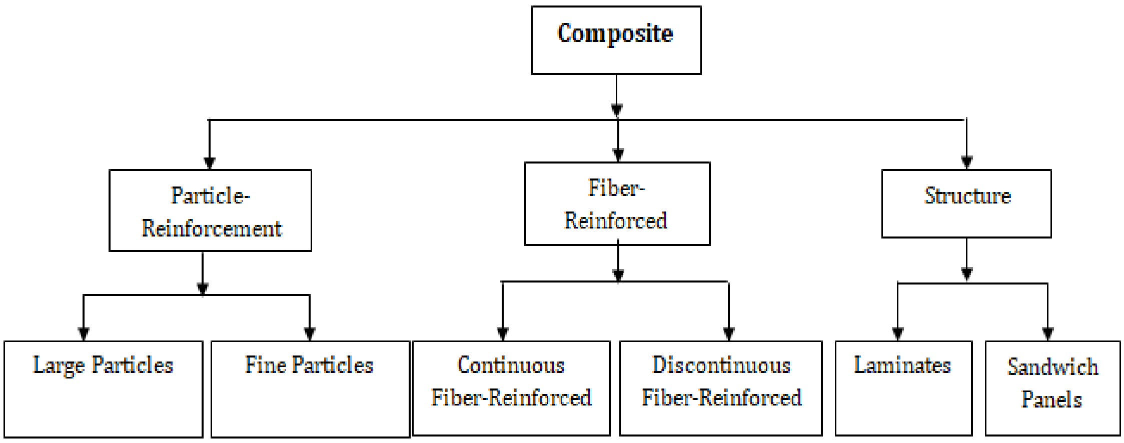

Fig. 6. Classification of composite materials (Based on reinforcement)

1.1.1. *Fibrous*

A fiber is significantly larger than its cross-sectional dimensions because of its length. The dimensions of the reinforcement indicate how well it can contribute properties to the composite. Because, the long dimension of reinforcement prevents the emergence of incipient cracks parallel to the reinforcement, which could otherwise lead to failure, especially in brittle matrices [29]. In addition, fibers are very effective in enhancing the matrix's fracture resistance. The small cross-sectional area of man-made filaments or fibers of non-polymeric materials reduces major flaws that may be present in the bulk material. The high strength and stiffness of polymeric materials may be due to the orientation of the molecular structure [30].

For fiber reinforcements, its dimensions determine its capability to the composite structure by contributing its properties [31]. To improve the resistance of the matrix, fibers are used which lowers the chance of failure to a minimum [32]. For polymeric materials, the direction of the molecular structure is significantly responsible for high rigidity and strength. Where the composite characteristics depend on the longitude of the fiber, such composites are called discontinuous fiber composites, or short fiber fibers that are random in fiber orientation [33], as shown in Fig. 7.

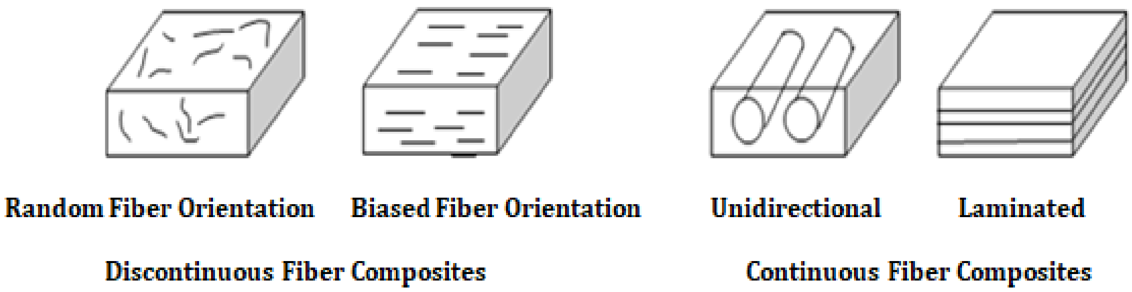

Fig. 7. Fiber-reinforced composites

When the fiber length is such that no further length increase will lead to an enhancement in the elastic moduli of the composite, it is referred to as the "continuous fiber composite."[34]. Fibers are usually small in diameter and twist easily when axially pressed, despite having excellent tensile properties. As a result, these fibers must be strengthened to prevent individual fibers from bending and buckling.

1.1.2. *Particulate*

The reinforcement of particulate composites is particle-based. This may be spherical, cubic, tetragonal, flat, or in any other form (regular or irregular). Particles do not generally increase fracture resistance in very effective ways, but they do increase composite rigidity to a small extent [35]. Particle fillers are commonly used for adjusting matrix material for thermal/ electrical conductivity, improving efficiencies at high temperatures, dropping friction, raising resistance to wear and abrasion, increasing machinability, enhancing surface strength, and diminishing shrinkages [36].

1.1.3. *Structural*

Structural composites are known as engineered products prepared of wood, plastic, glass, or carbon fibers. Examples of molded or extracted materials are outdoor deck flooring, fences, landscape timbers, siding, molding, trimming, and door frames [37]. These low-maintenance products can be smooth or simulate a grain of wood and are cracking-resistant. Laminar composites & sandwich structures are two types of structural composites [38].

Laminar composites are made up of layers of different materials. Various laminar composites are intended to improve the corrosion resistance of composites while maintaining high strength, low cost, & lightweight properties [39]. Thin coatings, thicker protective coatings, Thin coatings, thicker protective coatings, claddings, bimetallic coatings, and laminates are only a few examples [40]. Sandwich structures are made up of thin layers with a core in the center [41]. However, the novel designs can be elucidated by concentrating on the introduction of nanotubes, miscellaneous cores, and smart materials in sandwich structures [42].

1.2. Types of Fibers

The different types of fibers utilized in composite material are discussed below:

1.2.1. Natural Fibers

These fibers are sometimes referred to as natural (plant) fibers as they are taken from plants including wood, bamboo, cotton, sisal, jute, and so on. They are biodegradable and acquire mechanical qualities that are similar to synthetic fibers after surface treatments [43-45]

The effects of hybridization on the properties of jute/glass and jute/carbon laminates with polyester resin were examined by Flores et al. [46]. Nine laminates in all were manufactured using the vacuum infusion procedure. E-glass and carbon fabric reinforcements were used for this unidirectional jute. Comparing the hybrid composites' findings to the non-hybrid two-component laminates, they revealed usually intermediate characteristics. The hybrid composites' mechanical characteristics were 30–300% greater than the pure jute composite, but 50–75% smaller than the pure glass and pure carbon composites, respectively. The number of synthetic fiber layers in each hybrid affected The impact of hybridization and stacking sequence on the creation of biocomposites made of cotton mixed jute and pineapple leaf fiber was examined by Baigh et al. [47]. The findings demonstrate that hybridization, as opposed to pineapple leaf fiber reinforced polymer (JFRP) composites, improved flexural and tensile performances. The hybrid composite reached a maximum tensile strength of 32.16 MPa, while the JFRP composite had the greatest tensile strength of 35.16 MPa. Jute layers on the outer plies of the hybrid composites had the highest tensile modulus of 1.315 GPa. Furthermore, the hybrid composite that had three layers of jute plies sandwiched between alternating layers of pineapple plies and jute plies showed the highest elongation at 15.94%. The impact of hybridization on the resin and reinforcement on the mechanical characteristics of epoxy/polyester composite materials reinforced with jute and cotton fibers was investigated by Shah et al. [48]. The findings demonstrated that the hybrid composites of cotton/epoxy/polyester and jute/epoxy/polyester had tensile strengths that were, respectively, 12.25% and 10.06% greater than those of cotton/epoxy composites and jute/epoxy. Alshahrani et al. [49] studied the mechanical characteristics (tensile, bending, and shear strength) of jute-basalt/epoxy composite laminate. The aforementioned composite was fabricated by employing the hand lay-up technique. The result showed that the basalt/epoxy composite exhibited maximum tensile/bending strength, toughness/bending modulus, and in-plane shear/bearing strength. However, the jute/epoxy composite exhibited maximum bending strain and failure strain. In addition, the hybridization of fiber with basalt fiber enhanced the bending, tensile, and in-plane bearing and shear, properties of the developed composite.

1.2.2. Synthetic Fibers

These fiber Materials are made up of many small molecules synthesized polymers. Polymerization is the chemical reaction that produces polymers from monomers; however, this is a broad term since various chemical processes are involved in different polymerization reactions. In the early twentieth century, synthetic polymers, as modern polymers, contributed to the advancement of technology and applied sciences. Chemical reactions produce synthetic polymers, which are used in building construction and other applications [50]. However, the most widely used synthetic fibers are:

1.2.2.1 Carbon Fiber

Advanced structural composites using carbon fibers are used in the aerospace & sports industries. They have a very high stiffness and a very low density. However, carbon fibers have a hardness ten times that of glass fibers and densities half that of glass fibers. Despite their great strength, carbon fibers are typically not as strong as glass or aramid (Kevlar) fibers. Carbon fibers have exceptional thermal properties. Carbon fibers have a few other disadvantages, particularly when compared to glass fibers. The main disadvantage is the price. Fibers made of carbon are twice as costly as S-glass at their lowest price point, but certain grades can be 5 times more expensive than E-glass [51].

