2. **Review of Literature:**

1. **US Army Tank-Automotive command research and development center (1998):** The laboratory manual describes the in-depth procedure of designing of composite leaf spring for front and rear axle off the Army Vehicles. The load sustaining capacity, geometry, material, and method of manufacturing are few of the aspects considered at center and about which entire process of design and development steers.

2. **Venkatesan & D. Helmen Devraj (2000):** Project describes design and analysis of composite leaf spring made of glass fibre reinforced polymer. The objective is to compare load carrying capacity, stiffness and weight saving happened due to kind use of composite material as an alternate material for conventional steel. The same dimensions of composite leaf spring have taken to fabricate the E-glass/Epoxy unidirectional composite leaf spring. The simulation results have cross verified with experimental results, and it reach to the conclusion, the composite leaf spring leads to develop 67.35% less stress than conventional spring, the stiffness of composite spring is 64.95% more than steel leaf spring, natural frequency of vibration of composite spring is 126.98% more than steel leaf spring, and last but not the least, weight reduction is happened by 77% approximately.

3. **Y N V Santosh Kumar & Vimal Teja (2001):** Composite structure has chosen in the leaf spring design because it offers various advantages such as, stiffness, strength, corrosion resistance, high modulus of resilience, high strength to weight ratio etc. the work deals with replacement of conventional leaf spring by Mono Leaf Spring made of E-Glass/Epoxy. The component is modelled in Pro-E and analysis is carried out in Ansys Metaphysics Software.

4. **Dadasaheb Gaikawad et. al. (2001):** Manufacturing of mono leaf spring improve unsprung weight, poor ride quality and passenger comfort. The objective of paper is to give an idea about suitable composite which can be used in spring manufacturing which would serve the advantage as mentioned above. While proposing best FRP material for leaf sprig, few parameters have rigorously considered such as, manufacturing techniques and easiness, advantage and limitations of proposed material, processing difficulties etc.

5. **Sunil Chinthra & N Jeevan Kumar (2001):** The present work attempted to evaluate safe load on leaf spring at a speed ensures safe drive and passenger safety. The typical leaf
spring configuration of TATA-407 light commercial vehicle is selected for research purpose. Finite element analysis is carried out to determine safe stress and respective loads.

6. Ashish V Amrute et. al. (2002): Leaf springs are type of old suspension system generally used in commercial and transportation vehicles. The work is carried out on multiyear spring consist of three full length leaves in which one is with eyes ends used by a light commercial vehicle. The work also deals with replacement of steel leaf spring by composite spring (E-glass/epoxy). The objective of paper was to compare load carrying capacity, stresses reduction, weight saving. The CAE (Computer Aided Engineering) analysis is carried on steel leaf spring to determine and find the load carrying capacity, stresses induced, weight saving happened etc. The theory result have compared with CAE results.

7. Vivek Rai & Gaurav Saxena (2003): Automobile industries are focusing on weight and size reduction of components. The suspension system in automobile accounts for 10 to 205 of un-sprung weight. The use of GFRP (Glass Fibre Reinforced Plastics) makes things possible to implement without affecting the performance at all. The replacement of steel by GFRP will prove better on the front of weight reduction and increased load carrying capacity. The present work deals with replacement of multi leaf spring by Mono leaf composite for same stiffness and load carrying capacity. The design constraints are limited stress and deflection. Modelling and analysis is carried in Ansys.

8. Pankaj Saini et. al. (2004): The research work is centric to reducing the weight of suspension system without compromising with strength at all. The paper describes design and analysis of composite spring, the main objective of paper is to compare stresses and weight saving happened due to material alterations. The paper describes the advantage of using composite spring as a replacement to conventional steel leaf spring. The material selected for spring is glass fibre reinforced polymer (E-glass/epoxy), carbon epoxy and graphite epoxy. The leaf spring is modelled in AutoCAD 2012 and analysis is carried out in Ansys 9.0 software.