The major advantages of carbon fiber over conventional type of materials are high tensile strength/fatigue strength, thermal conductivity, and low thermal expansion coefficient

1.2.2.2 Kevlar (Aramid)

Aramid fibers, such as DuPontKevlar, play a critical role in advanced composites. The foundation of these fibers is the amide bond created by the interaction of the amine group and carboxylic acid.s. The energy-intensive failure mechanism of aramid fibers accounts for its superior durability. It's suitable for use in military, and ballistic applications like helmets and also for bullet-proof vests because of its energy-absorbing failure mechanism. It's also used for firefighting, also on the underside of race cars and planes (to defend against stone hits during takeoff and landing) [52].

Different types of Kevlar according to their toughness are

- Kevlar29 with medium modulus
- Kevlar49 with high modulus
- Kevlar149 with ultra-high modulus

1.2.2.3 GlassFiber

Glass is the most frequent fiber used in polymer matrix composites. It has several advantages, including resilience, low cost, and chemical resistance. E-glass & S-glass are the two most common styles. Since it was designed for electrical applications, the letter E stands for electrical. It is, however, still used for a variety of other purposes, including decoration & structural uses. The letter S stands for high silica material, which keeps its strength at high temperatures and has higher fatigue strength. For the reason of their low cost, high strength, & low density, glass fibers, also identified commercially as "fiberglass," are the most widely used reinforcements for PMCs. Glass fibers, unlike carbon or Kevlar fibers, are isotropic, which means they don't lose characteristics when filled in the transverse direction. Although, fiberglass is made by forcing molten glass into orifices at a temp. where the viscosity of the glass is just right. Composition of different glass fiber grades [53].

1.3. Matrix Materials

The different types of matrix material [14] for composite are shown in Fig. 8.

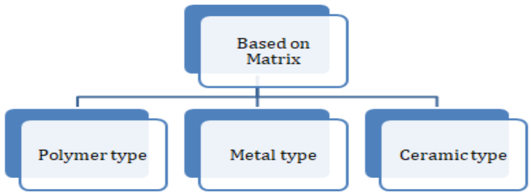

Fig. 8. Classification of composite materials (Based on matrix)

1.3.1. Polymer Type of Matrix

The most common types of matrix materials are polymeric matrix composites. For many structural applications, the mechanical characteristics of polymers are usually inadequate. They have very weak strength and stiffness when compared to metals and ceramics. By reinforcing other materials with polymers, these issues are resolved [54]. Second, high pressure or high temperatures are not required in the production of polymer matrix composites. Furthermore, less sophisticated equipment is needed to create polymer matrix composites. Polymer matrix composites thus gained acceptance and were frequently employed in structural applications [55-58].

1.3.2. Metal Type of Matrix

Metal matrices have greater strength, fracture resistance, and stiffness. In corrosive environments, MMCs can withstand higher temp. than polymer composites. These days, titanium, aluminum, and magnesium are the most used matrix metals; they are particularly helpful for aircraft applications. Metal matrix composites, including nozzles for fuel cells (rockets and space shuttles), housings, tubing, wire, heat exchangers structural elements, etc. are being considered for a variety of applications [59].

1.3.3. Ceramic Type of Matrix

These matrices type are mainly known for everyday wear and tear lasting longer than other materials rather than toughness their consistent improvement is seen in strength and stiffness. It's also the only type of matrix containing ceramic for both reinforcement and matrix material in composites [60].

Everything is held together by the resin system, which also uses the fibers to transfer mechanical stresses to the remaining portions of the structure. It protects the composite structure from damage, corrosion, and other environmental factors, as well as rough handling. In addition, resin systems are divided into chemical families, each of which is designed and assigned to serve a specific industry, offering benefits such as cost, structural efficiency, resistance to various factors, and legislative reinforcement [61].

1.4. Processing of Polymer Matrix Composite (PMC)

PMCs are classified depending on whether the matrix is a thermoset or thermoplastic polymer [62] as shown in Fig. 9.

Composites of a thermoset matrix are far more prevalent in the past, but composites of a thermoplastic matrix are now rapidly developing. Thermoplastic matrix composites have lower production costs than thermoset-mattress composites; they do not require mold cure, unlimited shelf life, ability to reprocess, low moisture content, weld capacity, and so on. High viscosities and manufacturing costs are some of the drawbacks of thermoplastic PMCs [63]. Temperatures, as well as the need for fiber or particle surface treatments, are all factors to consider. The simplest way of fabricating PMCs is open molding (contact molding). It's typically utilized to make huge, separate parts (swimming pools, boat bodies).

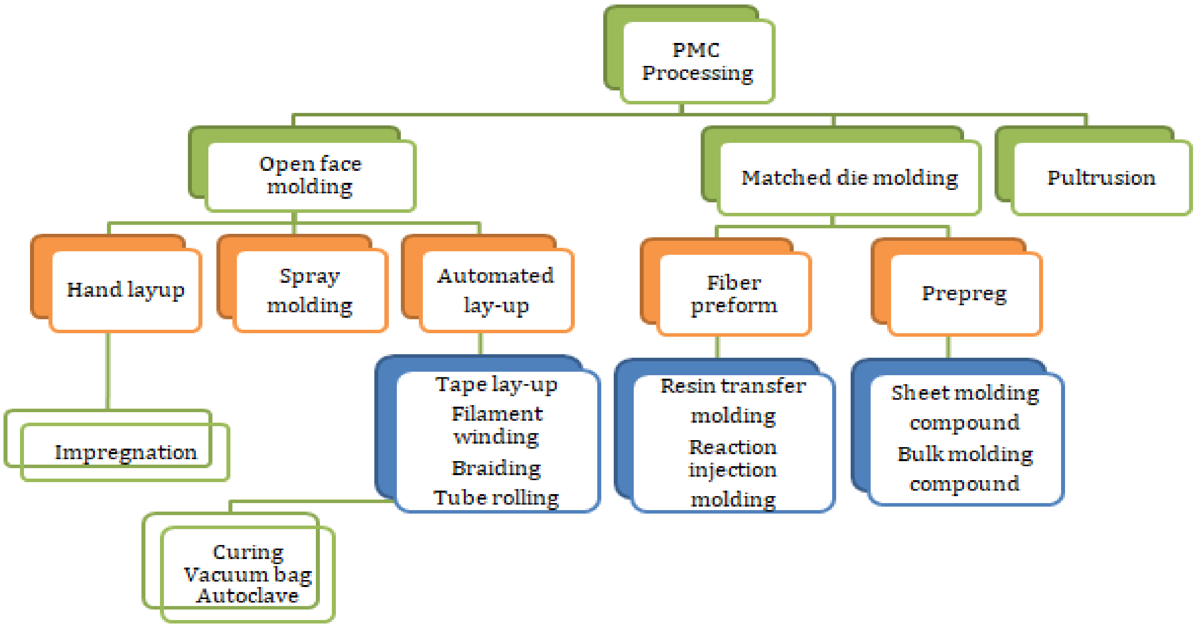

Fig. 9. Processing of PMC

1.4.1. Methods for Open Mold Fabrication

There are several methods for open mold fabrication, some of which are discussed below:

The Hand Lay-up method is the most widespread form of Open Molding. The method is a labor-intensive, manual process [64].

- Spray-up: During the procedure, two distinct sprays of the liquid resin matrix and chopped reinforcing fibers are applied to the mold surface. Only short fiber-reinforced composites, however, can be made. The cutter receives a continuous fiber and chops it [64].
- Automated tape lay-up: A large automated roller, similar to a packing tape roller, is utilized in this operation. The tape pressure is applied by the roller, which eliminates the need for a vacuum bag [65].
- Tape Lay-up: Using a tape application robot, layers of prepreg (liquid resin-impregnated reinforcing phase) tape are applied to the mold surface [66].
- Filament Winding: It involves winding a constant filament of reinforcing material in layers at various layers onto a rotating mandrel. The method is known as Wet Filament Winding when the filament is coated with a liquid thermosetting resin before being wound. The method is known as Dry Filament winding if the resin is sprayed onto the mandrel with wound filament [67].
- Vacuum bagging: It is a technique for securing items in a vacuum. Efficiency was increased by applying hydrostatic (air) pressure through a flexible membrane both before and during the curing process. The mold can be heated if the procedure is used to make completed goods, but doing so in the field for on-site repairs is more challenging [68].
- Autoclave curing: It is a process of part molding that uses one of the open molding methods and cures the part using vacuum, heat, and inert gas pressure [69].
- Match die molding: The basic method is to heat a resin of thermoset within a closed mold cavity at high pressure before the resin is healed using a chemical reaction of linked polymers [70]. The resin liquefies and flows into the desired component or part under pressure, taking the form of the mold cavity before hardening [70].

- RTM: Resin transfer molding is a manufacturing method similar to injection molding in which material is injected into a closed mold [71].
- Reaction molding: Two reactive materials are pumped into a mixing head at high rates and pressures and injected into the mold cavity to cure and solidify the chemical reaction. A laminate stack contains thermoplastic matrix-impregnated fibers and additional weight films for the desired fraction of fiber volume in the final product [72].
- Prepreg: A prepreg (short for pre-impregnated) composite is one that already has the resin applied to the reinforcement. This means that when working with prepreg, the only concern is shaping the element [73].
- Sheet molding: It is a ready-to-mold glass-fiber reinforced thermoset material commonly used in compression molding that is both a process and a material [74].
- Pultrusion: It is the process of pulling resin-impregnated glass strands through a die, similar to the extrusion of metal pieces, and used to produce composite material in the final form [75].

Overall, composite leaf springs offer many benefits than traditional leaf springs. These include (a) reduced weight (b) less fuel consumption (c) high damping capacity (d) less noise and vibration (e) Good resistance corrosion.

1.5. Statement of the Problem

The major problem in the automotive industry is the higher weight of the vehicle. A multi-steel leaf spring creates various problems such as fretting corrosion, less fatigue life, producing squeaking sound, more noise and vibration, etc. To overcome these issues composite materials play a significant role. Composite material offers a high strength-to-weight ratio, high stiffness, high fatigue strength, and has higher resistance against corrosion than steel leaf springs. Thus owing to these properties of composite materials, the weight dilemma of vehicle can be minimized by manufacturing a leaf spring of hybrid composite materials. However, a suitable combination of properties can be achieved by adopting the suitable method of fabrication, material type content of reinforcement, etc.

Although, various researchers [76-80] have designed and optimized a composite mono-leaf spring. However, very little literature is available on composite structure design, material physical test results, and mechanical properties of leaf springs. Hence, this review article aims to summarize the results (weight reduction %, deflection, young modulus, flexural and tensile strength) of various researchers working in the area of hybrid composite leaf springs. Finally, the future scope of the laminated hybrid composite leaf spring is discussed.

2. Literature Survey

2.1. Prior Studies Related to Materials for Leaf Spring

To replace the current synthetic fiber-reinforced composite material and conventional steel in car leaf springs, Assarudeen et al. [81] created a natural and synthetic fiber-reinforced hybrid composite material with optimal qualities. The reinforcements are banana and E-glass woven textiles, while the matrix material is a mixture of epoxy resin (LY556) and hardener (HY 951). Finite element analysis (FEA) is carried out on the CAD models of the Leaf spring that are created in CATIA V5 R20 and imported into ANSYS 15.0 workstation. This study compares the performance of banana/E glass-reinforced epoxy leaf springs with steel (65Si7) leaf springs. It has been discovered that the hybrid composite leaf spring may reduce weight by up to 81% and has lower costs, less stress, and higher strain energy. Dhiraj et al. [82] reported that composite mono-leaf springs have much lower stress, lower spring weight, and higher nature frequency than conventional leaf springs. Arun et al. [83] investigated the suitability of natural and synthetic fiber-reinforced hybrid composite material in automobile leaf spring application. By using natural fibers efforts have been made to reduce the cost and weight of leaf springs. A hybrid composite leaf spring with Jute/E-glass/Epoxy composite materials is modeled and subjected to the same load as that of a steel spring. Compared to steel leaf springs the laminated hybrid composite leaf spring weight reduction is achieved. Venkatesan et al. [84] compared the stiffness, load-carrying capacity, and weight reduction of composite leaf springs to traditional leaf springs. E-glass/epoxy unidirectional laminates with the same dimensions as a steel leaf spring were used to construct the composite leaf spring. ANSYS 10 is used to do the static analysis of the 2D model of a typical leaf spring, and the outcomes of the experiments are then compared. Additionally, ANSYS 10 is used to perform finite element analysis with full load on a three-dimensional model of a composite multi-leaf spring. The analytical and experimental findings are then compared. It is discovered that the composite leaf spring has 126.98% greater natural frequency, 64.95% higher stiffness, and 67.35% less stress than the steel leaf spring. A 76.4% weight is lost when utilizing an optimized composite leaf spring. Gnana et al. [85] employed hybridization techniques to enhance fatigue performance and weight reduction of hybrid composite leaf springs through carbon fiber mixed with glass fiber in the polymer matrix. The results showed that the developed hybrid momo composite (glass fiber+carbon reinforced plastic) withstands maximum deformation, load, and stress.

Hassan, M.R. et al. [86] performed the describing of a hybrid composite made of polyester and reinforced with glass fibers and jute. The results of the experiments showed that a composite made of natural & synthetic fibers has promising flexural, tensile, and hardness properties. The hybrid composite of three layers of glass fibers and two layers of hessian cloth (jute fiber) had the highest tensile strength. 104.63 mpa and 134.65 mpa were found to be the maximum strength and flexural strength, respectively. Bhanupratap, R. et al. [87] demonstrate the efficient fabrication of a hybrid composite using bidirectional jute kevlar reinforced epoxy by hand layup technique in various proportions. It has been shown that the proportions of natural (jute) and synthetic (Kevlar) fibers in the resin have a significant impact on the tensile strength. The hybrid composite's strength is increased due to the epoxy resin's proper transmission and distribution of applied stress. The tight bond between the matrix and the reinforcement and load carried by the reinforced epoxy hybrid composite improves its tensile characteristics with the addition of the key layer in the bidirectional jute kevlar. Patil, S.S. et al. [88] fabricated Kevlar/Jute reinforced epoxy. The results showed that by combining kevlar with jute fiber composites, the properties of kevlar-jute composites can be greatly improved, improving the properties of half-breed composites. The flexural consistency is influenced by the stacking arrangement (changing the location of kevlar handles). Layering classification has no impact on the tractable properties of kevlar and jute fibers with identical relative weight divisions. The ratio of kevlar to jute improves ductility, flexural quality, and strain vitality, and reduces the weight of the example. As the kevlar rate decreases, the epoxy rate decreases, lowering the cost, for example. Kapil K. et al. [89] investigated the flexural strength of the hybrid fiber-reinforced plastics (FRPS) composed of three distinct laminates. The hand lay-up method was utilized to create the hybrid FRPS. The manufactured specimens underwent three-point bending testing by ASTM D790 guidelines. The results show that the specimen with the highest flexural strength value is the one with the most Kevlar at the top. Hybrid FRP is a better alternative to traditional materials because of this feature. Leaf springs are made of this material. Ahmed, K.J. et al. [90] analyzed that Kevlar fiber has a higher FOS than carbon fiber, glass fiber, and steel, and it also has a higher weight-to-quality ratio than steel. As compared to standard steel springs, kevlar fiber springs have an 87 percent mass reduction. In comparison to all other materials, Kevlar fiber produces the best performance, but it is also the most costly. After kevlar fiber, carbon fiber outperforms all other materials in every category. The hand lay-up technique for reinforcing jute and Kevlar fiber in epoxy polymer matrix hybrid composites is the subject of Maharana S.M. et al.'s study [91]. The hybrid composites include a set proportion (20%) of kevlar, whereas epoxy resins were used to vary the quantity of jute. The effect of loading and fiber orientation on the material's tensile and flexural strengths is evaluated. To fabricate the polymer composite, several orientations, including 0°, 30°, 45°, and 60°, were employed. The polymer composites exhibited the maximum tensile strength at 40% fiber loading and 30% fiber orientations, and the highest flexural strength at 40% fiber loading and 45% fiber orientations. Because of the fiber loading, 50% of the composites had a greater void content. The composites' tensile fracture microstructure was utilized to detect fiber pullout and cracking.

According to experimental results, Sujon Md. A.S. et al. [92] investigated how the fiber orientation and stacking order of the fiber layers affect the mechanical characteristics of composite materials. The four carbon fiber layers positioned in the center and the three jute fiber layers evenly spaced on either side (J3C4J3) had the maximum tensile strength (571mpa). The C2J6C2, which has two layers of unidirectional carbon fiber on both sides and six layers of jute fiber in the center, has the highest rate of water absorption, impact strength (30 kj/m2), and bending resistance (455 MPa) (3.8 percent). Unidirectional hybrid composites have better qualities than hybrid composites in an angle and cross-ply. Ali A. et al. [93] research focuses on the flexural behavior of carbon/jute epoxy composites using computational and experimental investigation. Impact response is also characterized by a decline. A method based on weight according to the findings, as the percentage of jute increases, flexural strength decreases. Flexural activity simulations diverge more than 10% of the results of the experiment this is due to the waviness of the fiber, which causes a heterogeneous property distribution. Failure mechanisms were also revealed by the fractographic analysis in composite materials. An increase in the proportion of jute causes a larger damage area in drop weight effect studies.