9. G Gopal & L Suresh Kumar (2004): A three layer composite leaf spring with full length leave made of E-glass/epoxy is considered for study purpose. The result of composite leaf spring is compared with steel leaf spring which noted the advantages of using composite
leaf spring and can be listed as, better strength, light weight, longer life, high strength to weight ratio etc. The analysis of static structure is carried out in Ansys-12.

10. **Jayadeep J Patil & S A Patil (2004):** To conserve natural resources and economize energy weight reduction is prime focus of automobile industries. Weight reduction can be happened by choosing better material for design which optimizes manufacturing process further. Use of FRP (Fiber Reinforced Plastics) has made weight reduction possible without compromising with load carrying capacity, and thus it can consider as best alternative or replacement for the conventional material such as steel and chromium. FRP has more elastic energy storage capacity, high strength to weight ratio, high stiffness etc. Multi-leaf conventional leaf spring is replaced by Mono-leaf composite spring to achieve the advantage such as compact size, enhanced load carrying capacity enhanced life etc. the stress and deflection of composite leaf spring is compared with conventional leaf spring, at the end, it has been noted that, composite spring has high natural frequency, low stress, low deflection etc. fabrication of composite leaf spring is economical than steel leaf spring. The replacement of steel leaf spring by composite has brought 85% weight reduction approximately.

11. **Jignesh Patel (2005):** Efficiency and emission are important issues of automobiles and thus automobile industries are trying to produce vehicles which can provide high efficiency with low cost. The efficiency can be enhanced by reducing weight of vehicle, the leaf spring which carries maximum weight of vehicle is the best option considered for replacement. The weight reduction with adequate improvement in material properties of lead spring is achieved by replacement of steel by composites. The Force Motor Trax Cruiser’s Leaf Spring Model is considered for study purpose with same dimensional geometry. The materials chosen for leaf springs are E-glass/epoxy, Carbon epoxy and Graphite epoxy composite which are economical. The analysis is carried for deflection and bending stress on ANSYS software. The result of simulations states that, the deflection occurred in composite leaf spring manufactured with materials as mentioned above is noted less than deflection occurred in steel leaf spring under similar loadings. The weight of leaf spring manufactured by composite material is noted 70% less than weight of steel leaf spring. The strength to weight ratio of composite leaf spring noted
higher than steel leaf spring which enables it to sustain higher magnitude of load without compromising with estimated service life.

12. S Karditas et. al. (2006): The paper focused its work towards design of Serial Leaf Spring. The allowable stresses obtained from Wohler Curves determined experimentally and providing fatigue behaviour of product. In present work, parabolic 2-Leaf Spring for front axles of heavy duty vehicles used an example for design process. Wohler curve determined after conduction of 6 cyclic 4-poits bending tests, and developed strains were measured. The stresses distribution observed during FEA analysis is compared with stress pattern noted during experimentation.

13. Kumar Arora et. al. (2007): Fatigue life assessment of leaf spring is challenging task and engineers working in the field of leaf spring always facing a challenge to find alternative method of fatigue damage prediction. 65Si7 lightweight commercial vehicle leaf spring is chosen for study. First of all SAE spring design manual approach the fatigue test stroke is established, then by the intersection of maximum and initial stress, fatigue life of spring is predicted. The second method used in predicting of fatigue life is, “Modified Goodman’s Criteria”. In third method, code is written in FORTRAN for fatigue life assessment. In fourth method, CAD model of spring is prepared and analysis is carried out in Ansys. All the methods have yielded closer result to that of experimental.

14. R M Patil et. al. (2007): Present day many metallic leaf sprigs are available which are used in heavy and light duty vehicles. Convectional metallic leaf spring adds considerable static weight and reduces the fuel efficiency. Composite material is potential material which can be used for the replacement of conventional steel or chromium without giving up the strength at all. In the current research, composite leaf spring is fabricated using hand layup vacuum bagging techniques for composite manufacturing to replace metallic leaf spring of light passenger transportation vehicle. The experimental tests are also conducted to compare load carrying capacity and stiffness of composite leaf spring with metallic leaf spring. The fabricated metallic spring assembled in to vehicle and its real time performance is also studied which was matching with performance noted during experimentation and simulation.