Bhudolia, S.K. et al. [94] investigated in combination with thermosetting epoxy resin, the mechanical characteristics of electrically non-conductivity hybrid composites (thin non-cramping carbon clothing, Kevlar, and e-glass materials). Experimental findings showed a better performance for vibration and flexure testing of hybrid composites with a higher number of Kevlar layers. The impact success findings showed that while the peak load to failure rose with an increase in Kevlar layers, the absorbed impact energy increased with an increase in glass layers. Shahzad, A. et al. [95] used hybridization, and the mechanical characteristics of these composites' impact and flexural types improve significantly, especially when the skin is used as synthetic fibers and the heart is natural fibrous folds. Different natural surface fiber treatments have been used to increase the interface adhesion and therefore the mechanical properties of the matrices.

From the studies, It is evident that when natural and synthetic materials are combined at the outermost layer, composite materials with high strength, stiffness, and corrosion resistance exhibit greater flexural strength and 60:40 weight ratio of fiber & resin for less void content as the presence of it can affect the physical and mechanical properties of hybrid composite laminate. A sequence for the hybrid composite laminate structure is shown in Table 1.

Table 1. Hybrid composite laminate structure sequence [87, 88, and 95]

Layer 1	Carbon
Layer 2	Kevlar
Layer 3	Jute
Layer 4	Kevlar
Layer 5	Carbon

2.2. *Studies Related to Failure of Composite Materials*

Many studies have been conducted on the failure of composites from both the macro and micromechanical perspectives. At the micromechanical level, the processes and mechanisms of failure differ significantly depending on the kind of loading and are closely linked to the characteristics of the component phases, such as the matrix, reinforcement, and interface-interphase. Micromechanics-based failure predictions are just approximations in terms of global lamina failure and failure progression to ultimate multi-directional laminate failure, even if they are accurate in terms of failure initiation at key sites. A macro mechanical approach to failure analysis is favored because of these factors. The composite structural designer might choose from a variety of potential failure theories [96].

They are divided into three categories: partially interactive or failure mode-based theories (Hashin-Rotem, Puck); interactive theories (Tsai-Hill, Tsai-Wu); and limit or noninteractive theories (maximum stress, maximum strain). A theory's applicability and validity are determined by how well it fits with experimental findings and how easy it is to apply. The abundance of hypotheses is matched by a lack of appropriate and trustworthy experimental evidence, which makes choosing one hypothesis over another challenging. Lately, a great deal of work has been done to resolve this issue. The issue may be split into two sections: the first portion deals with predicting the failure of a single lamina, while the second half predicts the failure of the initial plies and the damage development that leads to the eventual failure of a multi-directional laminate [97]. Six failure theories were evaluated by C. T. Sun [98], who also provided comparisons between theoretical predictions and experimental findings. The evaluation of these failure criteria is based on available laminate and laminate strength data. All six criteria may predict identical results for various laminates under specific loading situations; therefore, their performance cannot be prioritized. As a result, several laminates are found for which the strength estimates made using these six criteria differ significantly. A theory's applicability and validity are determined by how easily it can be applied and how well it agrees with experimental findings [98]. Eighty percent of responders to an AIAA Failure Criteria Survey stated they used one of these four lamina failure criteria. Maximum Stress is often utilized at 22%, and Maximum Strain is most frequently used at 30%. The utilization of Tsai-Wu and Hill-Tsai was 12% and 17%, respectively [99]. The ply-wise failure criteria in the composite leaf springs were investigated by Saini et al. [100]. Four failure theories—the maximum stress failure theory, the maximum strain failure theory, the Tsai-Hill failure theory, and the Tsai-Wu failure theory—are used to model and analyze leaf springs to determine the failure criterion. Based on these ideas, a parametric analysis is used to compute the failure load. Hybrid composites are created and analyzed by changing the top, bottom, and center layers of the composite laminate to increase the maximum failure load. The four distinct cross-sections that are examined are HC1, HC2, HC3, and E-glass/epoxy. The study demonstrates that increasing the maximum failure load does result from changing the top, bottom, and center layers.

The component experiences increased strains as a result, whereas the Eglass/epoxy material experiences decreased stresses at the same distances from the laminate center. When just vertical loads are taken into account, HC3 displays a 30.7% increase in failure load; when vertical, side loads, and twist moment are taken into account at the same time, the failure load increases by 20.8%.

2.3. Studies Related to the Fabrication of Hybrid Composite Using Hand Lay-up

The most common process of composite fabrication is the hand lay-up technique, which is the easiest composite processing method and thus has the least infrastructural requirements. In some cases, the molding of a vacuum bag is used to complete a production process involving the use of a flexible film exposed to outside air [101]. In this process, composites are vacuumed so that air blisters can be removed from the laminate. Following this point, the material can be exposed to atmospheric pressure as it cures. However, this method of making leaf springs is not commonly used. The reason is that, in addition to the hand lay-up technique, it needs infrastructure that can increase manufacturing costs such as vacuum pumps and a vacuum bag made of highly skilled rubber-coated or polymer films and the pressure generated by the laminate eliminates an excess of resin. It is not commonly used due to these inherent factors [102].

Hand lay-up techniques:

The oldest method utilized for fabric composite manufacturing is hand lay-up. The samples are prepared in a specific order [103]. To prevent the polymer from sticking to the surface, the molding surface will be processed with release anti-adhesives. The top and bottom of the mold plate are then added to give the product a smooth finish a thin layer of plastic. The woven reinforcement layers are cut to the correct forms and placed on the surface of the mold. As mentioned before, the resin was combined with other components and infused with a support brush to uniformly disperse it onto the surface of the reinforcement already placed in the mold [104]. The other mats are then placed on the previous layer of polymers and pressed down with a roller to remove any trapped air and excess polymer bubbles. After that, the mold is sealed and the pressure is released, producing a single mat. The tissue composite is extracted from the mold surface once the mold has cured at room temperature. Figure 10 shows the schematic diagram of the hand lay-up [105].

Keerthi et al. [106] used hand lay-up techniques to fabricate composite leaf springs made of glass, carbon, Aramid fibers, and Epoxy resin. Then the tensile, flexural, and impact test of the fabricated composite samples was conducted and the results were compared to conventional leaf springs. Therefore, choosing composite materials throughout the leaf spring manufacturing process will result in increased efficiency. When compared to a steel leaf spring, each fiber has a greater strength when used alone, but when combined, the strength may be somewhat lower. The manufacturing process also plays a significant role. Because air molecules are included in the fiber during the production process, utilizing the manual lay-up approach results in lower strength. Thus, it is appropriate for light-duty vehicles. These composite leaf springs offer improved suspension performance, increased cushioning, and vibration absorption. We find that glass, carbon, and graphene fiber springs can provide more strength than carbon and glass fiber springs when we compare these two results.

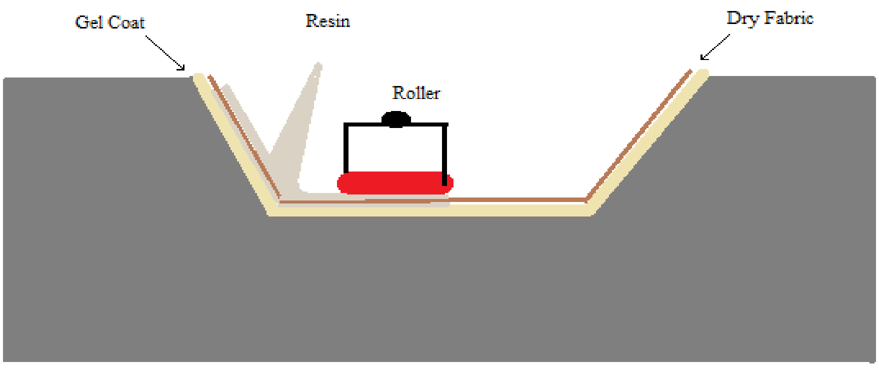

Fig. 10. Hand layup technique

3. Summary

The summaries of research work done by various researchers on polymer composite-based leaf springs using the hand lay-up technique are summarized in Table 2 and represented graphically in Fig. 11 (a) to (e).

Table 2. Summary of research work done by various researchers on polymer composite-based leaf spring using hand lay-up technique (Source: All published articles: Scopus and Non-Scopus)

S. No.	Author (Year)	Composite Material	Resin And Hardener	Load	Test Performed	Weight Reduction than steel spring (%)/ Stiffness	Deflection (mm)	Mechanical Properties			References
								Flexural Strength	Tensile Strength (MPa)/ Tensile Toughness (MJ/m^3)	Young's Modulus (GPa)/Modulus of Resilience (MJ/m^3)	
1	K. K. Sharma et al. (2020)	EBK-H	Epoxy 520 and hardener D	126.2 N	Flexural Test	The $K_2E_2B_2$ sample is stiffer than EBK-H by 1.06%	25.49	307.97 MPa	13.29 MJ/m^3	5.46MJ/m^3	89
		$K_2E_2B_2$		130 N			33.74	317.24 MPa	96.051 MJ/m^3	5.08 MJ/m^3	
2	S. K. Pati et al. (2020)	Jute E-Glass	Epoxy	1080 N	Tensile Test	NA	10.12	NA	9.3MPa	NA	107
		Kenaf E-glass									
3	K. P. Kumar et al. (2020)	Glass fiber	Epoxy (B-11 (3101)) VHV & hardener is (K-6(5205)	3.69 KN	Flexural Test	75%	103.07	788.07 N/mm^2	NA	NA	108
		Sisal fiber		0.67 KN		74.0%	88.43	107.039 N/mm^2			
		Hybrid fiber		2.02 KN		74.5%	101.73	365.119 N/mm^2			
4	R. K. R. Guduru et al. (2020)	Carbon fiber epoxy	Epoxy (AW-106) & Hardener (HV953-IN)	For flexural: & 892N For tensile:8431 N	Tensile & Flexural Tests	69.4%	4.2	1646.7 MPa	195MPa	NA	109
		Glass fiber epoxy		For flexural:441.4 N & For tensile: 8194 N		75%	5.6	814.8 MPa	109MPa		
		Carbon F.G. epoxy		For flexural:372.78 N& For tensile: 6926 N		69.4%	3.3	688 MPa	135MPa		
		Random F.G. epoxy		For flexural:147.15 N & For tensile: 2138 N		75%	5.4	271.6 MPa	55MPa		
5	Palin D er al. (2020)	CXSEA Composite (15%), (66×13×3)	Epoxy 103	Varying Load	Impact, Flexural & Tensile Tests	55%	NA	260 MPa	15.44MPa	NA	110
		CXSEA Composite (30%), (66×13×3)						410 MPa	55.54 MPa		
		CXSEA Composite (15%), (127×13×3)						230 MPa	12.86 MPa		
		CXSEA Composite (30%), (127×13×3)						430 MPa	58.92 MPa		
6	M. D. Teli et al. (2019)	GFRP (10 mm)	epoxy (YD128) & hardener (HY140)	Excess Load (10%)	Compression Test	GFRP was reduced to 67.70% Weight than EN 46.	34.46	1200 MPa	900 MPa	51GPa	111
		GFRP (12 mm)					19.94				
		GFRP (14 mm)					12.56				
		GFRP (16 mm)					8.41				
		EN 46 (10 mm)		9800 N			136.32	NA	666.03 MPa	183.40 GPa	
		EN 46 (12 mm)					78.89				
		EN 46 (14 mm)					49.68				
		EN 46 (16 mm)					33.28				

7	K. J. Ahmed et al. (2019)	Carbon	Epoxy	0 – 1000 N	Bending Test	80%	0-12	NA	NA	70GPa	90
		Kevlar								30GPa	
		Glass Fiber								34GPa	
8	Chalaamsalu (2019)	Carbon Fiber-sample-1	Epoxy	Flexural load=740N	Tensile, Flexural & Compression Tests	70.01%	13mm at 3875N load	641.72 MPa	1176 MPa	86.5 MPa	2
		Carbon Fiber-Sample 2		Flexural load=800N			15mm mm at 4874N load	690 MPa	1189 MPa	87.4 MPa	
		Carbon Fiber-Sample -3		Flexural load=870N			18 mm at 5874N load	750 MPa	1207 MPa	88.5 MPa	
		Carbon Fiber, Sample-4		Flexural load=810N			21 mm at 6874 N load	700 MPa	1252 MPa	91.7 MPa	
		Carbon Fiber, Sample-5		Flexural load=910N			24 mm at 7874 N load	790 MPa	1279 MPa	93.5 MPa	
9	S. K.Vignesh et al.(2019)	GFRP, S-Glass	Epoxy resin – LY556 & HY951 hardener.	100-1500 N	Tensile, Flexural & Hardness Test	70%	0.042 mm	397 MPa	53MPa	9300 MPa	112
10	M.A.Kattimini et al. (2019)	E-Glass	Epoxy	0-2500 N	Bending Test	NA	0-55 mm	NA	NA	89GPa	113
11	Thippesh L (2018)	Glass Fiber	Epoxy Ly 556 &hardener Aradur HY 951	0.5 KN	Bending Test	80%	0	417 MPa (max.)	NA	NA	114
				1 KN			0				
				2 KN			1.3				
				3 KN			2.2				
				4 KN			3.6				
				5 KN			5.2				
				6 KN			35.3				
				7 KN			66.5				
				7.7 KN			91.8				
12	G. R.Chavhan et al. (2018)	E-Glass Fiber	Resin LY 556 & Hardener HY 951	500 N	Bending Test	73.65%	0	196.71 MPa	NA	NA	115
				1000 N			0				
				1600 N			0				
				2000 N			0				
				3000 N			0				
				4000 N			0				
				4600 N			1				
				4800 N			2-29				
				5600 N			29				
				6400 N			29				
13	R.Vijayan et al. (2018)	E-Glass	Epoxy	3.47 KN	Tensile Test	NA	NA	NA	52 MPa	NA	116
				3.09 KN					48 MPa		
				3.13 KN					49 MPa		
14	U. J. Jadhao et al. (2018)	Carbon fiber	Epoxy	1000 N	Bending Test	76.4%	.21	NA	NA	NA	117
				1500 N			.35				
				2000 N			.41				
				2500 N			.48				
15	H. Banka et al. (2018)	E-Glass Fiber	Epoxy	2500 N	Bending Test	57.23%	1.73	NA	NA	210 GPa	118
16	A. M. George et al. (2017)	Woven E-glass	Epoxy L-12 & Hardener H407	240.571-10969.3 N	Tensile & Flexural Test	88.49%	73.52	200.48MPa at 240.571 N load	120.58 MPa at 7234.78 N load	50-73 GPa	119
		E-glass-banana						206.18MPa at 247.418 N load	160.97MPa at 9778.31 N	27-32 GPa	
		E-glass-flax						431.32MPa at 517.576 N load	182.89 MPa at 10969.3 N	60-80 GPa	
17	G. J. Abhyankar et al. (2017)	E-Glass	Epoxy	9300 N	Bending Test	41.07%	95	NA	NA	34 GPa	120
18	Y. S.Bhargav (2017)	E-Glass	Epoxy	50-400 N	Bending Test	75%	74 at 400 N	alkylamine	NA	85 GPa	121
		Jute glass					123.68 at 400 N			26.5GPa	
19	S. Pawar et al. (2017)	Carbon/Glass	Epoxy	1000 N	Bending Test	NA	14.8	NA	405.33 MPa	31.54779 GPa	122
				2000 N			28.6				
				3000 N			41.6				
				4000 N			53.2				
				5000 N			63.0				
				6250 N			71.3				
20	S. SatishKumar et al. (2017)	E-Glass & Aleovera	Epoxy	4.25 KN	Flexural test	85%	269.37	NA	NA	210 GPa	123
				8.50 KN			85.23				
				13.02 KN			34.91				