15. Rahul D Sawant et. al. (2008): Suspension system for all Terrain Vehicle is an important aspect from stability and handling point of view. The paper focused its research on,
mounting of front suspension of the ATV which is designed as lateral leaf spring to sustain in all environmental and loading conditions. The current suspension system is an independent one, as it mounted centrally and thus each side acts independent. The study and mounting of suspension system is happened by Subtract and Operate method to optimize the system, the analysis part of carried out in ANSYS.

16. **Edward Nikhil Karlus et. al. (2009):** The intent of 21st century for automotive sector is fuel economy and emission. The automobile designers are focusing on reducing the mass of vehicles and its component to achieve the objectives just mentioned above. The leaf spring is key target towards weight reduction as it adds the un-sprung mass to vehicle which affects the vehicle ride and stability to some extent. The paper focusing on design of Parabolic Mono Leaf spring to meet design parameters and constraints to precise possible extent and which are, length, width, suspension travel and stress etc. the paper assist to provide good values and guidance to automotive manufacturer about to standardize the current design and optimization techniques.

17. **K Ganesan et. al. (2009):** The main aim of research was to compare load carrying capacity, stiffness and weight saving of composite leaf springs with steel leaf springs at rated and over load conditions. Composite specimen is stacked for two different sequences like resin with clay and enhanced Nano particles, thickness and width of the cross sections are maintained as per the calculations during moulding. The design and analysis of leaf spring is carried out in Pro-E and ANSYS respectively.

18. **Bairagoni Naresh et. al. (2010):** The performance of composite and steel leaf spring is compared for similar loading conditions to note down response in terms of load carrying capacity, fatigue and dynamics behaviour, stiffness, weight, comfort etc. The modelling and analysis of spring is performed in Catia and Ansys respectively.

19. **K Rajesh et. al. (2010):** The research investigates suitability of natural and synthetic fibre reinforced composite material in automobile leaf spring application. By using natural fibres efforts have been made to reduce cost and weight of the spring. Composite leaf spring of material E-glass/epoxy is modelled and subjected to the same load as conventional leaf spring is. The static structural analysis is carried out in Ansys 11.

20. **Srekha Sangale et. al. (2011):** Suspension system of vehicle is an area where major innovations are carried nowadays. Weight reduction is considered on very priority basis
by vehicle manufacturer. The current research work shows replacement of conventional leaf spring of light commercial vehicle by composite leaf spring which is manufactured by using Carbon/Epoxy. The dimensions of composite leaf spring are considered same as conventional spring, the performances are noted in terms of, load carrying capacity, stress, deflection, weight saving happened etc.

21. S Nutalapati (2011): Design and Analysis of composite leaf spring for Mahindra “Model Commander 650 DI” is considered. The objective of research is to compare stresses, deformation and weight saving of composite leaf spring with steel leaf spring. The automobile industries have great interest to replace steel leaf spring by composite due to its high stiffness, good strength to weight ratio and good corrosion resistance properties. The material selected for spring is E-glass/epoxy as a replacement of steel. Results shows that weight of spring reduced by 85%, the fatigue life of composite spring found much higher than steel spring.

22. M Venkatesan et. al. (2011): Leaf spring is a crucial suspension element in automobile which minimizes vibrations, impact, shocks, thrust and bumps arrive due to typical road conditions. To conserve natural resources and maintain energy economy, Automobile manufacturers are trying to reduce the weight of vehicle either by saving the material or going for alternative material over the conventional material. Paper analysed configurations and methodologies that enables the researchers to select an alternative, feasible, advanced material which will be suitable for spring design. The CES (Cambridge Education Software) has used to shape the objectives such as weight reduction, conservation of natural resources by minimum energy utilization, which is nowadays ultimate goal of automobile manufacturer too.

23. Sagar B Mahajan et. al. (2012): Conservation of material is an important issue now days. The suspension system of an automobile vehicle is an area where such types of research are carried out regularly. Weight reduction is important priority given by manufacturers of automobile industries, and thus, it has attracted the attention of major researchers to go for the replacements of steel leaf spring by composite. This replacement doesn’t affect the load sustaining capacity of spring but reduced its weight and cost of manufacturing positively. The size of spring also reduces by considerable extent after such replacement makes happened to occur successfully. Objective of paper to study on the design and
analysis of composite leaf spring made up of, Glass Fibre Reinforced Composites. The design constrained considered is stress, deflection and thickness. The analysis is carried out in “Ansys 14.5”.