21	Y. S. More (2016)	Glass/Sisal Fiber-Sample-1	Epoxy	4169 N	Tensile & Flexural Test	35%	31.5	127.49 MPa	287MPa	NA	124
		Glass/Sisal Fiber-Sample-2						164.85 MPa	165MPa		
		Glass/Sisal Fiber-Sample-3						72.80 MPa	87MPa		
22	P. N. Pakale et al. (2016)	E-Glass	Epoxy	30000 N	Bending Test	71.73%	955.4	NA	NA	43 GPa	125
				28500 N			920.2				
				25000 N			835				
				20000 N			660.8				
				15000 N			498				
				10000 N			332.7				
				5000 N			142				
23	S. V. Gaikwad et al. (2016)	E-Glass	Epolon 5015 resin & polyoxy alkelenamine hardener	1000	Bending Test	79.13%	14.9	NA	395.16MPa	33.54779 GPa	126
				2000			29.6				
				3000			44.5				
				4000			56.8				
				5000			66.1				
24	T. R. S. Saini et al. (2016)	E-Glass	1.65	10 N	Bending Test	NA	0.4	NA	267.24 MPa	11.95 GPa	127
				20 N			0.6				
				30 N			0.95				
				40 N			1.45				
				50 N			1.65				
25	K. Rajesh et al. (2015)	E-Glass	Epoxy	3250	Tensile Test	68.15%	94	222 MPa	199.5 MPa	31 GPa	128
26	A. Mehndiratta et al. (2015)	GFRP	Epoxy	1842	Bending Test	86.424%	32	NA	NA	NA	129
27	Y.Patil et al. (2015)	E-Glass	Epoxy Dobeckot 520 F & hardener 758	4000	Bending Test	50.74%	3.9880	NA	400MPa	33548MPa	130
28	P, Manimaran et al. (2015)	GFRC &E-Glass	Epoxy	500	Bending Test	57.14	9	1200 MPa	900 MPa	NA	131
				1000			41				
				1500			49				
				2000			69				
				2500			84				
				3000			99				
				3500			119				
				3870			133				
29	R P. Ambare et al. (2015)	E-Glass	Epoxy	500 N	Bending Test	50%	8	NA	1300MPa	45 GPa	132
				1000 N			10				
				1500 N			12				
				2000 N			16				
				2500 N			22				
				3000 N			28				
				3500 N			35				
				4000 N			40				
				4500 N			46				
				5000 N			52				
30	M.A.Rajakumaran et al. (2015)	GFRP	Epoxy	72 N	Bending Test	NA	152.25	1200 MPa	900MPa	NA	133
				61 N			176.7				
31	M. Raman et al. (2014)	C-Glass	Epoxy	200 N	Bending Test	48%	4.3	NA	1370MPa	NA	134
				400 N			7.6				
				600 N			14.8				
				800 N			18.3				
				3900 N			72.1				
32	Suhasel et al. (2014)	E-Glass	Epoxy	1010.4	Flexural Test	44.6%	75	NA	NA	NA	135
33	S Rajesh et al. (2014)	Glass Fiber	Epoxy	100 N	Bending Test	71%	9	NA	NA	NA	136
				200 N			18				
				300 N			31				
				400 N			42				
				500 N			51				
34	P. Ravindra et al. (2014)	Carbon Fiber	Epoxy	100 N	Bending Test	22.15%	0.68	11.65MPa	1841 MPa	NA	137
				500 N			3.67	57.75MPa			
				1000 N			7.39	115.37MPa			
				1500 N			11.11	172.99MPa			
				3400 N			25.23	391.95MPa			

35	R. Kumar V et al. (2013)	E-Glass/Jute	Epoxy	50 N 100 N 150 N 200 N 250 N 300 N 350 N 400 N	Bending Test	75%	3 15 28 42 60 82 103 125	220.18 MPa	1550 MPa	NA	138
36	Autade R. S. et al. (2012)	Carbon Fiber	Epoxy	4.9 N 9.81 N 14.71 N 19.62 N 24.52 N 29.43 N 34.33 N 39.24 N 44.14 N 49.05 N	Bending Test	63%	0.43 0.82 1.4 2.09 2.44 3.09 3.88 4.47 5.15 6.01	NA	1830 MPa	NA	139
37	K K. Jadhao et al. (2011)	GFRP	Polyester (Neptol 1011)	2800N	Bending Test	85%	95	NA	NA	11.9 GPa	140
38	B. B. Deshmukh et al. (2011)	GFRP	E-Glass Epoxy	3000N	Bending Test	74%	105	NA	1550 GPa	60.52 GPs	141
39	G. S. S. Shankar et al. (2006)	GFRP	E-Glass Epoxy	4250N	Bending Test	85%	105	1200 MPa	900 GPa	NA	142

Here: NA: Not Available; GFRP: Glass Fiber Reinforced Plastic

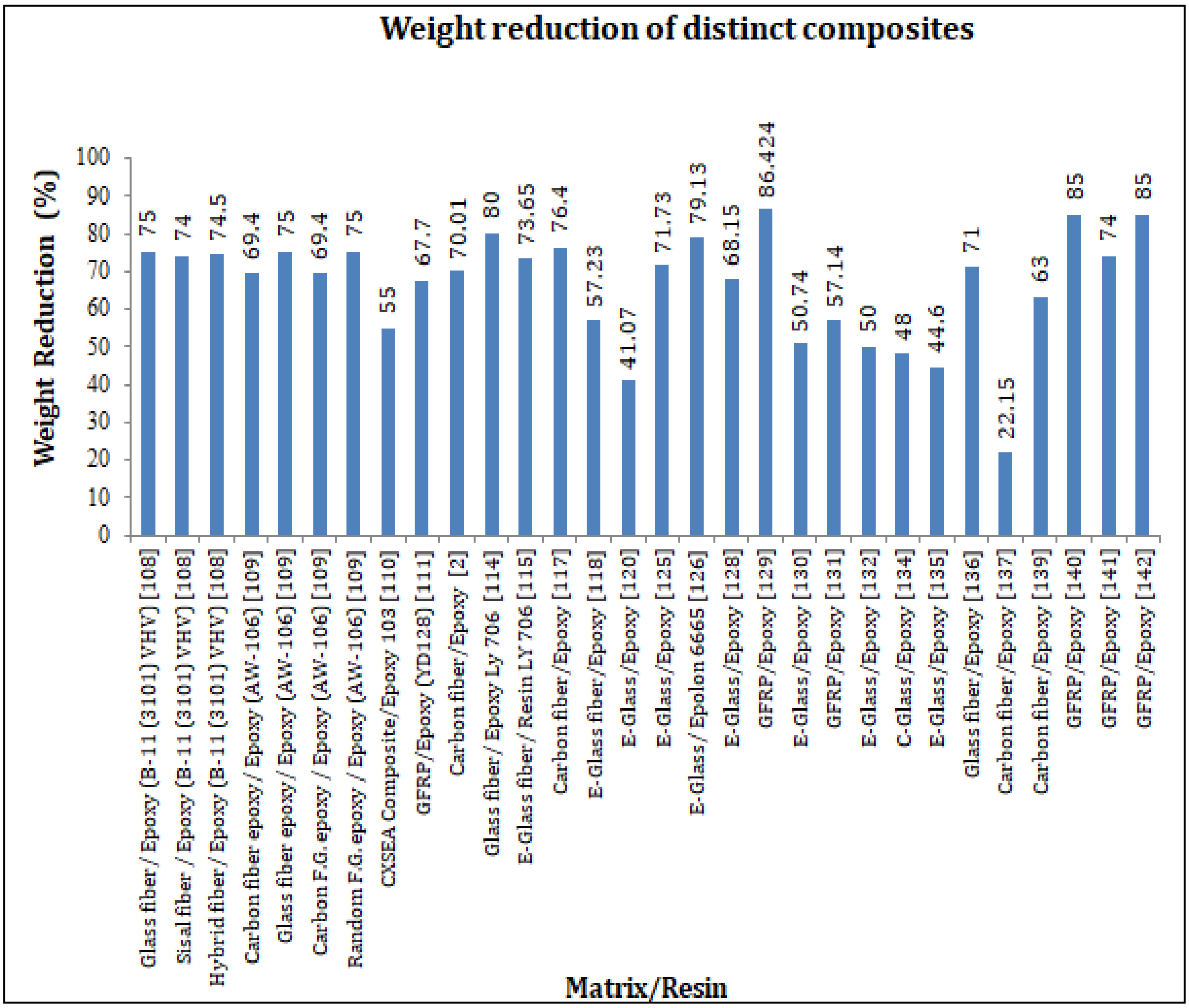

Fig. 11 (a). Graph between material/resin Vs. % reduction in weight.

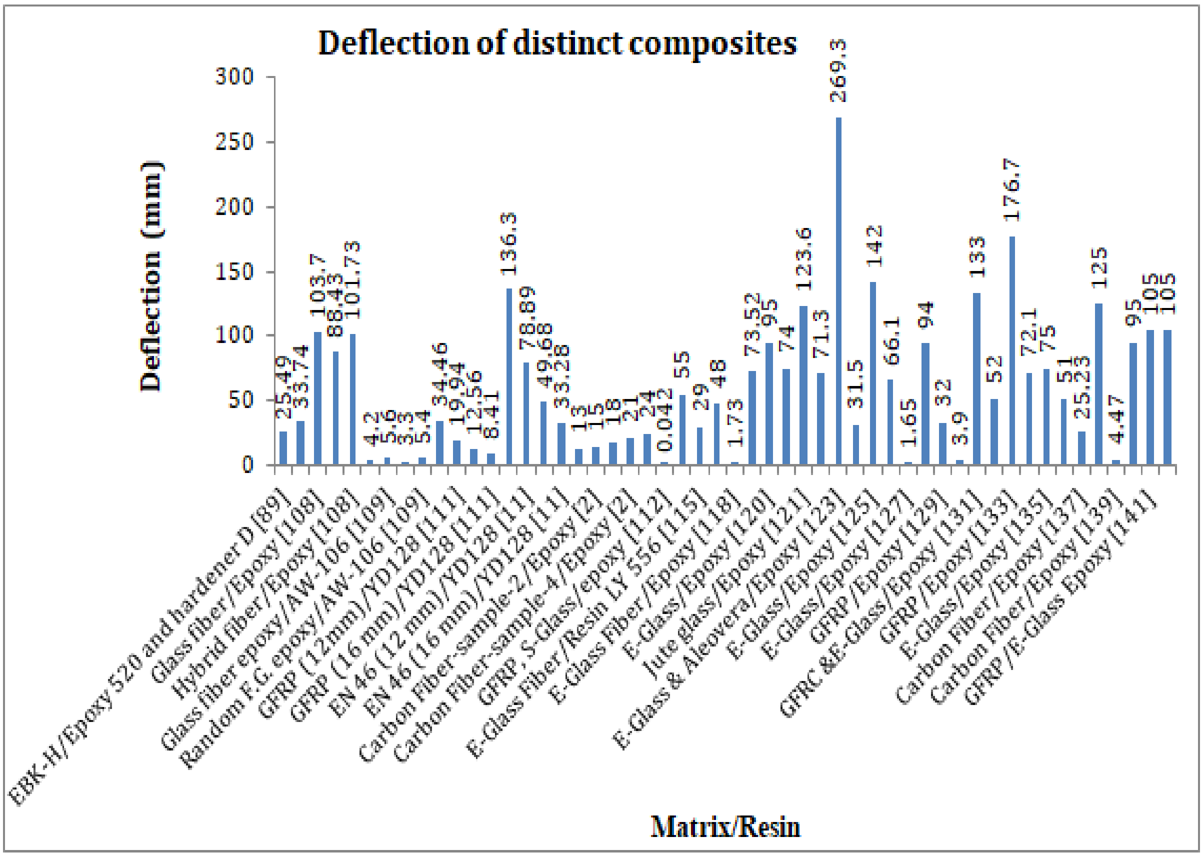

Fig. 11 (b). Graph between material/resin Vs. % deflection

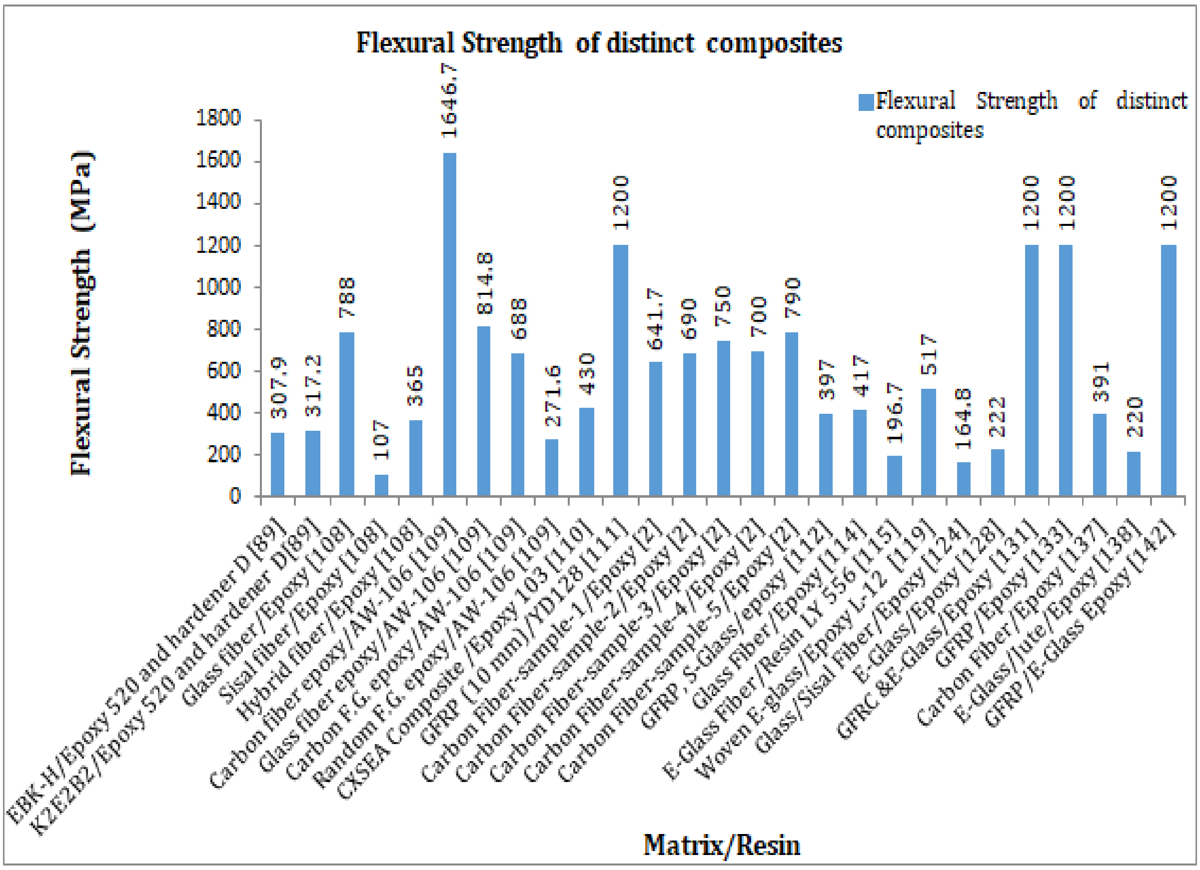

Fig. 11 (c). Graph between material/resin Vs. flexural strength

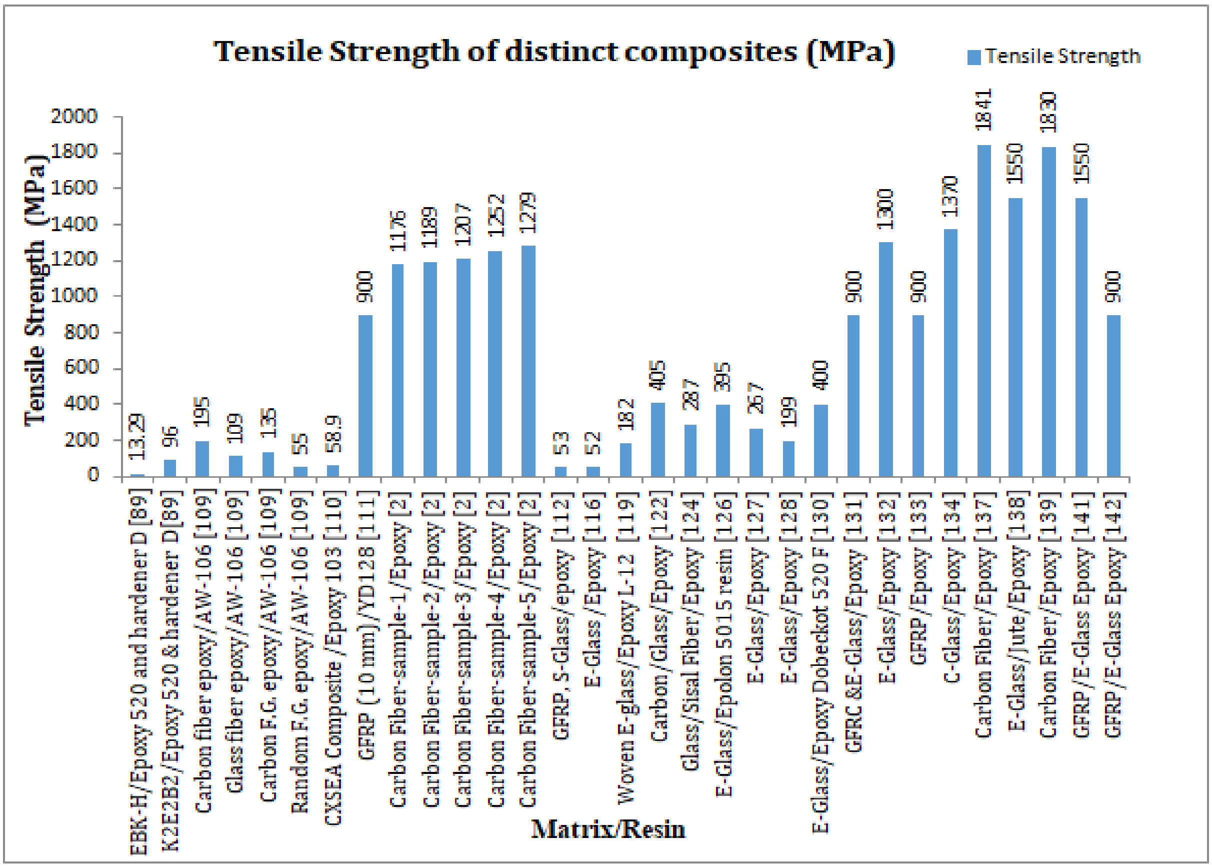

Fig. 11 (d). Graph between material/resin Vs. tensile strength

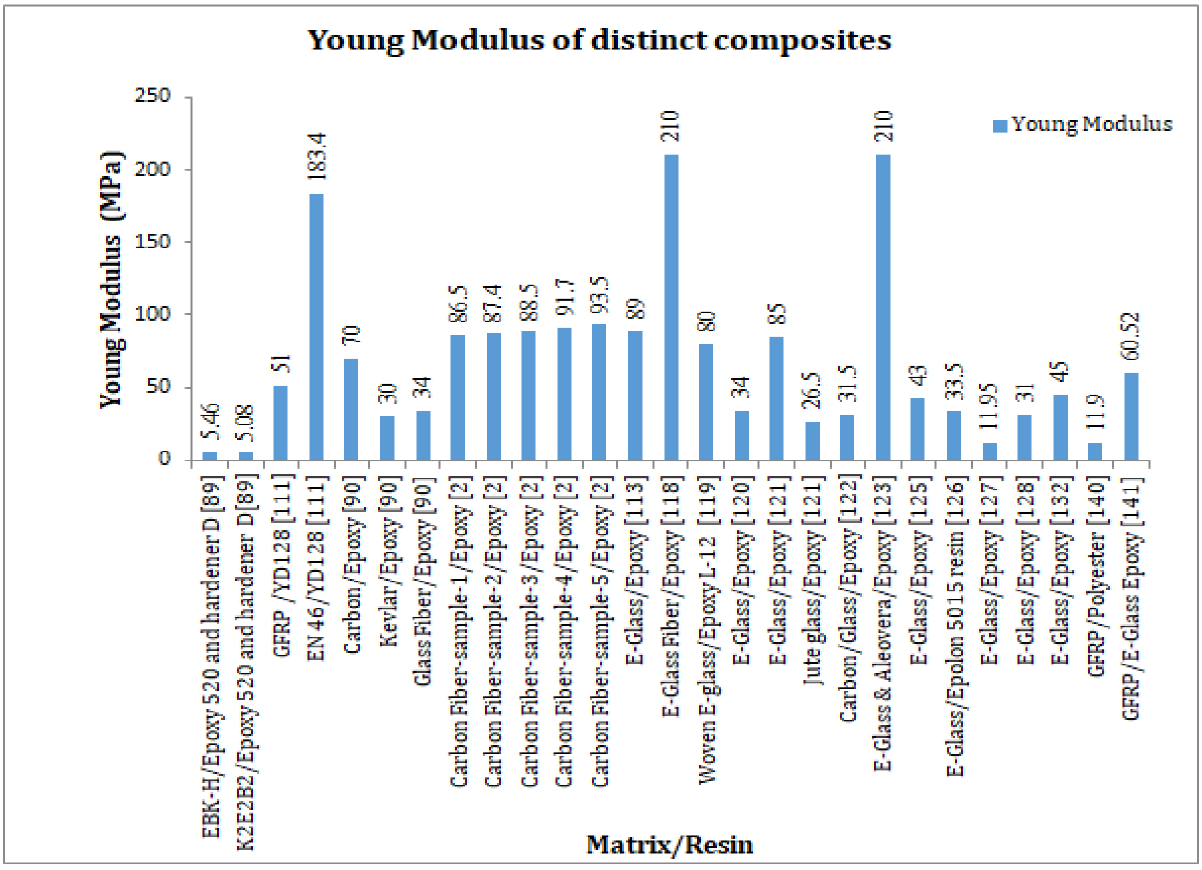

Fig. 11 (e). Graph between material/resin Vs. young modulus

Research indicates that reducing weight and switching to composite leaf springs from traditional ones are frequent problems in improving fuel economy and lowering air pollution. Additionally, the composite materials offer excellent riding qualities. Additionally, the fatigue life and stresses and deflections of the composite materials are significantly higher. Consequently, various composite materials may be used in place of steel to reduce weight, reduce stress, and enhance working conditions. The composition of leaf springs is influenced by the ratio of fiber to resin volume. The majority of research suggests that optimal material properties may be achieved in the fiber volume ratio range of 50% to 60%. The manual lay-up method is the most often employed production approach for composite leaf springs. In composite materials, there are factors specific to the ply arrangement. The majority of plywood layouts are made symmetrically. The maximum strain failure criterion is one of the several failure criteria that have been reported in the literature and is often used to assess the resilience of composite materials. Because the leaf spring behaves like a cantilever beam, this was taken into consideration during design. Many studies employed different tools for analysis, however, ANSYS software is the most frequently used.

4. Conclusions

Composite materials are becoming capable of meeting weight reduction and increased product strength. Many companies are interested in hybrid composite laminates these days because they have superior mechanical properties to single/mono composite materials and existing traditional materials such as steel. Additionally, the manufacturing method, the material properties, the type and content of strengtheners, and other parameters affect the performance of hybrid filler particles. However, among distinct fabrication methods, the Hand-lay-up molding method is very popular. However, to achieve the desired properties, the appropriate selection of these parameters is highly required. From the literature, composite laminates toughened with various fibers have improved mechanical properties significantly. The mechanical properties of carbon and Kevlar composites with natural fiber material like jute were discovered to be superior.

5. Future Scope

This study demonstrated the significant mechanical performance that can be achieved when using a hybrid composite system for composite-based leaf springs. This allows for the provision of design freedom with various reinforcements while also enhancing the structure's strength characteristics.

Because of its remarkable qualities, such as its low density, high flexural strength, and high stiffness, laminated composites have been used more and more recently. They are primarily utilized in shell constructions because they increase the structure's torsional stiffness. Better damping and flexural strength at a reduced mass as compared to metallic springs are the primary features of composite leaf springs. Using composite leaf springs can result in weight savings of around 60% [142-149].