24. Yogesh Sharma & V N Bartari (2012): The automobile industries are emerging with new techniques which have brought many innovations in existing material. The paper describes “Multi Leaf Spring Soaring Optimization”. Leaf spring accounts 10 to 20 percent unspring weight and suspension devices to assure passengers safety and comfort. Leaf springs used in many forms, such as, heavy duty vehicle leaf spring, light duty vehicle leaf spring which will absorb the jerk arrive due to up and down road conditions. The paper describes the shape change and impact of such shape change on load carrying capacity and strength of spring. The spring is design in Catia V5 and analysis is carried in ANSYS. The properties of conventional leaf spring along with basic dimensions are as it is carry forwarded in analysis of composite leaf spring, after first iteration, the change of geometry and its impact on strength and similar parameters has discussed later.

25. Krishna Kumar & M L Agrawal (2013): Simulation by CAE (Computer Aided Engineering) is performed on three different models of leaf springs. The basis spring model considered for optimization is EN45A. The flat profile of spring is changed to parabolic shape and effect in terms of load sustaining capacity, strength and stiffness has studied. The thickness of spring has decreased from centre to edge; the shape optimization reduces interleaf friction of mating leaves and enhances life of leaf spring ultimately. The EN45A is replaced by GRP (Glass Reinforced Plastics). The main objective of work is to reduce weight, stress and improve fatigue life under similar loadings.

26. Ruchik Tank & Srinivas Kurna (2014): As per automobile industries are concern, leaf springs are important milestone in the journey of product design and development. The multi leaf in contact with each other shows hysteresis behaviour when loaded and unloaded. The strength of leaf spring is predicted by methods such as endurance trial, rig testing etc. virtual testing gives flexibility to consider design change in terms of various parameters, and can be considered individually or combinely, it saves time and cost both. It generate information in early stage of design and save the cost which otherwise required to spend on prototype testing. Volvo-Eicher Commercial vehicle leaf spring has
considered for analysis purpose. The experimental results obtained via Rig test compared with Simulation results obtained via FEA (Finite Element Analysis). The result comparison or correlation reduces product design time and cost with otherwise need to spend on Test Rig to predict the possible failure and mode of failure.

27. J J Jayakanth et. al. (2015): The failure of leaf spring by fatigue is determined by NX Nastran, the analysis is carried out for different material representing the leaf spring. The suspension of vehicle subjected to millions of stress cycle which leading its fatigue finally. Thus spring is considered to design from the prospective such as, low weight, fuel efficiency, riding qualities, load carrying capacity, high stiffness, high strength to weight ratio, high elastic strain energy storage capacity etc.

28. Pinaknath Dewanji (2016): The paper focuses on design and analysis of composite laminate structure which can be mould in to different applications later, one such application can considered is leaf spring. The effect of fiber orientation is considered on composite strength and behavioural characterization. The laminated leaf spring made of unidirectional E-Glass/Epoxy with same dimensions as that of conventional leaf spring is used for the purpose of investigation. The deflection of composite leaf spring is greater than steel leaf spring for same load, the weight of composite spring reduced by 70%, and most importantly, the stresses induced in composite spring have noted less in value than steel leaf spring.

29. Amit Pradhan & Yogendra Rathore (2016): Leaf spring is common type of spring used in automobile applications preferably over helical or any other type of springs. Springs are thick in middle and tapered outward at end. Leaves of various length, bent for different radius of curvature and stacked for definite sequence, assembled to vehicle axle to absorb the vertical load, shocks and vibrations. Short leaf spring placed to bottom imparts the same shape to the various leaves placed above to it. The dimensions of composite leaf spring have taken as it is from the conventional leaf spring, the spring is modelled in Catia V5 and analysis is carried in ANSYS. The objective of paper is to compare load carrying capacity, stiffness, weight reduction happened etc.

30. Yogesh Nikam & Avinash Badadhe (2016): The research focused on design, analysis and fabrication of leaf spring. Suspension system considerably affects the behaviour of vehicle, vibration characteristics, ride comfort and stability etc. the springs are subjected
to million-billion stress cycles leading fatigue failure, and thus lot of research have been undertake to improve the performance of spring. The fibre glass material has found with good strength characteristics and light weight performance as compared to other composite and certainly with respect to conventional material. Author reviewed various applicable materials which can be used in composite leaf spring; author also added the performance comparison of each such material with other.

31. Kaveri A Katake et al. (2016): Automobile sector always focusing on enhancing the level of comfort, fuel economy, customer safety and satisfaction. Vehicle weight affects greatly on fuel efficiency. The weight reduction can possibly make happened without compromising with load carrying capacity at all, thus automobile parts manufacturer focusing their attention on replacement of metallic parts by composites to retain the same performance with reducing of weight and manufacturing cost positively. The paper deals with experimental and numerical stress analysis of suspension leaf spring of light motor vehicles. The material selected for leaf spring are GFRP (Glass Fibre Reinforced Plastics) & CFRP (Carbon Fibre Reinforced Plastics). The strength enhancement and thus stress reduction is achieved by varying fiber angle of orientation, volume to weight ratio of reinforcement, and length to depth ratio of fibre. The numerical and statics analysis has carried for two springs a mentioned above, the result of analysis also compared with results of conventional leaf spring to define the scope of further improvement or optimization. At the end of analysis it came to know that, composite leaf spring has compatible strength to stand with said load. The comparative result of weight, cost and deformation also added to the paper.

32. Sandeep Bhattacharjee et al. (2017): Automobile industries are keen interested in the replacement of steel leaf spring by fiber composite leaf spring. Good corrosion resistance, tailor abilities, high strength to weight ratio are few of the properties aspect which motivate the designer for the replacement of steel spring by composite. Composite is potential material which offers the advantage of weight reduction, strength enhancement etc. the paper focusing its entire attention in the study of fabrication and analysis of composite leaf spring. The Analysis is carried out in FEA (Finite Element Analysis).
33. **Harikrishnan B et. al. (2017):** The material considered in spring design is 65Si7 steel. The length of master leaf is 753.55mm; the analysis of spring is carried in Ansys 14.0. The equivalent stress, strain, total deformation were find out by applying load at bottom loading condition with eye end is fixed. Force of magnitude 10000 N was applied. The minimum deformation obtained was 0.0014, minimum stress was $3.66 \times 10^{-5}$ MPa, and minimum strain is $1.74 \times 10^{-10}$. The equivalent load sustaining capacity of modified model of leaf spring is more than regular leaf spring.

34. **May Mya Darli Cho et. al. (2017):** Leaf springs are used in automobile system to absorb the shock and thrusts. Suspension system determines riding comfort and amount damage possibly reach to automobile. Suspension system support vertical load and it absorbs the vibration also. Paper work towards optimization of leaf spring for Solar Vehicle with constraint of maximum bending stress, flexural stress, Von-Mises stress, deflection and natural frequency considered. Chromium steel AISI 5150 leaf spring is used for front and rear leaf spring material with thickness keep changing for different cycles of analysis. The optimum thickness and width are 8mm and 50mm respectively for front leaf spring, for rear leaf spring the values are 5mm and 45mm respectively. Von-Mises stresses in front and rear leaf springs are 755.44 MPa and 662.50 MPa respectively. Working frequency do not match with natural frequency of front and rear leaf spring at six mode shapes and that assures the chosen design of leaf spring is safe. Solid work is used in product modelling and Ansys was used in product analysis.

35. **Kale Deepak & Rachaiyya Arakerimath (2018)** The leaf spring made of glass fibre reinforced polymer used in automobile suspension. The performance of composite leaf spring noted superior than steel leaf spring in terms of parameters such as, stiffness, safe design, load carrying capacity, weight saving etc. the proposed leaf spring is used in Tata Sumo vehicle model.