Furthermore, the qualities of the material, including energy absorption, flexural strength, and modulus, can be impacted by the hybridization design. By covering the carbon fiber surface with two layers of basalt fibers, the maximum flexural strength was achieved [150]. The mechanical characteristics of a hybrid composite may be customized by altering the stacking sequences [151]. The amount of water absorbed can be greatly decreased by hybridization with carbon. Under the effect of the same force, the increasing impact resistance can be achieved by sandwiching the carbon-fiber plies between the basalt plies. The carbon fiber layer placed on the second layer enhances the laminate's ability to absorb energy [152], Therefore, by stacking the components of a hybrid properly, one may benefit from both types of reinforcement.

In general, there are several benefits to working with composite materials. From this vantage point, a few aspects of laminated hybrid composite leaf springs can be enhanced going forward.

In general, hybrid composite leaf springs have been very beneficial to the automobile industry [153]. The capacity of composite materials to absorb energy provides a special combination of less weight and fewer car part failures. Thus, laminated hybrid composites mono leaf springs are advised owing to the appealing qualities of leaf springs.

However, there is a scope to further improve the performance of hybrid composite leaf springs. There are numerous areas for future studies:

(a). To analyze the effects of distinct resins on the performance of leaf spring

(b). A detailed study on the effects of temperature on the stress and strain of the leaf spring material can be done in the future. As the environment temperature increases, the stresses of E-Glass and Kevlar 49 fiber get decreased hence the influence of temperature on the performance of the spring material should be done.

(c). Literature revealed that there is less research work on designing the leaf spring by altering the orientation and types of the fiber and ply. Hence, more research is required in this field. Also, more research is required on the design and dynamic analysis of laminated hybrid composite mono-leaf springs to improve their performance.

(d). Although, hybrid composite leaf spring is better than steel leaf spring due to its low weight and other properties. However, there is a need to solve the issue of failure and delamination of composite leaf springs owing to high-impact loading. In addition, various researchers are focused on model or computer simulation for predicting a variety of design variables of composite leaf springs. However, the optimum structural design of composite leaf springs for stiffness and other design parameters is needed by employing an effective algorithm or model. Results of various researchers [154-156] revealed that composite leaf springs offered better fatigue behavior as compared to steel springs. In addition, the hybridization techniques can be utilized effectively to enhance the weight saving and overall performance of the vehicle. It is worth mentioning that additional field testing is required in the future to define correctly the secondary design loads such as thrust, fatigue, torsion, creep, and other operational restrictions. Various researchers already proved that by applying Ni-based thermal sprayed coatings on steel parts, the resistance against wear and corrosion can be improved [157-164]. Thus, by applying a thin layer of metallic or ceramic coating onto critical areas of the leaf spring, thermal spray offers a multi-pronged defense against these threats [165].

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this review article. In addition, the authors have entirely observed the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy

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